

Investigating the Most Effective Energy Retrofitting Strategies for Improving Comfort and Energy Use in Residential Buildings in Albania

Jonida Murataj

Oxford Brookes University

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ABSTRACT

This thesis emerges from the climate emergency of recent years and the international efforts to mitigate the impacts of climate change. Although energy retrofitting residential buildings has demonstrated the ability to deliver up to a 90% reduction in energy use and offers multiple benefits on a national and dwelling scale, the level of retrofitting remains very low in Europe. This study aims to holistically investigate what the most effective energy retrofitting strategies are technically, economically and in terms of acceptance by homeowners, for improving energy use and thermal comfort in existing residential buildings in Albania.

The evidence from 49 case studies of residential buildings in Albania reveals they have poor energy and thermal performance, overheat in summer and have low indoor temperatures in winter, making energy retrofitting an urgent need. Eight retrofitting scenarios have been investigated for eight main archetypes of the Albanian building stock, in terms of energy savings and improvement of the indoor environment, using baseline energy models informed by empirical data collected through building and occupants' surveys, as well as monitoring of indoor temperature. Three indoor temperature profiles were developed using Hierarchical Cluster analysis and explained for contextual factors, to account for various occupant behaviours present in Albanian households.

External wall insulation (thickness of 10cm) was found to be the most effective single measure to reduce energy consumption by up to 52% in flats with silicate bricks, while deep retrofitting has shown the highest energy saving potential of up to 80%. A large reduction in temperature over 28°C was found for each scenario from over 70% to 21% of the occupied time. Cost-benefit analysis of each strategy identified the most cost effective strategies, which were thereafter evaluated for their acceptance by homeowners using semi-structured interviews. External wall insulation and replacement of single-glazed windows with double-glazed ones were the most effective single measures both financially and in terms of acceptance by the homeowners, while the combination of the two was found to be widely accepted as a package of measures. A deeper understanding of the extent and reasons for the lack of acceptability of energy retrofits by homeowners has been reached, including financial, administrative, institutional, and building-related factors, as well as individual circumstances such as income, education and inability to adapt to a new lifestyle.

Findings in this research demonstrate that modelling work itself is quite routine unless some of the findings are novel, and using empirical data for energy modelling would bridge the performance gap between the estimated and achieved energy savings through energy retrofits.

Ultimately, this study's empirical evidence suggests that there is a huge potential for energy savings through retrofitting and the findings can assist the decision making of homeowners, as well as policymakers, to address and overcome barriers to the large-scale implementation of energy retrofits in the Albanian housing stock.

To my husband Kel and my three beautiful children Liara,
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List of abbreviations

CC – Climate Change

IPCC – Intergovernmental Panel on Climate Change

COP26 – The 2021 UN Climate Change Conference in Glasgow

UN – United Nations

NDC – National Determined Contribution

NZE – Net Zero Energy

IEA – International Energy Agency

UNEP – United Nations Environment Programme

EU – European Union

BPIE – Buildings Performance Institute Europe

NEEAP – National Energy Efficiency Action Plan

EnCT – Energy Community Treaty

EST – Energy Saving Trust

TSB – Technology Strategy Board

GBPN – Global Buildings Performance Network

POE – Post-Occupancy Evaluation

CIBSE – Chartered Institution of Building Services Engineers

IAQ – Indoor Air Quality

O&M – Operation and Maintenance

UK DECC – UK Department of Energy and Climate Change

IET – Institution of Engineering and Technology

GDP – Gross Domestic Product

NZEB – Nearly Zero-Energy building

EC – European Commission

EPBD – Energy Performance of Building Directives

EPC – Energy Performance Certificate

ESCO – Energy Service Companies

ESA – Energy Services Agreement

FiT – Feed-in Tariff

RHI – Renewable Heat Incentive

GD – Green Deal

BPE – Building Performance Evaluation

ICT – Information and Communication Technology

BPS – Building Performance Simulations

UNFCCC – United Nations Framework Convention on Climate Change

ECC – European Charter Secretariat

GHG – Greenhouse Gas Emissions

AKBN – Agjensia Kombetare e Burimeve Natyrore

LPG – Liquid Petroleum Gas

INSTAT – The Institute of Statistics

UNECE – United Nations Economic Commission for Europe

NPV – Net Present Value

IRR – Internal Rate of Return

PP – Payback Period

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

SPSS – Statistical Package for Social Sciences

ANOVA – Analysis of Variance

NVivo – Qualitative Data Analysis Software

PV – Photovoltaics

LED – Light-emitting Diode

ERA – Energy Regulator Authority

ERE– Enti Rregullator i Energjise

ESB – Energy Saving Behaviour

EAB – Energy Average Behaviour

EIB – Energy Intensive Behaviour

COP – Coefficient of Performance

ISO – International Organization for Standardization

CFL – Compact Fluorescent Lights

ZCB – Zero Carbon Building

CHAPTER 1

Introduction

1.1. Climate emergency

Over the last decade, various unusual and extreme weather events have occurred across the world. Scorching hot temperatures have broken Europe's previous record of 48.8°C in Sicily, wildfires, and deadly flooding from heavy precipitation events in other parts of Europe have highlighted the indisputable impact of human activity on these extreme weather events (United Nations, 2021).

Since the 1980s, each decade has been warmer than the previous one, and this trend is expected to continue (United Nations, 2021). Climate change, together with energy security defined as “the uninterrupted availability of energy sources at an affordable price” (International Energy Agency, 2016) is a key global issue. It has been previously acknowledged in the Conference of the Parties in Paris (United Nations, 2015) that climate change represents an urgent threat to human societies and the planet, and deep reductions in global greenhouse gas emissions are required to restrict global temperature rises to 1.5°C. However, future weather projections in the Special Report on 1.5°C (IPCC, 2018) predicted with high confidence that the 1.5°C level is likely to be reached between 2030 and 2052 if emissions continue to increase at the current rate. The last Intergovernmental Panel on Climate Change (IPCC, 2022a) highlighted that limiting global warming to 1.5°C above pre-industrial levels now requires an immediate and deep emission reduction across all sectors — and is more likely to be exceeded. In the context of this climate emergency, the Glasgow Climate Pact (COP26) agreed that rapid action across the globe was needed on mitigation (reducing emissions), adaptation (helping those already impacted by climate change), finance (enabling countries to deliver on their climate goals) and collaboration (working together) (UN, 2021a). Each party is requested to report on its progress towards achieving its National Determined Contribution (NDC) and provide an annual Greenhouse Gas emissions report (UN, 2021b).

1.2. Net zero targets

One of the urgent challenges facing the built environment professions and industries today is achieving large reductions in energy consumption (Penoyre and Prasad, 2014).

The Net Zero Energy (NZE) target, which is designed to reach net-zero CO₂ emissions from energy and industrial processes by 2050, requires substantial international cooperation (IEA, 2020b). Notwithstanding that countries accounting for between 60-70% of global CO₂ emissions have announced net-zero emission pledges, all other countries, including developing ones, must also contribute if the ambition gap between current ambitions (Announced Pledges Scenario) and the pathway to achieving net-zero emissions (NZE) by 2050 is to be closed (IEA, 2020b). If delivered, net-zero targets could significantly reduce temperature rise (Climate Action Tracker, 2021; UNEP, 2021).

1.3. Emissions from Buildings and Residential Buildings in Particular

Buildings are one of the biggest energy users, consuming over one-third of final global energy and nearly half of the electricity consumption, contributing up to 40% of total direct and indirect CO₂ emissions (IEA, 2020a). Over the period 1990 to 2019, global CO₂ emissions from buildings increased by 50% (IPCC, 2022b). It is expected a further increase in energy consumption in buildings could exceed that of the transport and industry sectors due to the growing trend of urbanization and improvement of living standards (Jing et al., 2017).

Considering its sizeable contribution to global CO₂ emissions, the building sector offers a large mitigation potential for meeting Paris Agreement goals (IPCC, 2022b). Residential buildings are responsible for 70% (IPCC, 2022b) of global final energy demand from buildings. According to 2017 European statistics, space heating in residential buildings across the EU presents 64% of the final consumption (Laaroussi et al., 2020). However, it is expected that there will be larger needs for cooling buildings in the future and less heating demand (Bamdad et al., 2021; Yang, Javanroodi and Nik, 2021). Moreover, teleworking triggered by the Covid-19 pandemic and enabled by digitalisation caused an increase in residential electricity consumption on weekdays of up to 30% and 40% in the United States and Europe respectively (IEA, 2020a). Additionally, by 2050 the global residential floor area is projected to grow by 58% on its 2019 levels of 290 billion m²/yr (IPCC, 2022b), while 80% of the residential floor area growth is in the emerging market and developing countries, many of which have not announced net-zero pledges (IEA, 2020b).

1.4. The need for large-scale improvement in the residential building using energy retrofit

Existing buildings are responsible for a large share of energy consumption and CO₂ emissions. Around 75% of buildings in Europe are energy inefficient (European Parliament, 2017) and most of them do not comply with the latest energy-efficiency requirements (Heerema, Frappé-Sénéclauze and Wu, 2017). Approximately half of the residential buildings in Europe were built in the 1970s (EU, n.d.) before energy efficiency standards were introduced in building codes in most EU countries. Moreover, the fact that the buildings' lifespan is 150 years or more, most buildings that will exist in 2050 have already been built, however, they usually require a major refurbishment every 50 years (EST, 2011).

The European building stock offers a large potential for energy and emission savings through large-scale implementation of retrofits (IEA, 2020a), which are needed to reach the targets set by national governments. Around 70% of construction schemes target building retrofits in the EU (Piccardo et al., 2020), aiming to achieve the recommended carbon reduction by 2050.

Across Europe, high-performance building retrofits have already demonstrated their ability to reduce energy consumption by up to 90%, hence, improving the building stock can be the best measure to achieve energy efficiency (BPIE, 2011). On the other hand, there is an urgent need to improve the thermal and environmental performance of residential building stock due to their poor conditions, considering that people in the developed world spend up to 90% of their time indoors, with 69% of that time being at homes (Moses et al., 2019).

Despite the proven benefits, the actual rate of retrofitting in Europe is only 1%, which is insufficient to achieve substantial emission reductions. Therefore, the pace of retrofitting needs to increase as early and as fast as possible to provide long-term gains (Streicher et al., 2021). The main barrier is the high upfront investment costs required for retrofitting, so the real challenge for the retrofit industry is to create mechanisms for capital-intensive energy retrofits (Francis, 2014).

1.5. Energy Poverty

Due to the extensive amount of scholarly attention dedicated to households suffering from inadequately heated homes, energy poverty has become a widely recognised social challenge among researchers and policymakers. 'Energy Poverty' is the term commonly

used to describe problems of energy deprivation in homes, involving economic, infrastructural, social equity, education and health concerns, especially in the developing countries (Bazilian, Nakhooda and Van de Graaf, 2014; Bouzarovski and Petrova, 2015). There are various definitions of energy poverty, however they all refer to a level of energy consumption that is insufficient to meet certain basic needs. According to Bazilian, Nakhooda and Van de Graaf (2014), energy should not only be physical assessable to people, but also it should be affordable and of acceptable service quality, including adequacy, reliability and safety.

Energy poverty can be measured using three approaches according to a technological (population with no access to energy services) , physical (minimum energy consumption associated with basic necessities) or economic threshold (maximum percentage of income that it is reasonable to earmark for energy spending) (González-Eguino, 2015). Economic threshold is the most widely used system for measuring energy poverty in developed countries and is set as a percentage of 10% of available income spent on energy to keep the home in a satisfactory condition (Bouzarovski and Petrova, 2015; González-Eguino, 2015). However, in the case of Albania, there is a discrepancy of energy used for heating and the need to heat homes. Because energy bill is less than 10% of the income does not mean that homes are heated adequately, nor the adequacy of energy services available in the home. In contrary, there are evidences that show that households cut down on other types of basic consumption such as food or health spending (Laderchi, Olivier and Trimble, 2013). A rapid increase in general poverty, could also indicate domestic energy deprivation, as has been previously noticed in Macedonia (Buzar, 2007). Therefore, special attention should be taken when talking about energy poverty in these countries. Furthermore, energy efficiency improvements in the existing housing stock should be increasing considering the rapidly increase of energy prices.

1.6. Case of Albania

Although Albania has no international obligations to reduce its greenhouse gas emissions (United Nations Human Rights, 2015), it has committed to reduce CO₂ emissions (708 kT CO₂ emissions) by 11.5% by 2030, compared to its baseline scenario of 2016. Its reduction will focus on energy and the industrial processes sectors (European Commission, 2016a). The Ministry of Economy, Trade and Energy, as a signatory to the Energy Community Treaty (EnCT), has prepared the Albanian National Energy Efficiency Action Plan (NEEAP) to align local legislation with EU legislation on energy efficiency. As a candidate country status to EU holder, Albania must persuade

EU politicians to develop long-term policies to reduce greenhouse gas emissions (IPCC, 2014). On the other hand, Albania's built area and the energy consumption in the building sector are expected to increase because of the continuous development of the country. Further, there is an urgent need to increase the thermal comfort in the existing homes in Albania.

Despite the acknowledged reality that improving the energy performance of existing housing stock provides the greatest potential for energy savings and achieving national and global carbon reduction targets, case studies of unsuccessful retrofitting activities, even when they are technical and financially viable, indicate there are multiple barriers to success. Often, they are associated with relatively high levels of uncertainty of their acceptance or successful outcome because of different perspectives on the goals and the way to achieve them held by different stakeholders due to different backgrounds, knowledge, position, objectives, and interests. Therefore, the retrofits that take place need to be considered in a wider context than purely technical and economical and must include occupants' acceptance based on their perceptions and needs.

1.7. Aims and objectives

Against this context, this PhD study aims to take a holistic approach to determine what are the most effective retrofitting strategies technically, economically and in terms of acceptance by homeowners, for improving thermal comfort and energy use of residential buildings in Albania.

By effective it is meant that strategies are:

- Technically feasible in terms of their application to different types of residential buildings.
- Economically feasible in terms of cost-effectiveness and affordability.
- Acceptable by homeowners in terms of upfront cost, culture, and appearance.

The objectives identified to meet the overall aim are to:

1. Empirically assess the energy performance and thermal comfort of a sample of Albanian homes in summer and winter to inform the energy models.

2. Develop baseline energy models for selected Albanian residential archetypes.
3. Model using dynamic thermal simulation energy savings and improvement of indoor environment from deploying a range of best-practice retrofitting strategies in residential archetype dwellings. (Technical feasibility)
4. Assess the most cost-effective solutions using a Cost-Benefit Analysis approach. (Economic feasibility)
5. Evaluate the most accepted energy retrofitting strategies in terms of costs, culture and appearance, with the Albanian homeowners. (Acceptability)
6. Develop a holistic retrofit framework that holistically assesses the performance of residential retrofit measures against technical, economic and acceptance by homeowners.

This research brings monitoring, energy modelling, Cost-Benefit Analysis, and people's perceptions together through the proposed RetrofiTEA framework to develop feasible measures for energy retrofits of existing buildings in Albania. Treating households as in-depth case studies and developing better energy modelling informed by reality and pre-retrofit surveys, as well as including information regarding energy use, occupants' perceived comfort, satisfaction, and their needs and expectations to create a full picture of the actual performance of the house, will be central to predicting energy savings and reducing the gap between the estimated and achieved energy savings from the application of various energy retrofitting strategies.

This study seeks not only to reach an optimal balance between costs and benefits but also to search for the balance that will make people accept undertaking retrofits. Factors affecting their willingness to accept energy retrofitting strategies will be examined, including social and cultural factors, with the importance of these factors to be considered in future energy and retrofit policies and incentives. The results achieved through this analysis highlight the huge potential that energy retrofitting the existing housing stock in Albania offers in energy savings, as well as improvement of the indoor environment. They are perceived as strong and deep enough to provide the foundations for developing programs that will increase the uptake of energy retrofits.

1.8. Structure of thesis

The thesis consists of 10 chapters, organised into 6 sections as illustrated in Figure 1.

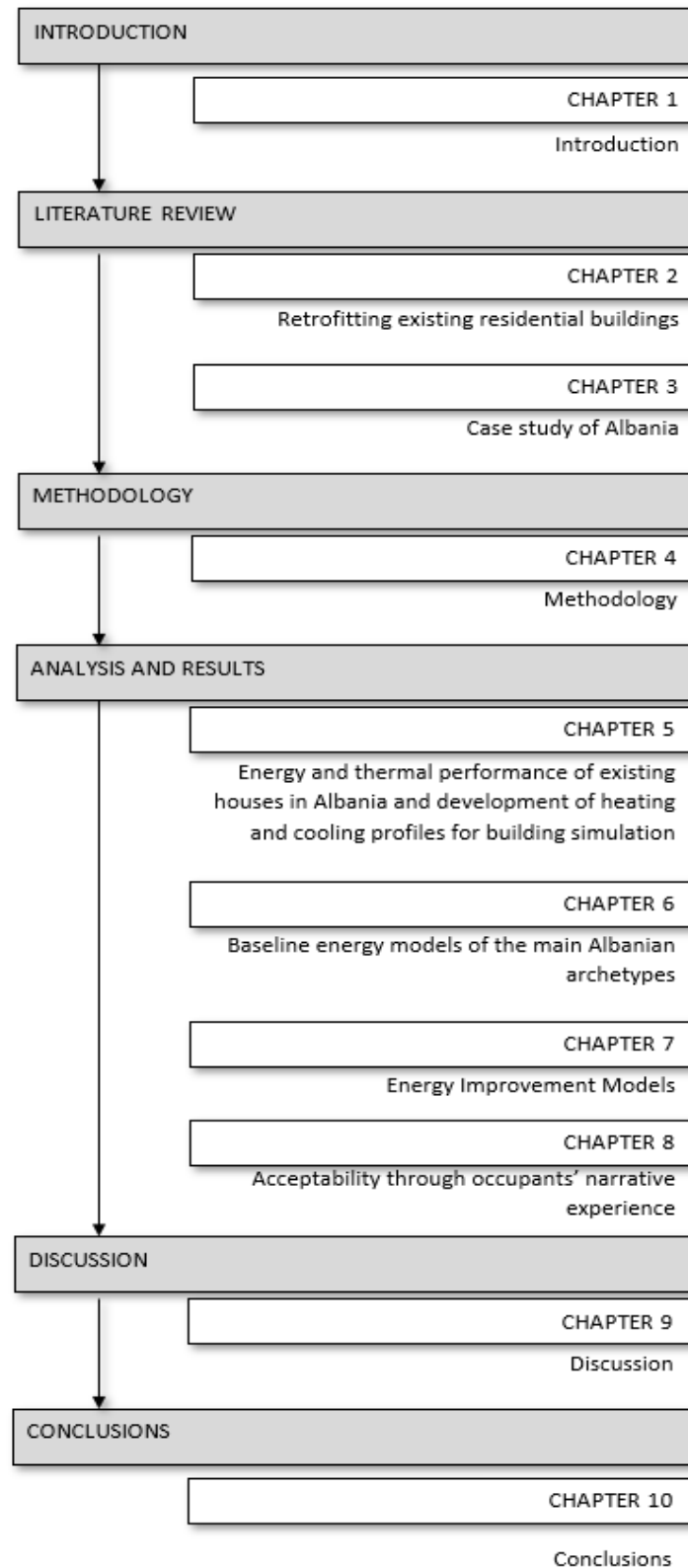


Figure 1: Structure of the thesis

Section 1: Introduction

Chapter 1 gives the overall context that serves as the foundation of the study, leading to its overall research aims and objectives.

Section 2: Literature review

The literature review has been organised into two chapters.

In Chapter 2, retrofitting of residential buildings has been studied through an in-depth literature review. Various approaches used to retrofit have been explored, before focusing on benefits, unintended consequences and barriers experienced when retrofitting residential buildings. The latest and main European guidance has also been briefly overviewed. Next, the performance gap between design/construction and in use has been researched, including when and why it happens and how can the study mitigate it. The role of occupant behaviour in the performance gap, and in the predictions of energy savings through energy simulations have been explored. Finally, lessons have been drawn from past retrofitting programs to inform future retrofitting programs, policies and projects.

Chapter 3 introduces the case study of Albania and continues with a detailed review of legislation on energy and retrofits, followed by case studies of retrofitting in Albania. Barriers and drivers to retrofitting in Albania have also been explored.

Section 3: Methodology

Chapter 4 presents a detailed description of the adapted methodology used by this study. The proposed framework has been developed through three main components: technical feasibility, economic feasibility, and acceptability.

Section 4: Analysis and results

This section consists of three chapters including empirical data analysis and the core of the research.

Chapter 5 provides an in-depth and empirical assessment of the energy performance and thermal comfort of a sample of Albanian homes in summer and winter. Details regarding energy use, indoor temperature monitoring and thermal comfort have been analysed, followed by the development of indoor temperature profiles of Albanian homes for baseline energy models concerning contextual factors.

Chapter 6 presents the results of dynamic model simulation of baseline energy models for each archetype.

Chapter 7 gives the results of improvement scenarios. Models of retrofit financing, including returns in investment, and payback periods have been analysed for each retrofitting strategy.

Chapter 8 presents the results and analysis of the interviews with the homeowners, including examining the factors affecting homeowners' acceptability of various strategies.

Section 5: Discussion

Chapter 9 presents the overall results of the study and provides an in-depth discussion. The discussion concludes with recommendations for policymakers, housing providers/developers and homeowners to consider when developing policies, and projects and choosing retrofit strategies respectively.

Section 6: Conclusion

Chapter 10 gives the concluding remarks of the study and states its contribution to learning. Moreover, limitations of the research have been listed, followed by recommendations for further research.

1.9. Papers from this thesis

The research presented in this thesis has had input into one peer-reviewed journal paper and three peer-reviewed conference papers (Appendix 1)

1. Murataj, J., Gupta, R. and Nicol, F. (2022). 'Developing Indoor Temperature Profiles of Albanian Homes for Baseline Energy Models in relation to Contextual Factors', *Energies*, 15(10), DOI: 10.3390/en15103668
2. Murataj, J., Gupta, R. and Nicol, F. (2018). 'Energy and thermal performance of apartment buildings in Albania: the case of a post-communist country', *Proceedings of 10th Windsor Conference 2018 - Rethinking comfort*, 865-883, Windsor, UK, 12th-15th April 2018
3. Murataj, J., Gupta, R. and Nicol, F. (2017). 'Influence of occupant behaviour on thermal comfort and energy use in Albanian homes', *Proceedings of International Conference for Sustainable Design of the Built Environment SDBE 2017*, 623-632, London 20th-21st December 2017

4. Murataj, J., Gupta, R. and Nicol, F. (2017). 'Energy and thermal performance assessment of existing residential buildings: the first step to introducing successful retrofitting strategies in Albania', *Proceedings of 33rd PLEA International Conference Design to Thrive*, Vol 1, 104-111, Edinburgh, 2nd-5th July 2017

CHAPTER 2

Retrofitting existing residential buildings

2.1. Introduction: Chapter outline

This chapter provides the relevant background issues for this study. It creates an overall picture of the building retrofits, starting with an exploration of the reasons to retrofit and some of the unintended consequences that need to be considered when undertaking retrofitting in residential buildings. After, an analysis of different approaches to energy retrofitting of existing residential stock is undertaken, explaining the fundamental issues associated with each approach.

A variety of issues that potentially contribute to a performance gap between the predicted and actual performance of energy retrofitting measures are also presented. They are distinguished by an in-depth review of the actions and people involved throughout the retrofit process to understand where and why the performance gap occurs and how it can be minimised. Acknowledging that energy use in buildings is considered a social problem rather than a technological one, a review and analysis of the social side of retrofitting are also undertaken to focus on people engagement.

The chapter closes with an overview of the main challenges acknowledged in introducing energy retrofits in residential buildings and the main lessons learned from various retrofitting programmes.

First, the use of the 'retrofit' definition in this thesis needs to be addressed. It is often claimed that it is an end-point definition that excludes the influence of people's energy practices (Fawcett, 2014). Therefore, in the context of this thesis, the term 'retrofit' is used to announce the act of adding or upgrading to an existing house, in one or various stages, to improve its energy performance and meet the required emission target reduction in current and future climate, and which, to be executed, must be accepted by the homeowner. It is also expected to be cost-effective and to improve the comfort, convenience and aesthetics of the house and the quality of life of the occupants living in it. In the existing literature, other jargon has been used to describe the 'retrofit', such as 'refurbishment', 'renovation', 'upgrade', 'transformation', 'adaptation', 'repairs', and 'renewal' of existing buildings (Ma et al., 2012; Zhang et al., 2021).

2.2. Retrofits

2.2.1. Why do energy retrofits?

Buildings are one of the biggest energy users and contributors to global carbon emissions, accounting for over 40% of global CO₂ (IEA, 2020a). Therefore, the building sector and especially residential buildings have a great potential for energy saving (Wei *et al.*, 2018; Hu *et al.*, 2020). Around 80% of the energy savings potential of energy efficiency in buildings has been untapped in the last decade (Belaïd, Ranjbar and Massié, 2021). Furthermore, it is expected that the retrofitting of existing stock will be an inevitable process in the future, given that one major refurbishment is typically estimated to happen every 50 years for most buildings in Europe (EST, 2011).

Indeed, retrofitting has been shown to improve the energy performance of existing buildings by upgrading buildings' conditions (Prabatha *et al.*, 2020). Across Europe, high-performance building retrofits have already demonstrated an ability to deliver up to a 90% reduction in energy consumption, hence, improving the building stock, and can be the best measure to achieve energy efficiency (BPIE, 2011). On a macro-level, that would also mean less energy dependence on other countries (Belaïd, Ranjbar and Massié, 2021). Renovating the existing building stock will not only have a huge impact on energy savings but will also provide benefits from economic growth, job creation and reducing the risk of fuel poverty on a local, national and global scale (Technology Strategy Board, 2014; Global Buildings Performance Network, 2015). It will also assist in reducing energy dependency, given that the rises in energy prices in the last 20 years have been sharp and show no sign of abating (Francis, 2014).

Many retrofit programmes have shown that retrofitting residential buildings can provide huge financial, comfort, environmental and social benefits (Technology Strategy Board, 2014; Prabatha *et al.*, 2020). Other benefits of energy retrofitting buildings that are widely acknowledged, but are rarely accounted for, are improvement of property value or rental fees as well as an extension of building lifespan (Zundel and Stieß, 2011; Zeng *et al.*, 2018; Belaïd, Ranjbar and Massié, 2021). The energy efficiency of a property is rapidly becoming a significant factor in terms of value and buildings that fail to undergo retrofits will see their value eroded much faster than ever before (Francis, 2014). A Danish study found other important motives to retrofit were to improve 'architectural quality' and get a 'better-looking' house (Mortensen, Heiselberg and Knudstrup, 2014).

However, on the household level, energy retrofits offer even more benefits. Improving energy performance is not always the motivator for householders to undertake retrofits. Rather, improving the indoor environment can be the main reason to retrofit, as was

found in a study exploring the perceptions of benefits and barriers of energy renovations among homeowners in Sweden (Azizi, Nair and Olofsson, 2019). In practice, improving the indoor environment is one of the most important benefits of energy retrofitting for the occupants (Azizi, Nair and Olofsson, 2019; Ortiz, Itard and Bluysen, 2020) as it is interlinked with positive health effects (Organ, Proverbs and Squires, 2013). One study (Alabid, Bennadji and Seddiki, 2022) found that uninsulated homes have a potential risk of dampness and mould growth that can lead to health conditions. The necessary carbon reduction cannot be achieved if the building's fabric cannot maintain an acceptable level of comfort (Penoyre and Prasad, 2014). 'Improving comfort and maintaining good physical and structural conditions of house' has been identified as being an important motivational driver for almost all types of energy efficiency retrofits, except solar PV panels (Ebrahimigharehbaghi *et al.*, 2021).

2.2.2. Unintended consequences of retrofits

Many studies have reported unintended consequences of retrofits (Gupta and Gregg, 2012b; Gupta and Gregg, 2013; Brotas and Nicol, 2017; Pérez-Andreu *et al.*, 2018; Tink *et al.*, 2018; Sanchez-Guevara *et al.*, 2019; Ortiz, Itard and Bluysen, 2020; Urbikain, 2020; Baglivo *et al.*, 2022; Escandón *et al.*, 2022), which should be carefully accounted for when designing, constructing and using the retrofitting strategies. The most prevalent unintended consequences are listed below:

Overheating and thermal discomfort

The new climatic conditions have exposed residential stock to low thermal and energy performance, which will be vulnerable if no investment is made in retrofitting (Sanchez-Guevara *et al.*, 2019), especially in the case of low-income households (Santamouris and Kolokotsa, 2015) and those with elderly residents (van Hoof *et al.*, 2017). However, making the buildings more airtight and improving building fabric has been shown to reduce heating loads and provide comfortable temperatures in cold weather, while increasing the risk of overheating in hot weather (Brotas and Nicol, 2017; Lomas and Porritt, 2017; Tink *et al.*, 2018). Moreover, it is expected that energy consumption will increase for cooling and decrease for heating (Bamdad *et al.*, 2021).

However, a recent study of social housing stock in Spain (Escandón *et al.*, 2022) found 38% of those studied were at risk of overheating in the present climate, whilst almost 100% will be at risk by 2050 — highlighting the urgent need to retrofit the housing stock. Therefore, retrofitting options should be carefully selected and evaluated. Several studies have highlighted the high-risk of internal wall insulation causing overheating

(Mavrogianni et al., 2012; Gupta and Gregg, 2013), whilst external wall insulation could reduce overheating compared to an uninsulated house (Gupta and Gregg, 2013)

Furthermore, it is important to always count on the building's occupants because POE studies have shown that buildings that do not give people adaptive opportunities to make changes to their environment are more liable to overheat (Leaman and Bordass, 1999). However, the scientific community has still not reached widespread consensus on the criteria by which potential overheating can be assessed or the minimum conditions considered acceptable for health inside a home during the summer period (Escandón et al., 2022), despite the large amount of work that has been conducted in the area of thermal comfort.

Overheating criteria

The most commonly overheating criteria are established by CIBSE (CIBSE, 2013; Brotas and Nicol, 2017), according to which a building is overheated when the operative temperature exceeds 28°C during more than 1% of the occupied hours in the living areas of dwellings (26°C in bedrooms). However, for naturally ventilated buildings, where the occupants have greater control of indoor conditions, CIBSE revised these criteria in the Technical Memorandum TM52 (CIBSE, 2013), in which the evaluation of the risk of overheating was based on the thermal comfort adaptive criteria set out in European Standard EN15251 (En, 2007):

- Criteria 1: Hours of exceedance, according to which there should be less than 3% of the occupied hours in which the operative temperature (T_{op}) exceeds the maximum temperature (T_{max}) by 1°(K) or more during a typical non-heating season (1 May — 30 September).
- Criteria 2: Daily Weighted Exceedance: according to which the daily severity of overheating is assessed in terms of temperature rise and duration over time and should be less than six-degree hours in any one day.
- Criterion 3: Upper Limit Temperature, which determines the maximum acceptable indoor temperature, in which the usual adaptive means are not sufficient to restore thermal comfort. Based on these criteria, operative temperature (T_o) should never exceed the maximum temperature (T_{max}) by more than 4°(K).

However, for naturally ventilated dwellings, the recent Technical Memorandum TM59 (CIBSE, 2017) set two criteria for compliance for avoiding overheating:

- Criterion A: Hours of Exceedance of the CIBSE TM52; and,

- Criterion B: The steady-state criterion for night-time in bedrooms defined in CIBSE Guide A for Environmental Design (the 26° limit).

Poor ventilation

Retrofitting is often associated with highly airtight structures to achieve the required thermal and energy performance. However, there is a high potential risk that radon levels could more than double in poorly ventilated retrofitting buildings (Passive House +, 2019), as well as a higher risk for humidity problems (Ortiz, Itard and Bluysen, 2020). According to May and Rye (2012) there is also an increased risk of interstitial condensation when there is limited space to install insulation material, especially on roofs. The moisture created in the building envelope may lead to a deterioration in the effectiveness of the thermal conductivity of the material, especially of the insulating layer (Guo et al., 2020). Condensation that can occur at the interface between the insulation and the brick can lead to mould growth (Kolaitis et al., 2013). Reduced ventilation can also result in radon problems and overheating, as well as the build-up of pollutants (Ortiz, Itard and Bluysen, 2020). On the other hand, mechanical ventilation can cause the air quality to deteriorate when it is not well designed and maintained (Withers, 2019).

Therefore, special consideration should be given when designing and constructing retrofit details to avoid moisture. According to Harrestrup and Svendsen (2015), leaving a cavity gap of at least 200mm in timber frames would mitigate the moisture risk as well as decrease the possible heat savings through the wall from 66% to 54% compared to the original wall, as well as provide a total building heat saving of 3kWh/m²/yr. Any mechanical ventilation should be carefully designed, taking into consideration factors including the size of the dwelling, climatic conditions, building type and construction, and be properly maintained. The occupants should be provided with clear and tailored instructions and training on its proper use.

Health issues

Improved thermal insulation and increased airtightness of the building envelope lead to increased dampness and mould problems, resulting in 'bad' indoor air quality (IAQ) and exposing the occupants to health risks (Bonnefoy et al., 2004; Richardson and Eick, 2007). Airways, nose and skin symptoms have been associated with dampness at home in different studies, as well as an increased risk of respiratory symptoms and allergies in young children (Azizi, Nair and Olofsson, 2019). House dust mites can also find perfect breeding conditions in a humid indoor environment of above 70% and can cause occupants to experience allergic reactions (McDonald and Tovey, 1992). Higher levels of radon have been found in homes with double glazing, and loft and wall insulation were

associated with the higher airtightness of these structures (Meyer, 2019; Symonds et al., 2019). On the other hand, poor maintenance of mechanical ventilation can cause air pollution resulting in health problems and discomfort (Bluyssen, 2019). Poor design of the systems can also lead to high noise levels from ventilators and airflow from ducts or from pumps that can cause annoyance and stress (McClellan and Hamilton, 2010). Furthermore, overheating in homes is associated with a higher risk of dehydration, respiratory illness, and heart problems, especially in vulnerable populations (elderly, infants, and immunocompromised people) (Kovats and Hajat, 2008; Lomas and Porritt, 2017).

On the other hand, in attempts to upscale retrofitting, manufacturers have introduced new materials, including aerogel. Notwithstanding that aerogel has been classified as novel insulation material and is applicable to most building elements and with very good thermal conductivity of below 0.025W/mK (Guo et al., 2020), studies have reported it can cause upper respiratory tract irritation as particulates of aerogel can be deeply inhaled into lungs during handling (Niemeier, Page and Burr, 2014). Therefore, careful choice of materials as well as adequate ventilation strategies are required that take into account the design and weather conditions, as well as occupants' needs and expectations.

2.2.3. Approaches to energy retrofitting of existing residential stock

Several approaches are tested through different government-funded programmes to achieve the required reduction of carbon emissions while minimising the performance gap. Energy retrofits can take different shapes, considering how deep they are and the way the measures are undertaken; all at once or over time. The selection of a building retrofit approach is affected by various factors, including building conditions, budget and cost-effectiveness of the strategy, the value brought to the property and the owners' preference to name a few (Alabid, Bennadji and Seddiki, 2022). A building energy retrofit typically takes one of three forms: behavioural interventions, shallow and deep retrofit.

The first form is related more to the operational schedule indicated by the occupant's behaviours and energy savings are achieved by improvements in building operations and maintenance (O&M) procedures (Prabatha *et al.*, 2020). This method usually results in average savings of up to 25% (D'Agostino, Zangheri and Castellazzi, 2017), and even up to 50% (Zhao et al., 2017). Whilst it does not need huge capital investments, it would be challenging to obtain awareness and commitment among the occupants.

A 'shallow' or 'elemental' approach applies individual measures such as enhancements to building fabric, lighting efficiency, and heating system efficiency (Delmastro, Mutani and Corgnati, 2016) and have mostly targeted the fuel-poor (Jones, Lannon and

Patterson, 2013). Although recent research has suggested a substantial reduction in carbon emissions cannot be delivered from any single intervention (Hewitt, 2012), different measures have different technical potential and actual energy savings could reach up to 50% (DECC, 2012). The most common and basic building retrofit has been considered to be the upgrade of an existing system or equipment, such as replacing a boiler or lights (Regnier et al., 2018). However, other studies (Osmani and Davies, 2013) have prioritised improving the envelope thermal insulation as the most successful design approach for low-energy retrofits for UK housing. Notwithstanding there is a danger of generating a 'lock in' effect, as a building that is insufficiently deeply retrofitted will not get a second chance to be adequately retrofitted within governmental carbon reduction timeframes, a shallow retrofit does not significantly compromise a later deeper retrofit (Penoyre and Prasad, 2014). Retrofitting, even if it is shallow, should be seen as the first step in a larger, longer-term plan to prepare the building for a zero or low carbon future (Penoyre and Prasad, 2014). Moreover, the feedback received from the improved comfort can be used to encourage people to realize further energy reduction interventions.

A deep energy retrofit takes a whole-house approach, where the entire fabric and systems of the building have to be evaluated, re-designed and reconstructed in an integrated way (Penoyre and Prasad, 2014). They have shown the ability to improve the energy performance of a building from 65% to 95% because of the high interaction of multiple measures to optimise the performance of the building as a whole (National Energy Foundation, 2014). Deep retrofitting ensures that the property needs are fully assessed and are tackled in the right order to ensure minimum disruption (Department of Energy and Climate Change, 2009; Gupta and Chandiwalla, 2010).

However, the retrofit process may become more complex and expensive when the occupants remain in their homes during work hours (RAP, 2011; Galvin, 2014b; Gupta *et al.*, 2015a; Traynor, 2019). Notwithstanding their large effectiveness in reducing energy consumption, deep retrofit is not an option for the majority of projects, mainly due to its high upfront costs and payback period (Penoyre and Prasad, 2014). Deep retrofitting is also dependant on the age of the building elements (Nägeli *et al.*, 2019). The lack of immature or relatively expensive technologies that achieve operational energy reduction can prevent undertaking deep retrofit on a large scale (Penoyre and Prasad, 2014). A Swiss study (Streicher *et al.*, 2021) investigated a range of deep energy retrofit pathways for residential building stock with different climate scenarios, combining economic and environmental objectives that represented different stakeholder interests

of policy objectives. They found that early and deep retrofits should be encouraged due to the high potential for energy savings and long-term benefits.

Careful consideration of the depth of retrofitting should include the cost and emission reduction target, as energy savings from a combination of measures often are not equal to the sum of savings from individual measures, as can be seen in Figure 2 (Jones, Lannon and Patterson, 2013).

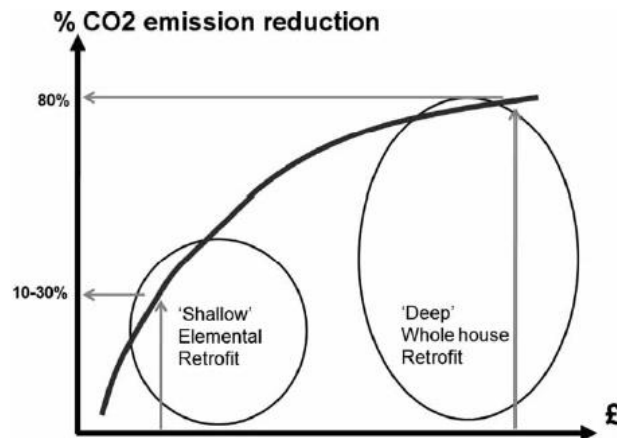


Figure 2: The relationship between cost and complexity of retrofits and the amount of CO₂ emission reduction

Source: (Jones, Lannon and Patterson, 2013)

Because a deep retrofit requires a high capital cost, often it is undertaken over time. Advantages of the 'over-time' approach are beginning to be recognised because of its user-centred philosophy (Fawcett, 2014). Feedback, awareness and action incorporated into this approach by a continuous relationship between homes and people and the spread of costs and disruption over the years could increase the uptake of low carbon retrofits (Darby, 2010; Fawcett and Mayne, 2012; Fawcett, 2014). Moreover, trigger moments (particular life stages of a household, including expanding the family or retirement, where there might be maximum potential for home refurbishment) (Energy Saving Trust, 2011) can be used to do renovation works (Simpson *et al.*, 2016). It is recommended that an energy-efficiency hierarchy be adopted for domestic retrofit projects, beginning with the building fabric ('fabric first' approach) and then employing a range of measures to increase the efficiency of various systems, before providing low/zero-carbon technologies to supply the remaining energy demands (RAP, 2011; Jones, Lannon and Patterson, 2013; Karvonen, 2013). However, there is a risk of stopping the retrofit journey once the comfort is improved, and it is difficult to predict the savings that can be achieved at the starting point of the retrofitting process. It is

acknowledged that modification of behaviour can reduce a significant portion of carbon emissions and that reducing demand is almost entirely a matter of human behaviour (Penoyre and Prasad, 2014). Various occupant behaviours create different patterns of energy consumption, requiring different design approaches (Penoyre and Prasad, 2014).

To accelerate deep retrofit, economic incentives are needed as well as further development of innovative and highly-efficient technologies and increased research (Streicher *et al.*, 2021). Furthermore, a one-step approach to deep retrofitting can be cost-effective and will become technically more efficient and feasible in the next few decades (IET, 2020).

In this context, careful evaluation of the energy retrofit approach options should be taken, considering various building aspects as well as the different needs and expectations of the occupants. Notwithstanding, deep energy retrofits of the entire housing stock would take several decades (Streicher *et al.*, 2021). Whatever approach is followed, shallow or deep, the fabric first approach is advocated by many researchers (IET, 2020).

2.2.4. Reducing energy demand through retrofitting – a ‘wicked’ problem

Thinking about a house and its residents as a single energy system is complicated because of the interconnections of its components (Technology Strategy Board, 2014). Therefore, achieving energy reduction is considered a ‘wicked’ problem (Gupta and Gregg, 2012a) because of the complexity and fragmented nature of retrofits (Stafford, Gorse and Shao, 2011; Karvonen, 2013; Judson and Maller, 2014), mainly because of incomplete or contradictory knowledge, the number of people and actions involved, the large economic burden, and its nature of interconnectivity (Kolko, 2012) (See Figure 3).

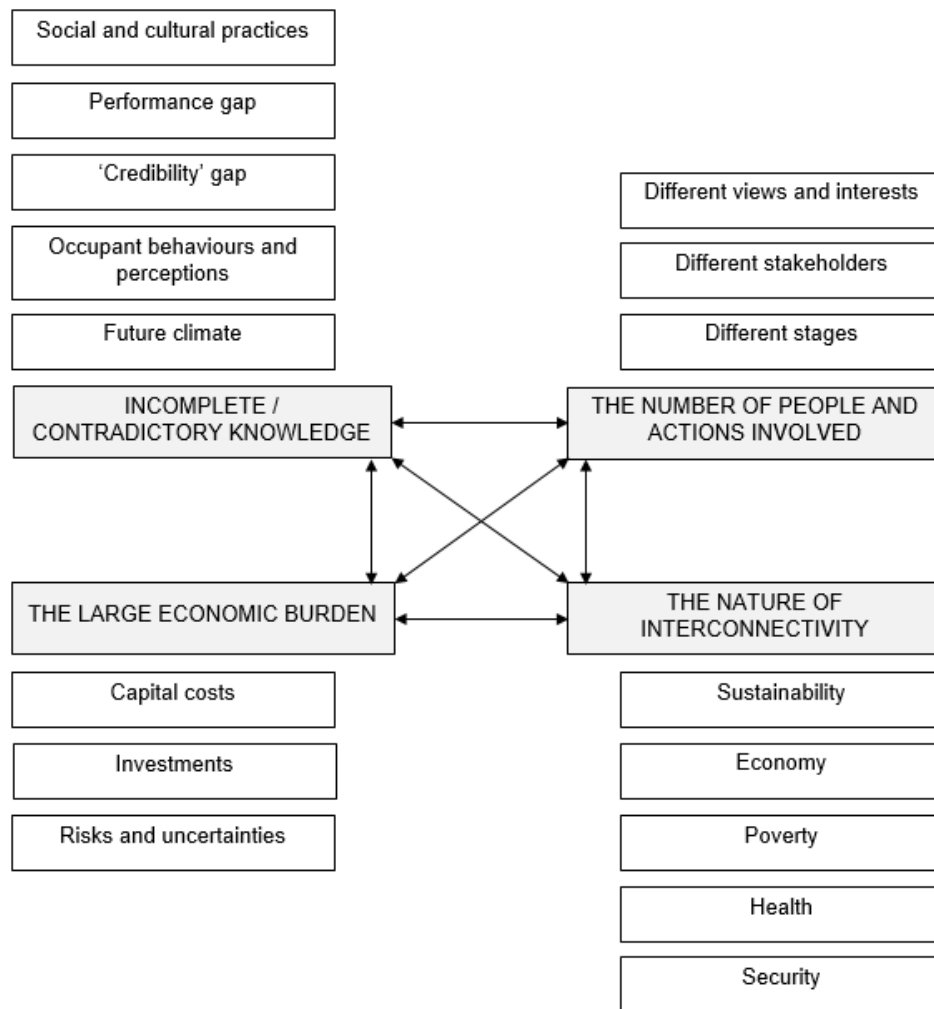


Figure 3: Interconnectivity of components of the energy system.

Source: Drawn by the author based on (Kolko, 2012).

A whole system and action research approach is required (Gupta and Gregg, 2012a) integrating detailed analysis and synthesis of all factors and elements involved on many levels to make complex systems more tractable (Auyang, 2004).

Incomplete or contradictory knowledge

Retrofit projects are usually characterised by high levels of uncertainty and risk due to lack of information and the complexity of tasks (Ferreira, Pinheiro and Brito, 2013). Although the predictive techniques of the energy performance of buildings are well developed now, there still exists a ‘credibility’ gap between performance expectations of energy performance and actual fuel consumptions outcomes. This is mainly because the often used assumptions are not well enough informed by what happens in practice, because few people who design buildings go on to monitor their performance (Bordass, Cohen and Field, 2004). In addition, the regional, social and cultural variations including

differences in climatic conditions, income level, building materials and techniques, building stocks and appreciation of historic value are complex, and the boundaries are difficult to define (Kohler, 1999; Lee and Gilleard, 2002; Juan, 2009; Ferreira, Pinheiro and Brito, 2013) and they have probably been underestimated (Kohler, 1999). On the other side, the sources of information are diverse, incomplete and contradictory (Ortiz, Itard and Bluysen, 2020).

A recent analysis of barriers preventing the take-up of energy efficiency options in buildings emphasises the significance of the embedded social practices that shape energy use in buildings (Bartiaux *et al.*, 2014; Judson and Maller, 2014; Vlasova and Gram-Hanssen, 2014), focusing on the 'entangled' cultural practices, norms, values and routines that underpin domestic energy use (Barr, Gilg and Shaw, 2011; Ozaki and Shaw, 2014; Webber, Gouldson and Kerr, 2015). Improvements in the energy performance of buildings will require closing the feedback loop and reducing the 'credibility gap' as well as the performance gap that occurs between design expectations of energy efficiency and actual fuel consumption outcomes, through a transparent report of expectations at the design stage of actual energy use, and a clear description of the building in use (Bordass, Cohen and Field, 2004).

The number of people and actions involved

The performance gap is characterised by a multi-stakeholder nature (Bordass, Cohen and Field, 2004; Fedoruk *et al.*, 2015) with a huge diversity of backgrounds, knowledge, position, roles, experience, objectives and interests, and with different perspectives on the goals that need to be achieved and the way to achieve them (Van Bueren, 2009; de Wilde, 2014; Cohen and Bordass, 2015; Zou *et al.*, 2018; Sibilla and Kurul, 2020). Moreover, the costs and benefits of retrofits are distributed throughout their life cycle and create impacts on different stakeholders (Prabatha *et al.*, 2020). According to Hu *et al.* (2020), the presence of multiple stakeholders, causes uncertainties in building energy performance design, implementation and final effects. Indeed, Golubchikov and Deda (2012) indicated that the retrofit policy implementation was affected by the information asymmetry that does exist among stakeholders. Various stakeholders evaluate designs based on their knowledge, purpose or interests (Shin *et al.*, 2017). Moreover, there is a long sequence of transactions, decisions, processes and approvals throughout the building retrofit process and, at each stage, there is a potential for creating a 'performance gap' (Zero Carbon Hub, 2014). This fragmentation between different disciplines remains a significant problem, even though the need to move toward a more collaborative approach to energy retrofits is recognised (Sibilla and Kurul, 2020).

Zou *et al* (2018) named three main obstacles to communication and collaboration among various stakeholders: knowledge (due to the lack of life cycle thinking and integrated delivery methods), technology (technologies used for communication and collaboration are still immature), and implementation (there is not enough initiative and interest to communicate and collaborate). Kirby (2019) supports the knowledge exchange as it facilitates the tackling of problems from a transdisciplinary perspective, considering the cognitive skills and habits of the stakeholders involved in mutual learning processes (Sibilla and Kurul, 2020).

Therefore, stakeholder requirements and decision priorities should be considered together in determining regional policies, as the often-adopted 'one-size-fits-all' view in retrofit planning and policymaking is not the right approach (Prabatha et al., 2020). Moreover, an interdisciplinary practice should be considered when planning new policies, where various stakeholders are encouraged to contribute in areas beyond their professions (Sibilla and Kurul, 2020). Involving them and tying together the policy, implementation and learning stages of any retrofit must be the focus of a whole-systems approach for retrofit research, to meet the carbon-reduction targets (Bell *et al.*, 2010; Gupta and Gregg, 2012a). All stakeholders, including clients, design and building teams, users, homeowners, managers, policy makers and industry will need to engage much more closely with achieved performance, delivering better transparency between intention and outcomes (Bordass, Cohen and Field, 2004; Butera, 2013; Fedoruk et al., 2015; Jia et al., 2021). Furthermore, energy policy development should capture all the diverse interests among the different stakeholders to be successful (Prabatha et al., 2020).

The large economic burden

The economic challenge of tackling climate change is estimated to cost between 1% and 2% per year of global GDP. This is compared to the 5% to 20% of global GDP per year responding to the impacts of climate change will require (Stern, 2007). To have a good chance of limiting the temperature increases associated with climate change to 2°C, US\$31 trillion will be required to promote energy efficiency in buildings over the next four decades (IEA, 2013). Long-term economic and environmental performance is increasingly being the focus on choosing between different alternatives available at the whole building level (Goh and Sun, 2016), element or system level (Pellegrini-Masini *et al.*, 2010). Even more, these decisions have a profound impact on the building's life if they are taken in the early phases of the design (Bogenstätter, 2000; Cole and Sterner, 2000; Sterner, 2000; Arja, Sauce and Souyri, 2009; Goh and Sun, 2016). However, high upfront costs have a considerable impact on the low patronage of energy retrofits (Syal

et al., 2013; Webber, Gouldson and Kerr, 2015; Hrovatin and Zorić, 2018; Dolšak, Hrovatin and Zorić, 2020; Liu, Tan and Li, 2020). Moreover, savings from energy efficiency upgrades are frequently found to be less than predicted, increasing concern about their effectiveness in reaching energy savings goals (Galvin, 2014a; Ben and Steemers, 2020) and in meeting the short-term financial return criteria of businesses, investors and individuals (IPCC, 2014). Therefore, although retrofits offer great potential in meeting carbon reduction targets, two-thirds of the economically viable potential to improve energy efficiency in buildings will remain unexploited by 2035 unless there is a concerted policy push (IEA, 2013).

The nature of interconnectivity

Reducing energy on buildings involves a process that involves a wide range of technical, economical, institutional, social, and cultural issues. Therefore, decision-making is rarely based on a single dimension (Janikowski, Kucharski and Sas-Nowosielska, 2000) and the retrofit of a building should consider not only its functional requirements but also energy consumption, investment costs, environmental impact and wellbeing (Chantrelle *et al.*, 2011); and social aspects of comfort, health, quality of life and service performance (Ferreira, Pinheiro and Brito, 2013). Not all retrofits can deliver positive environmental outcomes and economic benefits as they depend largely on other factors, including local energy prices, emission factors, and environmental conditions of a region (Prabatha *et al.*, 2020). The process of decision-making between this complex array of requirements is considered 'the art of good design' (Bell *et al.*, 2010). Holistic and multi-criteria designs are required to be adopted in the practice of energy retrofits, allowing for the combination of different performance requirements as well as finding balanced solutions for computing parameters, including environmental, comfort, life-cycle, energy requirements, etc. (Lassen *et al.*, 2021).

2.2.5. Retrofit policy: the latest European guidance on retrofit

Reducing energy consumption and the associated carbon emissions in buildings through retrofitting is complex and involves various stakeholders. Moreover, many issues and barriers affect them from being successful and widespread, including technical issues, financial options, stakeholders' interests and objectives, building types and climate contexts, occupants' behaviour, etc. Therefore, government-administrated policy instruments are needed to support the uptake of reductions of energy consumption and carbon emissions in the building sector (Bulkeley, 2015). Nearly zero-energy buildings (NZEBS) have been proposed as a core policy to decarbonise the energy sector by

combining energy efficiency with the deployment of renewables and the Member States shall insure that all new buildings are NZEBs by December 31, 2020 (European Commission, 2010). An NZEB is a building that “*has a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources, produced on-site or nearby*” (European Commission, 2010). To reduce operational greenhouse gas emissions, a step forward from the current nearly zero-energy building (NZEB) to zero-emission building (ZEB) was proposed by the European Commission (2021) by January 1, 2030, for all new buildings and January 1, 2027, for all new buildings occupied or owned by public authorities.

Zhang *et al* (2021) have recently undertaken a systematic review of the state-of-practice of retrofit policy instruments for residential buildings and have grouped the retrofit policy instruments in four groups as an interplay between instruments and various stakeholders:

1. *Direction and command* instruments, aiming to tackle the initial stage of the interventions for retrofits, including setting overall strategies, targets, and requirements. At the EU scale, the European Commission and Parliament have mandated energy interventions on existing building stock through the Energy Performance of Building Directives, starting from EPBD 2002/91/EU (EU, 2002) to its recast of 2010/31/EU (EU, 2010) and 2018/844 (EU, 2018), requiring all the countries to establish and develop long-term retrofitting strategies and targets.
2. *Assessment and disclosure* instruments aim to create the necessary tools for benchmarking energy consumption, identifying retrofit opportunities and recognising operational issues of systems (Ma *et al.*, 2012; Zhang *et al.*, 2017; Zhang *et al.*, 2021) to encourage energy retrofits. Under this umbrella of instruments, different certification programmes for homes, energy equipment and materials have been launched in different countries that aim to raise people's knowledge and awareness regarding energy efficiency (Evans, Roshchanka and Graham, 2017). The Energy Performance Certificate scheme introduced in France and the UK assigns each building a rating from A to G, with A being the most energy efficient. These instruments are used to estimate and evaluate actual energy savings based on pre-retrofit energy models validated by monitored energy data.
3. *Research and service* instruments aim to increase occupants' awareness of energy retrofits and provide technical support for retrofit practitioners through research-related instruments and public service-related instruments (Zhang *et*

al., 2021). Under this set of instruments, governments have introduced and developed research and programs for developing new technologies and innovative retrofit plans. On the other hand, governments have developed training programs and supporting tools to strengthen practitioners' knowledge and skills associated with energy retrofits, as well as training programs for occupants to improve their awareness of retrofitting their homes and behavioural change (Prabatha et al., 2020; Zhang et al., 2021).

4. *Financial incentive* instruments aim to facilitate the uptake and implementation of energy retrofits in residential buildings. Financial incentives and capital support can be of different types, including grants, subsidies, tax credits, low-interest loans and third-party financing (Baek and Park, 2012; Wilson, Crane and Chryssochoidis, 2015; Delmastro, Mutani and Corgnati, 2016; Bjørneboe, Svendsen and Heller, 2018; Pombo, Rivela and Neila, 2019; Bergman and Foxon, 2020; Hu *et al.*, 2020) or even payment of energy bills, energy efficiency mortgages and crowdfunding (Bergman and Foxon, 2020).

In Europe, the revised EPBD 2018/844 adds new elements, including cost-optimal minimum energy performance requirements for new buildings and for retrofitting existing ones (EU, 2018). Various financial mechanisms have been used in various countries as a means of funding energy retrofits. Owner financing has been by far the most prevalent form of investment in energy retrofits and is mainly associated with strategies that have low upfront costs and have proven to have a typical payback period of three to five years (Francis, 2014). On the other hand, lenders can only justify the loan when retrofits bring in revenue beyond that generated by energy savings and when energy retrofits increase the value of the property. However, energy service companies (ESCOs) are commercial entities that provide holistic energy solutions that are typically large-scale investments, and the investment risk is assumed by ESCOs themselves if the return on investment is poor.

Apart from traditional funding models, other models of finance have been emerging, facilitated by the developing regulations and new market and government initiatives. They are arrangements with a third party, which could be an energy provider as in the case of 'on-bill' utility financing, or a service and equipment provider in the case of an energy services agreement (ESA) and equipment lease finance respectively. Government can also play an important role in energy retrofit financing through programmes designed to encourage energy retrofits, such as the Feed-in Tariff (FiT), the Renewable Heat Incentive (RHI) and the Green Deal (Francis, 2014). Through the Green Deal programme,

billpayers would be able to obtain energy efficiency improvements without having to pay for the upfront costs of retrofit works. However, the overarching 'golden rule' is that estimated savings on energy bills must be equal to, or greater than, the costs added to the energy bill (DECC, 2012).

However, all instruments should be combined to achieve effective policy implementation (Weiss, Dunkelberg and Vogelpohl, 2012; Liu, Tan and Li, 2020; Zhang et al., 2021) and uptake of retrofits.

2.3. Performance gap

Retrofitting is considered the most cost-effective way of reducing energy demand and carbon emissions in the housing sector (European Commission, 2006; BPIE, 2011) and it offers the greatest potential for standardization (Tweed, 2013). Yet, actual energy consumption has been found to be less than official calculations and estimations (Demanuele, Tweddell and Davies, 2010; Gupta and Chandiwala, 2010; Carbon Trust, 2011; Glad, 2012; Gupta and Gregg, 2012a; Ma *et al.*, 2012; Sunikka-Blank and Galvin, 2012; Galvin and Sunikka-Blank, 2013; Tweed, 2013; Galvin, 2014b; Gram-Hanssen, 2014b; Gupta, Barnfield and Hipwood, 2014; Technology Strategy Board, 2014; Zero Carbon Hub, 2014; Yan *et al.*, 2015; Gupta and Gregg, 2016; Delzendeh *et al.*, 2017; Jia, Srinivasan and Raheem, 2017; Ren, Chen and James, 2018; Zou *et al.*, 2018; Palma, Gouveia and Simoes, 2019; Ben and Steemers, 2020), making decarbonising the existing housing stock not particularly easy, despite several funding rounds from government and professional expertise (Gupta *et al.*, 2015a). There is a lack of understanding of the factors affecting energy use that are significantly contributing to this gap (Demanuele, Tweddell and Davies, 2010). The International Energy Agency defines two main groups of factors affecting the building energy performance, namely: technical and physical factors, including climate, building envelope and equipment; and, human factors, including operation and maintenance, interior conditions and occupant behaviour (Yoshino, Hong and Nord, 2017).

Building Performance Evaluation (BPE) is a process that systematically investigates the performance gap by comparing the actual performance of buildings and their systems to their expected performance (Gupta and Gregg, 2021). Post Occupancy Evaluation (POE), as a subset of BPE, has been the main diagnostic tool of buildings' actual performance since the late 1960s, when it began to be used in North America and Western Europe and it serves to collect information that contributes to minimising this performance gap (Gupta *et al.*, 2015a; Zou *et al.*, 2018; Lassen *et al.*, 2021).

The information collected includes measured data such as energy consumption, temperature variation, lighting and noise levels, etc., and survey data from the occupants' perspective, including comfort, aesthetics, occupant satisfaction and management (Gupta and Gregg, 2014). This energy performance gap can occur at different stages of retrofit delivery (Carbon Trust, 2011; Gupta *et al.*, 2015a) contributing to achieving a different standard of 'build to' or 'operated to' from 'designed to' (Penoyre and Prasad, 2014). The BPE approach of a UK Government's innovation agency, the Technology Strategy Board (TSB), focused on the evaluation of building performance in two periods (Gupta, Gregg and Cherian, 2013):

1. *Post-construction / early occupancy* – the stage of the building that allows an intensive and invasive evaluation of the as-built condition of the building, generally concerning the building fabric performance (Gupta and Gregg, 2021). Fundamentally, evaluating the as-built performance of a building or dwelling in the pre-occupancy stage would provide the designer or the technician with performance data that can be used to calibrate the energy models and examine the gap between the as-designed and as-built energy performance of the building, without the influence of occupancy-related factors (Gupta and Gregg, 2021).
2. *In-use / post-occupancy* – performance of the building over an extended period, after fabric and systems have stabilised and the occupants are more familiar with the building (Gupta, Gregg and Cherian, 2013). After evaluating the 'as built' performance of the retrofit, BPE can be used for identifying, quantifying and resolving the gap between 'as designed' and 'in-use' performance. This BPE approach combines systematically collected and analysed qualitative and quantitative information related to fabric performance, energy performance and environmental conditions with feedback received during the whole building delivery (Gupta and Gregg, 2014).

However, a retrofit BPE process map should be explored and followed from the pre-retrofit design stage and during the retrofit construction stage, followed by the post-construction and in-use stage. Gupta and Gregg (2014), developed a process map for evaluating the retrofit performance of non-residential buildings based on these four main stages of retrofit delivery.

2.3.1. Pre-retrofit stage: Existing performance of the building

Evaluating the performance of the building post-retrofit is more complex compared to a new built because it should not only be compared against the retrofit design but also against the existing performance, which in fact should serve as baseline performance for benchmarking the improvement, savings and benefits post-retrofit (Gupta and Chandiwalla, 2010). Because of the lack of pre-retrofit evaluation, in the early stage of the design, considerable assumptions and predictions are used due to a lack of data about various aspects of the building (Bordass, Leaman and Ruyssevelt, 2001; Demanuele, Tweddell and Davies, 2010; Zero Carbon Hub, 2014). Furthermore, energy modelling is being used to inform the designer about the energy performance of their design. However, energy modelling is not commonly used in the early stages of project development and is seen as a separate technical issue (Zero Carbon Hub, 2014). Even when energy modelling has been used for estimating the energy consumption of the building, accurate prediction is not easy for designers due to limited data, knowledge and experience (Zero Carbon Hub, 2014; Zou et al., 2018), as well as oversimplifying the reality, which is very complex (Gorse et al., 2016). Moreover, designers tend to overemphasize issues that can be modelled numerically (Lassen et al., 2021) and often building design solutions are implemented without taking into consideration the whole building performance (Lassen et al., 2021).

Therefore, a full understanding of the conditions of the house and the resident's needs is essential to design a consistent methodology followed by detailed surveys, and flexible contingency plans (Technology Strategy Board, 2014). Engaging the residents from the start can increase their understanding of the retrofit intents (Technology Strategy Board, 2014; Niu, Pan and Zhao, 2016) and undertaking occupant surveys before and after occupying a new house helps to identify the issues to be addressed, the success achieved and what needs further improvement (Bordass, Leaman and Ruyssevelt, 2001; Gupta and Chandiwalla, 2010; Technology Strategy Board, 2014).

2.3.2. Retrofit design stage

Quality of the design

Decisions made at the very beginning of the development process can have a significant effect on achieving the energy and carbon reduction targets (Zero Carbon Hub, 2014). Often, designs tend to be very complex and unrealistic, contributing to excessive work needed, work delays and sequences, further expenses and unhappy clients. "Keeping it simple and doing it well" (Bordass, Leaman and Ruyssevelt, 2001) can lead to a more

comprehensive design, which can be easily manageable. A pleasurable integration must also be provided among the building's elements, systems and services and the house should be considered as one system (Adreu and Oreszczyn, 2004; Carbon Trust, 2011; Zero Carbon Hub, 2014), with no complex controls and user-friendly instructions (Technology Strategy Board, 2014). Otherwise, it can lead to ad-hoc construction stage decisions (Zero Carbon Hub, 2014) and unnecessary energy consumption. Moreover, the energy performance of the detailed design must be updated as the project nears the construction stage, to provide a more accurate actual energy performance of the building (Demanuele, Tweddell and Davies, 2010) and to close the gap between the 'as-designed' and 'as-built' energy performance of the building.

Involving and engaging main stakeholders and occupants from the beginning

A significant reason for a performance gap occurring in the design stage is the failure to involve the occupants from the first stages of the design process, despite the negative impacts that might have on project initiation and execution due to their low awareness, poor cooperation and opportunistic behaviours (Jia et al., 2021). Acknowledging that building design affects occupant habits and actions, as well as a special consideration, should be taken in an early phase of architectural design through considering occupants' expectations (Lassen et al., 2021). According to Laaroussi et al (2020), the occupant's integration should be given the same priority as any other aspects before designing the solution or technologies, as failing to do that is considered a major barrier to ensuring the efficiency of the applied strategies.

Successful decisions can be made by engaging the main stakeholders early on and establishing clear communication between them (Guerra-Santin et al., 2013; Technology Strategy Board, 2014).

Beyond energy efficiency

Comfort, environmental issues and aesthetics have often been not carefully considered in the design of energy-efficient buildings (Lassen et al., 2021).

2.3.3. Retrofit construction stage

Involving and engaging all the teams

The lack of communication and engagement between the site and the design team, especially regarding the in-site changes to the design results in 'unbuildable' or 'uninstallable' details to be modified on-site (Zero Carbon Hub, 2014), affects the as-built performance of the building. The site teams often suffer from a lack of knowledge and

understanding of thermal design and performance principles, and skills, which reinforces the need for continual training (Wingfield et al., 2011; Technology Strategy Board, 2013; Zero Carbon Hub, 2014; Global Buildings Performance Network, 2015; Fylan et al., 2016). Therefore, it is important to keep constant communication and coordination between the construction and design teams throughout the retrofit process, including the use of data from performance measurements undertaken during the construction stage, to inform a process of continuous improvement in design, construction and in conjunction with the supply chain (Wingfield et al., 2011). Suppliers also need to be engaged during construction to ensure that the construction team is properly trained to undertake the work and to provide training and support when using innovative products or technologies for the first time (Technology Strategy Board, 2014). This way, improvised approaches that can affect the energy performance of the building can be prevented. Fylan et al. (2016) highlighted the difficulties that the contractors face when working around utilities cables and equipment.

Mid-construction testing

Tests after completion of the retrofit works have exposed many unintended consequences during the construction stage, therefore the importance of mid-construction testing is highlighted in many retrofit projects (Gupta and Chandiwalla, 2010; Carbon Trust, 2011; Wingfield et al., 2011; Guerra-Santin et al., 2013; Gupta, Gregg and Cherian, 2013; Fylan et al., 2016; Gupta and Gregg, 2016; Gupta and Gregg, 2021). However, adding several tests during construction can add money and time to the building process (Fylan et al., 2016), so choosing the right fabric performance test is fundamental (Guerra-Santin et al., 2013)

2.3.4. Post-Retrofit and Early Occupancy Stage

Empirical studies undertaken in the post-construction stage have demonstrated the prevalence of performance gaps and an inconsistency in build quality (Gupta and Gregg, 2021). Performance tests, including thermographic surveys, heat flux tests, AP tests, co-heating, and smoke tests should be programmed at appropriate stages (Wingfield et al., 2011) and performed in more than one location (Guerra-Santin et al., 2013) to potentially identify any underperformance that can be dealt with before it is too late (Wingfield et al., 2011).

Handover process

Often the occupants find themselves in a building with new technologies and new controls without an appropriate handover process, forgetting that these technologies are

designed to be used and exploited by humans (Laaroussi et al., 2020). Occupants' expectations and habits, as well as their evaluation of comfort or satisfaction, may change when they are introduced to new and advanced technology (Madsen and Gram-Hanssen, 2017). In these cases, they might need to spend more time, money and effort to mature them (Bordass, Leaman and Ruyssevelt, 2001), or they will simply not use them at all. Ascione et al. (2020) found that older people prefer to interact with the fenestration system and not with the heating or cooling system, because they are worried about compromising its functioning, leading to an increase of energy use above 31% above that expected in the residential buildings. Often behaviours are not in line with the design, resulting in unexpected interactions like rejecting the technologies, misusing, or hacking (changing settings) (Scott, Bakker and Quist, 2012). Engaging residents early and frequently in the process (Demanuele, Tweddell and Davies, 2010), helping them to understand how to manage, operate and maintain their homes at different times of the year is mandatory (Adreu and Oreszczyn, 2004; Carbon Trust, 2011; Fylan *et al.*, 2016) as they are considered as a main cause of performance gap (Gaetani, Hoes and Hensen, 2016).

A gradual handover of the building such as a soft-landing approach, followed by a bedding-in period of at least one year has to be considered to fine-tune the building with the design and construction teams engaged (Carbon Trust, 2011) to help occupants with the new technologies and controls, and also get feedback on their work.

2.3.5. Post-Retrofit and in-Use Stage

The evaluation of building performance post-retrofit is undertaken in terms of both energy performance and environmental performance, and occupant satisfaction. Continuous monitoring/metering of energy, water and environmental variables are collected and then benchmarked against the pre-retrofit baseline performance to determine the savings in energy consumption and improvements in environmental conditions. Furthermore, questionnaire surveys and interviews with occupants are undertaken to assess their satisfaction and behaviour (Gupta and Gregg, 2014). Systems, controls, and occupant behaviour are further evaluated through walkthroughs of the retrofitted building. Lately, collecting continuous subjective feedback from occupants using Information and Communication Technology (ICT). similar to Post-Occupancy Evaluations (POE), has been seen as vital to secure occupants' involvement and help close the performance gap (Lassen *et al.*, 2021). Recent research regarding occupant behaviour in buildings has focused on collecting data relating to occupant behaviour in actual buildings

(Laaroussi *et al.*, 2020), which is largely acknowledged to have significant impacts on building energy consumption (Yan *et al.*, 2017; Ortiz, Itard and Bluysen, 2020).

Controls

The best-designed building may become an energy-wasting one if it is not appropriately operated (Butera, 2013). Unfortunately, the complexity and position of controls are often responsible for the energy consumption of buildings exceeding the predicted value (Demanuele, Tweddell and Davies, 2010). Although residents might not be present during retrofit works, one thing is certain: they will be living in the retrofitted home. Therefore, they need to feel that they are in control of their property and can 'manage it' on a day-to-day basis, rather than having fully automatic systems (Bordass, Leaman and Ruyssevelt, 2001; Carbon Trust, 2011; Wingfield *et al.*, 2011; Technology Strategy Board, 2014). Indeed, it is found that full automation of the indoor climate measures causes a significant reduction of occupant tolerance for discomfort, as it removes their control of the situation (Karjalainen, 2013). On the other side, according to Ortiz, Itard and Bluysen (2020), having the ability to control, or even just having the perception of being able to control the environment and surroundings, has been shown to reduce the effects of stress, and increase overall health.

Feedback and feed-forward

The feedback and feed-forward from buildings in operation is a valuable resource for the design community and building owners and operators to establish virtuous circles of continuous improvement (Bordass, Leaman and Ruyssevelt, 2001). However, they often do not get this feedback, partly because of the lack of involvement throughout the retrofit process and partly because the best practice lessons from the construction stage are very rarely communicated to the design team (Zero Carbon Hub, 2014). Consequently, lessons about the practical implications of their design decisions on as-built performance are not learnt (Zero Carbon Hub, 2014) and mistakes are repeated (Carbon Trust, 2011).

On the other hand, construction teams and manufacturers often do not get feedback about their work and technologies because of their lack of involvement after handover. To prevent repeating mistakes, the building teams must get engaged and record all the project processes, as well as summarise findings for future use (Technology Strategy Board, 2014). While end-users must be involved providing feedback so they can be aware and motivated to reduce energy consumption (Austin and Charlson, 2012), the feedback needs to be personalised with environmental data, comfort, and health data as well as being easy to access (Ortiz, Itard and Bluysen, 2020).

Zangheri, Serrenho and Bertoldi (2019) highlighted the impact that providing tailored feedback to the household in a clear, engaging and direct way can have on energy consumption, with a potential electricity reduction of 5-10%. Canale *et al.* (2019) and Zangheri, Serrenho and Bertoldi (2019) have observed energy savings between 2-23% depending on study location, type of feedback, type of consumption etc. Arens *et al.*, (2010) concluded their study by envisioning future measures that enhance occupant feedback capability are to be incorporated into normal building operation and control, as well as being specified in building designs. Continuous subjective data collection includes participatory sensing apps where occupants voluntarily provide feedback through a smartphone app (Konis and Annavaram, 2017), internet-enabled thermostats, or wearable and static devices, where control behaviour is tracked and logged (Gupta *et al.*, 2016; Kim *et al.*, 2019) have been used in recent studies to investigate occupant behaviours and are available in the market as Smart building solutions (Lassen *et al.*, 2021). According to Khosrowpour *et al* (2018), the purpose of the energy feedback is not only to increase occupants' awareness of energy consumption but also to integrate them to contribute to the energy efficiency strategies and to secure communication with the residents, helping them to control and preserve energy. Therefore, integrating occupants in the process would give them the possibility to contribute to the energy-saving potential of energy retrofits (Laaroussi *et al.*, 2020)

2.3.6. Summary of the issues that affect the performance gap of retrofits and recommendations to reduce it

As reviewed, a performance gap can be created in every stage of the retrofitting delivery process. However, Fedoruk *et al.* (2015) suggest future research should determine the stage of the building's life cycle that offers the greatest opportunities to close the performance gap. Gupta and Gregg (2016) have also recognised the importance of identifying and understanding where the performance gap occurs within the retrofit process. An overview of the main issues that cause the performance gap in each stage of the retrofitting process, followed by recommendations, is given in Table 1.

Table 1: Summary of the issues that cause the performance gap in each phase of retrofitting process associated with recommendations (drawn by the author)

	Issues	Recommendations
Pre-Retrofit Stage	• Lack of understanding of stakeholder's decisions and behaviours • Lack of pre-retrofit evaluation	• Tailor retrofit to match specific, existing conditions of the house • Take a much more rigorous approach to detailed design, including undertaking and checking thermal calculations • Add a pre-retrofit survey to reveal how the house is being used • Pre-occupancy data collection method
Retrofit Design Stage	• No targets • No responsibilities • No communication between project teams • Lack of engagement with residents and other stakeholders early on • Lack of knowledge and skills from the design team • No integrity, and complexity of the design • Lack of building system flexibility • Lack of information for passive design • Lack of detailed management plan • Lack of contingency plans • Lack of considering construction sequencing • Lack of detailed cost analysis • Limitations of modelling tools • Assumptions and predictions • Lack of model calibration with real data • Lack of consideration of occupant behaviour in early design • Overestimating automation system's performance • Uncertainty related to human data • Obstacles to using actual data in modelling and simulations • Limitations of energy models	• Set clear and achievable performance targets • Define responsibilities from the beginning • Engage and motivate the project team early on • Engage residents early on • Calibrate energy models with real data on energy and environmental performance • Include in energy modelling other things which use energy in a building • Consider the use of monitoring-based occupancy profiles and building monitored energy and environmental data • Consider passive strategies since the early design • Consider occupant expectations • Consider the stochastic nature of occupant behaviour
Retrofit Construction Stage	• Lack of communication between the site and design teams • Lack of engagement of the design team • Lack of engagement of occupants • Lack of skills and abilities of workmanship • Low build quality • Lack of keeping in-situ records • Lack of continual verifications on the developing design	• Use and communicate to the construction teams the best practice lessons from the construction phase • Continue involvement and engagement of the design team once on site • Engage residents and neighbours in the process as early and as fully as possible • Carefully follow installation and commissioning guidance provided by the manufacturers • Continue training • Prepare building logbook • Apply mid-construction stage testing
Post-Retrofit and Early Occupancy Stage	• Poor commissioning • Lack of a graduated handover • Complexity of controls • Lack of engagement of occupants • Lack of technical knowledge among occupants • Lack of follow-on support	• Post completion, proper commissioning needs to be carried out to ensure that systems operate at their optimum efficiency and that controls are operating as intended • Consider applying the Soft Landing approach that allows a gradual handover of the building • Consider a bedding-in period of at least a year to fine-tune the building

	• Introduction to new technology	• Plan follow-on support for the long term • A real-time display can make people more aware of their energy use • Provide training for residents • Provide user-friendly manuals • Consider offering more control to the resident rather than fully automatic systems
Post-Retrofit and in-Use Stage	• Lack of feedback communication with the design teams • Lack of engagement with the occupants • Lack of post-retrofit evaluation • Lack of transferability of information and knowledge from building to building • Lack of tracking occupant satisfaction	• Undertake POE • Monitor environmental conditions and check against the baseline model • Add a post-retrofit interview and walk-through to reveal how the house is being used • Provide feedback on your existing buildings, learn from good results and don't repeat mistakes • Engage residents early on
Sources: (Bordass, Leaman and Ruyssevelt, 2001; Adreu and Oreszczyn, 2004; Bell <i>et al.</i> , 2010; Demanuele, Tweddell and Davies, 2010; Gupta and Chandiwalla, 2010; Carbon Trust, 2011; Wingfield <i>et al.</i> , 2011; Guerra-Santin <i>et al.</i> , 2013; Gupta, Gregg and Cherian, 2013; de Wilde, 2014; Gupta and Gregg, 2014; Technology Strategy Board, 2014; Zero Carbon Hub, 2014; Global Buildings Performance Network, 2015; Guerra-Santin <i>et al.</i> , 2016; Gupta and Gregg, 2016; Niu, Pan and Zhao, 2016; Jia, Srinivasan and Raheem, 2017; Madsen and Gram-Hanssen, 2017; Shin <i>et al.</i> , 2017; Zou <i>et al.</i> , 2018; Laaroussi <i>et al.</i> , 2020; Gupta and Gregg, 2021; Lassen <i>et al.</i> , 2021)		

Most issues related to the decision taken or action missed from the beginning of the design process have a huge impact on the future energy performance of the building. Many of the factors affecting the performance gap in the design stage are directly linked to the design project itself, including limitations and lack of targets, as well as the level of knowledge and skills of the design team. Most of the issues identified in the design stage, or even later in the retrofit delivery process, are a result of not establishing the pre-retrofit performance of the building that is used as a baseline performance and serves as a benchmark against which the building performance after retrofit is compared to. However, there are other factors related to the lack of communication, engagement, and understanding between various stakeholders and project teams. The later factors significantly affect the performance gap in each stage of the retrofits. Nevertheless, in their review of the most recent studies on the performance gap, Zou *et al* (2018) underlined the need to extend building performance gap research to the whole building life-cycle as the performance gap happens in all stages and they are interconnected.

Successful retrofits have shown that managing the project from the initial design is vital for achieving the intended energy performance. Communication and integration between teams should start from the beginning (Niu, Pan and Zhao, 2016), with clear performance targets and responsibilities. However, the communication of feedback back to the design team is essential at any stage of the retrofitting process. Involvement and engagement

are also found to be more important in the design stage than in the other stages because of the increasing need to engage stakeholders early on in the design (Adreu and Oreszczyn, 2004; Carbon Trust, 2011; Wingfield *et al.*, 2011; Technology Strategy Board, 2014; Zero Carbon Hub, 2014) and at all times. Though, to have a successful collaboration, the retrofit decisions should be accepted by all parties before the works start. A lot can be done in terms of training the project teams and residents to increase their knowledge and skill level. This is especially important during the design stage where qualified designers and specialists are necessary for producing a holistic design.

Proper modelling should be provided and informed by reality through pre-retrofit surveys of the house and with its residents to reveal how the house is used and the residents' expectations, what they like and dislike, as well as how flexible they are about accepting the strategies in terms of their cost, appearance, social and cultural implications and so on. Pre-occupancy data collection is proposed in recent studies as a new data collection method that aims to help designers to evaluate and optimize a design before construction (Shin *et al.*, 2017; Zou *et al.*, 2018). However, combining post-occupancy and pre-occupancy data would facilitate the information and knowledge to be transferred from one specific building to another one. In the same way, testing the design against benchmarks throughout the design and construction stage ensures that changes and modifications of the design are understood, and unintended consequences are considered. Of great importance is the involvement of occupants' from the early stages of the architectural design, considering their expectations, perceptions and comfort, as well as habits and actions (Lassen *et al.*, 2021). Furthermore, tracking occupant satisfaction through continuous subjective feedback would improve not only occupant satisfaction, but also energy use, helping to close the performance gaps as well as empowering future holistic design choices and solutions that are more robust, and have a lower environmental impact and a longer lifetime (Lassen *et al.*, 2021).

This analysis enforces the idea 'Well begun is half done', and the more the process is towards the end, the less that can be done to minimise the performance gap, underlining the role of pre-retrofit evaluation of the building before designing the retrofit project.

2.3.7. Establishment of a baseline performance based on empirical evidence to minimise the performance gap

The effectiveness of the retrofit process can be increased by using a user-centred approach (Vischer, 2008), that can be informed by building performance evaluation undertaken before the retrofit, including information regarding energy use, occupants' perceived comfort, satisfaction and their expectations, which creates a full picture of the

actual performance of the house (Gupta and Chandiwalla, 2010). A holistic design solution that incorporates the occupant's impressions, perceptions, and expectations regarding various fields would make satisfaction assessments for assessing the performance of such designs (Lassen *et al.*, 2021). In addition, evaluating the user perceptions and behaviour with building performance in housing through integrating occupant feedback methods before retrofitting enables the occupant to have a better understanding of the measures, and is seen as essential to improve the uptake and effectiveness of household energy efficiency and low-carbon interventions (Gupta and Chandiwalla, 2010).

Different occupants living in the same type of house can have energy consumption that changes by a factor of three or more, mainly because occupants behave in more complex ways than designers account for (Janda, 2011), suggesting that it is the user that determines the energy consumption in homes (Gram-Hanssen, 2010). Wei *et al* (2017) showed that the energy-saving potential of retrofit measures was significantly influenced by occupants' heating behaviour. Therefore, users' behaviour must be understood and should not be used as an excuse by designers for not achieving the performance targets (Stevenson and Leaman, 2010).

Energy model calibration with the real data on energy and environmental performance gathered through pre-retrofit monitoring of the building (Gupta and Gregg, 2016), including the possibility of integrating the occupants' behaviours into building simulations based on measured observations rather than assumptions (Guerra-Santin *et al.*, 2016), would minimise the performance gap between the expectations and outcomes

2.4. Human factor on retrofit performance

2.4.1. Understanding the factors that influence occupant behaviour

It is widely recognised that occupant behaviour has a significant impact on building energy demand and on indoor thermal comfort conditions (Ascione *et al.*, 2020), even in high-energy performance dwellings (Santangelo *et al.*, 2018), which influences the effectiveness of energy retrofits (Steemers and Geun Young, 2009; Sunikka-Blank and Galvin, 2012; Gram-Hanssen and Georg, 2018; Ben and Steemers, 2020). Occupant behaviour can be affected by various factors, including building characteristics, social and personal characteristics, rebound effect, personal comfort, lifestyle and cultural background, occupant's knowledge and skills, as well as occupant's experience (Zou *et al.*, 2018). According to (Abrahamse *et al.*, 2005; Chen, Xu and Frey, 2016) there are also social-psychological factors that may also influence thermal comfort and energy

behaviours including beliefs, values, norms, social trust, habits, energy-saving attitudes, motivations, perceived behavioural control and environmental concerns. Ebrahimiagharehbaghi *et al.* (2021) consider the multiple origins characteristic of the factors that influence occupant behaviour and categorise them as motivations, barriers, contextual and personal factors. Fabi *et al.* (2013) classified these factors into five groups: physical environmental factors, contextual factors, psychological factors, physiological factors and social factors. Tam, Almeida and Le (2018) grouped the factors influencing occupant behaviour into objective factors including environmental conditions, such as temperature, air velocity, climate or noise; and, subjective factors depending on the personal perception of comfort affected by age, metabolic activity, a particular mood, habits, sensations and social interaction. Energy-related occupant behaviour can be adaptive (de Dear, Brager and Cooper, 1997; Humphreys and Nicol, 1998; Nicol and Humphreys, 2002) or non-adaptive (O'Brien and Gunay, 2014) as illustrated in Figure 4 by Hong *et al* (2017).

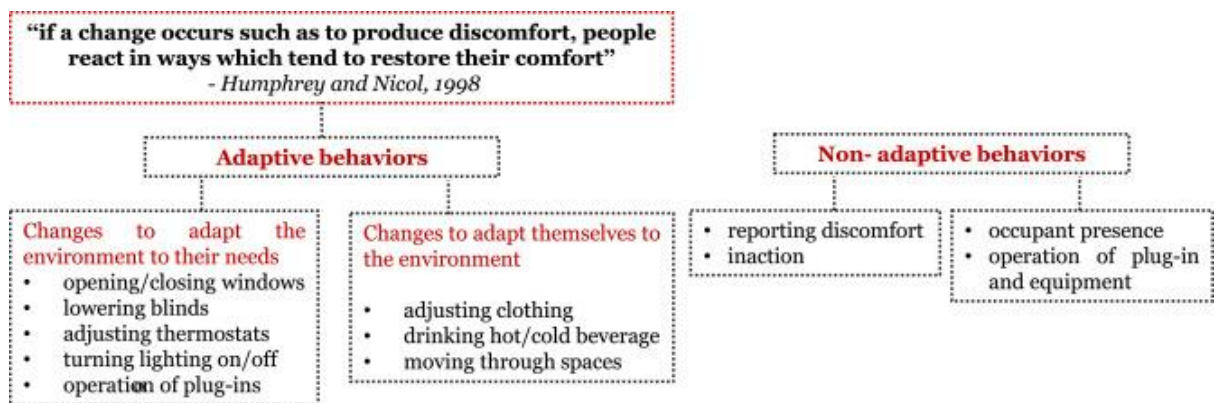


Figure 4: Energy-related occupant behaviours influencing building energy consumption and comfort

Source: (Hong *et al.*, 2017)

Within the energy-related adaptive behaviours category, occupants either make changes to adapt the environment to their needs or adapt themselves to their environment (de Dear, Brager and Cooper, 1997). Nicol and Humphreys (2002) described that “*occupants with more opportunities to adapt themselves to the environment or the environment to their requirements will be less likely to suffer discomfort*”. While in the energy-related non-adaptive behaviours category, action concerns the addition of electric equipment which affects the electric consumption of the building (Ascione *et al.*, 2020), as well as occupants' presence. Reporting discomfort or choosing inaction, can also affect the final building energy performance (Hong *et al.*, 2017).

Various approaches have been used in recent studies on the impacts of occupant behaviours on building energy performance. Three main research approaches have been identified by Laaroussi *et al* (2020): 1) Data collection and analysis based on data collection through sensors and communication technologies, b) occupant behaviour modelling that aims to develop a model that takes into consideration the behaviours and drivers over time, and c) an energy feedback approach to collect knowledge about the occupant's characteristics related to their behaviours, needs and preferences. An interdisciplinary and multidisciplinary approach, unifying language, unfolding methods, metrics, benchmarks, and platforms to compare results (Hong *et al.*, 2017) is crucial for understanding occupant behaviour, due to a technological-social contradiction as pertains to the human-building interaction effects on building energy use (Yan *et al.*, 2017). Delzendeh *et al* (2017) also suggest that the impacts of occupants' behaviour on the total energy consumption of buildings be studied in a multi-disciplinary approach incorporating sociology, psychology, economics, engineering and design factors. Mills and Schleich (2012) have previously suggested the cross-country analysis of occupant behaviour are needed to guarantee the validity, robustness, and efficiency of future studies, considering that climatic, cultural, and socio-demographic behavioural factors are different for each country, a point also acknowledged by D'Oca *et al* (2017).

2.4.2. Approaching retrofitting socio-technically rather than purely technically

Approaching retrofitting with a wide range of technical solutions has been found to be an ineffective way of reducing energy consumption and CO₂ emissions, resulting in expanding the performance gap (Tweed, 2013; Vlasova and Gram-Hanssen, 2014). This occurs because many of the issues associated with retrofitting are recognized as socio-technical rather than purely technical (Tweed, 2013). Therefore, a socio-technical system theory is proposed as the way of engaging social behaviours in retrofit technology (Galvin and Sunikka-Blank, 2014; Gram-Hanssen, 2014b; Judson and Maller, 2014), at multiple levels (Gupta and Gregg, 2012a), suggesting that emotions and feelings are important in the shaping of experience (Tweed, 2013). Socio-practice theory, as the dominant approach within socio-technical energy studies, helps to shift the focus from individuals towards more collective approaches (Karvonen, 2013; Bartiaux *et al.*, 2014) through bridging individual lifestyles and broader socio-technical systems of provision (Spaargaren and Van Vliet, 2000; Hargreaves, 2011) and suggests that close examination of the historical, cultural and situated character of retrofit processes opens the way for more radical approaches in policy and design (Shove *et al.*, 2008).

Although social practices are often used to study everyday life, household routines and interventions, there is little evidence of how these practices interact with other everyday practices (Judson and Maller, 2014). Bartiaux et al. (2014) discuss in their study whether retrofitting can be considered a practice in itself, and have concluded that it is not yet a practice as a result of the small or contradictory effects that the four components of the practice have on energy-related renovations. Moreover, the configuration of these components varies for different places, times and between performers (Hand, Shove and Southerton, 2007; Judson and Maller, 2014). However, some users of practice theory focus on the micro-level and the habitual rather than including a longer period when understanding retrofits (Karvonen, 2013). Because the nature of retrofit works are periodic and inconsistent rather than every day, Bartiaux *et al* (2014) have proposed to consider home retrofits as 'bundles' of separate practices rather than only one practice. Again, this conclusion comes as a result of the micro-scale consideration of retrofitting around the individual household and individual house, as one of the limitations evidenced by Karvonen (2013) and Bartiaux *et al.*, (2014).

There is a limitation in this proposition that different households behave in different ways. However, we must accept that the buildings, together with their habitats, coevolve and retrofitting is an intervention not only in the building's structure but also in the rhythm of its occupants (Karvonen, 2013). Madsen and Gran-Hanssen (2017) emphasize that technology not only plays a big role in shaping our habits, and how occupant expectations and habits change when they are introduced to new technology, but also the technology may shape and affect the occupant's evaluations of comfort or satisfaction, and especially to the indoor climate, which has been particularly investigated for the thermal field (Kim and de Dear, 2012; Schweiker, Risetto and Wagner, 2020). Social norms largely shape human social behaviours from daily behavioural decisions to group interactions (Haque, Lemanski and de Groot, 2021). Karvonen (2013) and Gupta, Barnfield and Hipwood (2014) encourage the community approaches, where people engage and learn from each other and form a network between actors for facilitating the process of co-evolution of the build environment and society (Karvonen, 2013), helping to develop a culture of energy (Stephenson *et al.*, 2010) and sustainable living (Karvonen, 2013). It is recognised that individual actions are influenced by group actions and pressure for group conformity (McDonald and Crandall, 2015; Haque, Lemanski and de Groot, 2021). Achieving this will also require more information about retrofitting processes and possible linkages between retrofitting practices and everyday practices (Vlasova and Gram-Hanssen, 2014).

2.4.3. Acceptability

There is little coordinated evidence of how people use their houses, how they feel about them, and their fears and aspirations (Ravetz, 2008; Tweed, 2013), how and why they decide to retrofit their houses (Crosbie and Baker, 2010), and how every day and energy-consuming practices afterwards will be influenced by the chosen technology and building in general (Vlasova and Gram-Hanssen, 2014). Many households don't consider renovating the house until building components are approaching the end of their useful life (Achtnicht and Madlener, 2014; Alam *et al.*, 2019), they want to improve the house's functionality (Caputo and Pasetti, 2017), or when they are at a reference point of their lives named 'trigger points' (Energy Saving Trust, 2011), reflecting a change in their life such as marriage or expanding of the family (Energy Saving Trust, 2011; Simpson *et al.*, 2016).

Their role in the energy performance of the house is underappreciated or unacknowledged (Karvonen, 2013). That is why treating each household as an in-depth case study (Gupta and Barnfield, 2013; Tweed, 2013; Ingle *et al.*, 2014) and proposing the solution specifically for them, is needed to understand the people who live in the properties. Through careful systematic longitudinal monitoring at a micro-scale, it can be determined whether designs stand up in the face of occupant's use and needs, to what extent information and advice affect the way occupants use their properties and make informed decisions about their energy consumption (Wingfield *et al.*, 2011). Notwithstanding that energy retrofitting has the potential to change the occupants' preferences, (Greening, Greene and Difiglio, 2000), different cases of unsuccessful retrofitting activities, even when they are technical and financially viable (IPCC, 2014), indicate multiple barriers.

Haines and Mitchell (2014) suggest that different social backgrounds can have a huge impact on the ways and extent to which homeowners retrofit their homes. However, whilst it is widely recognized that socio-cultural norms determine collective acceptance of new technology, especially in low-income households (Haque, Lemanski and de Groot, 2021), there is little attention to how social-cultural influencers affect everyday energy behaviours (Shove and Walker, 2014). Haque, Lemanski and de Groot (2021) explore the reasons why renewable energy projects are not always accepted by end-users, considering the socio-cultural environment of energy users, even though they offer positive gains for low-income communities. Often, they are associated with relatively high levels of uncertainty of their acceptance or successful outcome (Butera, 2013) because of different perspectives on the goals, and the way to achieve them, from different stakeholders due to different backgrounds, knowledge, position, objectives and interests

(Roberts, 2001; Van Bueren, 2009). It is also related to the low levels of existing knowledge regarding energy issues, even though it is assumed that people are cognitively prepared to participate in energy decisions (Janda, 2011), and because information often is incomplete and contradictory (Ortiz, Itard and Bluysen, 2020). When this happens in the USA, where only 12% of Americans could pass a basic test on energy knowledge (NEETF, 2002), it becomes more severe in a developing country like Albania, where information and awareness about energy has just recently started to be publicized. Against this context, it is vital to understand how users' expectations affect their acceptance of retrofits and what factors affect occupants to choose one strategy over the other and to what extent. These factors can be central to the success of retrofit schemes.

2.5. Energy simulation as a dynamic energy prediction model

Buildings' energy simulations are one of the most common methods for estimating the energy demand of existing buildings, as well as energy savings from retrofitting projects (Guerra-Santin and Silvester, 2017). However, there is often a significant discrepancy between the predicted and actual energy consumption of buildings (Gupta and Chandiwalla, 2010; Gupta and Gregg, 2012a; Ma *et al.*, 2012; Sunikka-Blank and Galvin, 2012; Gram-Hanssen, 2014b; Yan *et al.*, 2015; Delzendeh *et al.*, 2017; Jia, Srinivasan and Raheem, 2017; Ren, Chen and James, 2018; van den Brom, Meijer and Visscher, 2018; Ben and Steemers, 2020), which is influenced by different factors and is largely caused by the complex interdependencies that occur between the fabric, services, controls, and occupant behaviour (Gupta and Kapsali, 2016; Gram-Hanssen and Georg, 2018). The physical design factors such as building features and the effect of external weather are the focus of many building simulation tools, while it has been challenging to incorporate the interaction between occupants and buildings, even though there has been significant research on occupant behaviours in buildings in recent years (Jia, Srinivasan and Raheem, 2017). Only five out of 27 factors that were suggested in previous studies reviewed by Wei, Jones and de Wilde (2014), i.e., room type, occupancy, indoor relative humidity, outdoor climate, and time of day, have been used to model space-heating behaviour in building performance simulations (BPS). Generally, occupant behaviour is oversimplified and predefined through static schedules in building performance simulations, ignoring its stochastic nature, dynamics, and diversity (Gorse *et al.*, 2016). Improving assumptions about building operations has been a key challenge in recent research (Kavgic *et al.*, 2010; Aragon *et al.*, 2017; Guerra-Santin and Silvester, 2017; Abuimara *et al.*, 2019).

2.5.1. Influence of Occupant Behaviour in Building Energy Simulations

It is widely recognised that occupant behaviour has a significant impact on building energy demand and on indoor thermal comfort conditions (Steemers and Geun Young, 2009; Sunikka-Blank and Galvin, 2012; Gram-Hanssen and Georg, 2018; Ascione *et al.*, 2020; Ben and Steemers, 2020). Nonetheless, integrating occupant behaviour into building energy simulations is challenging (Jia, Srinivasan and Raheem, 2017), as it is usually oversimplified and predefined through static schedules in building performance simulations (Menezes *et al.*, 2012; Gaetani, Hoes and Hensen, 2016; Hong *et al.*, 2017; Ascione *et al.*, 2020; Ben and Steemers, 2020; Laaroussi *et al.*, 2020). Due to a lack of pre-retrofit evaluation in the early stage of the design and a lack of data about various aspects of the building, considerable assumptions and predictions are used (Bordass, Leaman and Ruyssevelt, 2001; Demanuele, Tweddell and Davies, 2010; Zero Carbon Hub, 2014). Therefore, the improvement of occupants' presence and modelling their actions in building simulations is essential to enhance the accuracy of the building energy simulation process (Yan *et al.*, 2015). Yao and Steemers (2005) claimed that the number of occupants and the length of the period in which the dwelling is occupied are the main factors influencing energy consumption. Yan *et al.* (2015) also found that occupant–building interaction is affected by the arrival, departure, and duration of absence of occupants. Jia, Srinivasan, and Raheem (2017) described how occupant presence/absence in rooms is not enough for occupant behaviour modelling and how further information is needed regarding the adaptation to the indoor environment and the occupants themselves.

Indoor air temperature has been found to significantly influence the performance of energy-efficiency measures (Dodoo, Yao Ayikoe Tettey and Gustavsson, 2017), and assuming one standard indoor temperature profile for energy modelling for all homes would contribute to the performance gap between the actual and estimate energy consumption in homes. Developing various indoor temperature profiles would overcome this assumption and would assist in better calculations of energy consumption in homes, as well as more accurate predictions of energy savings through energy retrofitting.

However, the indoor temperature is highly affected by occupant behaviour, which itself can be affected by various factors, including a building's characteristics, social and personal characteristics, rebound effects, personal comfort, lifestyle and cultural background, occupants' knowledge and skills, and occupants' experience (Zou *et al.*, 2018).

In this context, to investigate the effect of occupant behaviour on the indoor temperature in homes, this study investigates the association of indoor temperature profiles with socio-demographic characteristics (education level, household size, presence of children or retired people, income, and monthly energy bill), as well as behavioural factors (cooling and heating usage patterns during the day and night) for each household selected, along with the effect of building characteristics (building type and size, period of construction, existence of wall insulation or double glazing, and type of heating or cooling).

2.6. Main lessons learnt from several retrofitting programmes in Europe

Although the domestic sector offers the greatest potential for standardisation to reduce CO₂ emissions from buildings, a one-size-fits-all approach may be difficult to apply, mainly because of the different stories of people associated with the buildings (Tweed, 2013). The relationship that residents have with their properties is highly complex, and understanding this relationship is critical to designing and producing low-carbon housing that works for a range of households now and over their lifetime in the properties (Wingfield *et al.*, 2011). Considering the multi-dimensional benefits that energy retrofitting has not only at the national and global level but also in occupant's life, future energy retrofitting programmes must consider the lessons learnt from the retrofitting activities undertaken in the past. The most prevalent ones are illustrated in Table 2. Attention should be given to delivery models to be applied to reduce energy consumption and the associated CO₂ emission reduction as well as to the supply chain, rather than the level of CO₂ reductions to be achieved (Gupta *et al.*, 2015a). Therefore, developing a socio-technical approach that takes into account both building and occupants, considering both physical and social factors that influence energy consumption (Crosbie and Baker, 2010; Gupta and Chandiwalla, 2010; Tweed, 2013; Gupta, Barnfield and Hipwood, 2014; Judson and Maller, 2014; Gupta and Gregg, 2015; Gupta *et al.*, 2015a) remains in the centre of retrofitting programmes. It is found that post-retrofit energy consumption may vary dramatically even for neighbouring houses with nearly identical construction (Andersen *et al.*, 2009; Gram-Hanssen, 2013; Ingle *et al.*, 2014; Ascione *et al.*, 2020), because people behave in different ways and there is no 'standard' household (Shove, Pantzar and Watson, 2012). Moreover, socio-technical variables associated with different households such as income, background, education level and employment, can

influence their attitudes towards energy consumption (Guerra-Santin *et al.*, 2016). These behavioural patterns, which can be determined by lifestyle, preferences, attitudes, perceptions of comfort, personal background, and household characteristics (Andersen *et al.*, 2009), and the way people retrofit their homes need to be situated with the everyday practices that take place in the home (Vlasova and Gram-Hanssen, 2014) and should be considered in the early stages of the design (Lassen *et al.*, 2021). This tailored-made information and strategies would serve to motivate diverse households with different characteristics (Azizi, Nair and Olofsson, 2019).

The involvement of the community (Karvonen, 2013; Gupta *et al.*, 2015a) and the need to consider the households as in-depth case studies (Gupta and Barnfield, 2013; Tweed, 2013; Ingle *et al.*, 2014) are probably the essential findings that if considered, will create great potential for minimising the performance gap through addressing social, institutional and technical barriers (Karvonen, 2013).

‘Design is the result of choices’ (Margolin, 1989) based not only on aesthetic preferences (Moore and Karvonen, 2008) because it is not only choosing a thing but a way of life (Winner, 1977) that accommodates everyday practices. This is why people must be involved before work starts and in every decision-making throughout the process (Gupta *et al.*, 2015a) and their perspectives should be treated in interchange with the experts’ views (Gram-Hanssen, 2014b)

Table 2: Main lessons from retrofitting programmes to inform future approaches

Future energy retrofit approaches should:	Author(s)
Adapt socio-technical approaches that take into account both the building and the occupants within to address both the physical and social factors that influence energy consumption.	(Crosbie and Baker, 2010; Gupta and Chandiwalla, 2010; Tweed, 2013; Gupta, Barnfield and Hipwood, 2014; Judson and Maller, 2014; Vlasova and Gram-Hanssen, 2014; Gupta and Gregg, 2015; Gupta <i>et al.</i> , 2015a).
People are different, retrofitting projects are different, and thus energy policy should also be different.	(Gram-Hanssen, 2014b)
Consider buildings with different histories and different people who live in them.	(Tweed, 2013)
Give intention to the programme design and formulation itself through encouraging innovation and considering risk and uncertainty associated with innovation. Moreover, they must focus on outcomes wider than energy and carbon reduction, such as comfort, indoor air quality, health and elimination of fuel poverty.	(Gupta <i>et al.</i> , 2015a)

Move the attention from “ <i>what level of CO₂ reductions are to be achieved to how (delivery models) these radical reductions can be achieved and by whom (supply chain)</i> ”.	(Gupta <i>et al.</i> , 2015a)
View the households as in-depth case studies rather than as statistical generalisations.	(Gupta and Barnfield, 2013; Tweed, 2013; Ingle <i>et al.</i> , 2014)
Inform and engage people in the decision-making process.	(European Commission, 2012)
Involve local, community-based programmes that simultaneously address the social and technical issues of domestic energy use.	(Karvonen, 2013; Gupta <i>et al.</i> , 2015a)
Different methods and technologies used by different disciplines and stakeholders that engage technological research with social behaviour at multiple levels are required.	(Gupta, Gregg and Cherian, 2013)
Apply a systematic approach to the collection of data and evaluation, rigorously and consistently to inform design, modelling and benchmarking.	(Austin and Charlson, 2012; Cutland Consulting, 2012)
A retrofitting process where expert views and homeowners’ perspectives can interchange is desirable.	(Gram-Hanssen, 2014b)
Recommendations need to be developed from the design stage through to the operation.	(Gupta and Kapsali, 2016)
Building design and technologies should interact with occupant preferences, capabilities and needs in an energy-efficient way.	(Bluyssen, 2020)
Give particular attention to the health effects of occupant behaviour on retrofitted homes.	(Ortiz, Itard and Bluyssen, 2020)
The online tools can support homeowners by providing information for every step of the retrofitting process.	(Azizi, Nair and Olofsson, 2019)
The need for tailored-made information and strategies to motivate diverse households with different characteristics.	(Azizi, Nair and Olofsson, 2019)

However, the statement from (Janda, 2011), “Buildings don’t use energy: people do” has shifted the attention from the building to the people living in it. There is an urgent need to develop a culture of energy and essential changes are required not only in buildings but also in the way people behave (Stephenson *et al.*, 2010; Janda, 2011; Karvonen, 2013). Therefore, education on energy should be much more comprehensive, integrated, and interactive (Darby, 2010; Janda, 2011), through the integration of occupant feedback methods before retrofits (Gupta and Chandiwala, 2010), including occupant training (Crosbie and Baker, 2010; Gupta *et al.*, 2015a). Knowledge networks that facilitate information exchange between stakeholders by including the occupants both before and during retrofit works have shown to be successful (Bartiaux *et al.*, 2014; Gupta *et al.*, 2015a).

Retrofit evaluations have revealed the need to understand occupant behaviour, drivers and factors affecting their decision to retrofit (Sunikka-Blank and Galvin, 2012; Tweed, 2013; Webber, Gouldson and Kerr, 2015; Simpson *et al.*, 2016), what to retrofit and how

deep (Gupta and Gregg, 2016). Recent research (Yan et al., 2017) underlines the importance of considering the stochastic nature, dynamic nature and diversity of occupant behaviour in building performance simulations, and not only represent it with oversimplified and predefined static schedules or fixed settings and rules. Using empirical evidence through pre-retrofit evaluation to establish a baseline performance is found to be essential to evaluate the success of retrofits (Gupta and Chandiwalla, 2010).

Finally, but not least, factors other than just energy and environment can affect the success of energy retrofits and to increase the level of retrofit delivered, they must be aesthetical, stylish, and fit with current lifestyles (Crosbie and Baker, 2010; Haines and Mitchell, 2014).

Table 3 summarises some of the main lessons from retrofitting programmes regarding occupant's behaviour, feedback and information.

Table 3: Main lessons from retrofitting programmes regarding occupant's behaviour, feedback and information

Issues to be addressed regarding occupant behaviour, feedback and information:	Author(s)
"Buildings don't use energy: people do". Therefore, essential changes are required not only in buildings but in the "entire fabric of society".	(Stephenson <i>et al.</i> , 2010; Janda, 2011; Karvonen, 2013)
There is a need to develop a culture of energy.	(Stephenson <i>et al.</i> , 2010; Janda, 2011)
Integration of occupant feedback methods before improving existing housing to improve the effectiveness of household energy efficiency and low-carbon interventions.	(Gupta and Chandiwalla, 2010).
Integration of the evaluation methods with occupant training, education and advice to avoid unintended consequences.	(Crosbie and Baker, 2010; Gupta <i>et al.</i> , 2015a)
Education should be much more comprehensive, integrated, hands-on and interactive.	(Darby, 2010; Janda, 2011)
Further development of knowledge networks as they have shown to be beneficial in providing advice for occupants both before and during the retrofit work.	(Bartiaux <i>et al.</i> , 2014; Gupta <i>et al.</i> , 2015a)
Exchange of the lessons learnt from retrofit evaluation to prevent the repetition of the revealed mistakes.	(Austin and Charlson, 2012; Gupta <i>et al.</i> , 2015a)
The information regarding retrofit interventions should be clear, concise and easily available and should contain realistic expectations.	(Crosbie and Baker, 2010) (Cutland Consulting, 2012).
A better understanding is needed of drivers of energy retrofits regarding occupants' decisions.	(Sunikka-Blank and Galvin, 2012; Tweed, 2013; Webber, Gouldson and Kerr, 2015; Simpson <i>et al.</i> , 2016)
The inclusion of contextual and behavioural variables in building energy models to increase the accuracy of predictive models.	(Yan <i>et al.</i> , 2017)
The stochastic nature, dynamics, and diversity of occupant behaviours must be considered in the building of performance simulations for more accuracy.	(Yan <i>et al.</i> , 2017)
Establish a baseline performance based on empirical evidence.	(Gupta and Chandiwalla, 2010)
To increase the level of retrofit delivered, the interventions must be aesthetical, stylish, and fit with current lifestyles.	(Crosbie and Baker, 2010; Haines and Mitchell, 2014)

2.7. Summary

Home retrofits have a great potential to achieve energy and carbon emission reduction targets. Even if they do not meet the targets, occupants will benefit from improvements in their comfort, satisfaction and health, as well as an increase in the value of their

homes, to name a few. Households could benefit from applying retrofitting at different levels and stages throughout the lifetime of their building, based on technical and economical feasibility as well as their social/cultural situation. However, deep retrofitting is recommended to make the most of the interventions. Still, regardless of their great potential in meeting national and global targets, home retrofits are not taken up because of many technical, economic, institutional, social and cultural barriers which interact and strengthen each other. Moreover, the process of retrofitting is very complex and is seen from different angles by different stakeholders, creating a gap in the real performance of the interventions. Therefore, predicting the potential that energy improvement has, in reality, is very difficult.

On the other hand, through an analysis of the performance gap throughout the retrofit process, various factors were found to impact the potential energy savings of the retrofits in the existing housing stock. As many studies have indicated (Andersen *et al.*, 2009; Guerra-Santin and Itard, 2010; Shove, Pantzar and Watson, 2012; Vlasova and Gram-Hanssen, 2014), the role of occupants' behaviour in consumption is increasingly important. Involving them from the beginning of project design can ensure a deep understanding of their needs and expectations while increasing their understanding of the works. Furthermore, involving other stakeholders from the design stage to handover and feedback will offer more potential in achieving the performance targets of the project.

Based on this in-depth literature review of retrofitting in residential buildings, it can be concluded:

Firstly, it is almost impossible to eliminate the performance gap of a building retrofit because of its complexity and involvement of human factors that are highly variable and unpredictable. This supports the recommendation given by Demanuele, Tweddell and Davies (2010) that it is more practical and feasible to estimate a range in which energy consumption is likely to fall and highlight the key factors affecting where a building's energy use will fall within that range, rather giving specific energy predictions. This will allow designers and occupants to focus on the factors which influence their building's energy performance most significantly.

Secondly, proper modelling, informed by reality and pre-retrofit surveys of houses, is significant in minimising the performance gap. Therefore, treating households as in-depth case studies (Gupta and Barnfield, 2013) can reveal real information about how the house is being used and the real potential for energy improvements based on the interaction between people and buildings. The information gathered through field

measurements and surveys would provide a closer prediction of the energy performance of homes than using modelling assumptions.

Thirdly, there is a need to understand what makes people decide to retrofit their homes and how they make these decisions. A better understanding of occupants' expectations, perceptions and behaviours is required to be able to make better estimations of energy savings. Understanding the factors that make homeowners retrofit and how they retrofit is essential in increasing the uptake of retrofits in the residential sector.

Fourthly, "adding people" into policy and practical measures for home retrofits is of great significance (Gram-Hanssen, 2014b). They should not be seen as isolated passive receivers of retrofits but as individuals with social norms, perceptions, and expectations. The socio-technical approach has been advised for future retrofit programmes that take into consideration occupants' needs and expectations before and after retrofits. The connection between technologies and everyday life, rather than only efficient technology, should be the focus of future policies to achieve energy savings.

Finally, multi-dimensional and interdisciplinary research for strategies integration and knowledge networks needs to be developed between main stakeholders and communities involving occupant education and support (Gupta and Gregg, 2016; Zou *et al.*, 2018). Reducing energy use requires not only changing the shape and nature of buildings but also the entire fabric of society; preparing people to accept their responsibility in the built environment (Janda, 2011). Even more, the design of buildings and technologies should interact with occupants' preferences, capabilities and needs in an energy-efficient way, as well as create a healthy indoor environment (Bluyssen, 2020; Ortiz, Itard and Bluyssen, 2020).

CHAPTER 3

Case study of Albania

3.1. Introduction: Chapter outline

This chapter presents an overview of the case study of Albania and why it is important to retrofit its housing stock. Information regarding residential building stock, energy consumption and housing typologies is given. Furthermore, legislation on energy and retrofitting in Albania is explored, followed by an evaluation of the barriers and drivers for energy retrofits. Available research regarding energy in buildings and retrofitting in Albania, although very limited, is collected and analysed. Finally, considering the available information, a discussion and evaluation of a retrofitting approach to be undertaken in the context of Albania is provided at the end of this chapter.

3.2. Why Albania?

The Kyoto Protocol (United Nations, 1998) has set binding emissions reduction targets for industrialised countries and the European community, recognising that they are largely responsible for the current high levels of GHG emissions in the atmosphere. Albania has been a Party to the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) since 2005 and holds the status of the Non-Annex I Party, and with a candidate country status to EU, it is mandatory that Albania, to bring its legislation in line with the EU to persuade EU politicians to accept it as a member of the European Union. Although Albania, as a developing country, has no obligations to reduce greenhouse gas emissions (United Nations Human Rights, 2015), the built area and the energy consumption in the building sector is expected to increase as a result of the continuous development of the country. Moreover, Gupta (Université Total, 2013) remarked that we expect people to spend more time in buildings in the future in developing countries, than in developed countries (90% of the time), resulting in increasing energy consumption and health issues. Therefore, special consideration is given to developing countries, recognizing the importance of reducing emissions and building resilience to climate change impacts on them (European Commission, 2016). It is recommended that the Albanian Government and community take action to develop long-term policies to reduce greenhouse gas emissions (IPCC, 2014). Furthermore, as in many countries in Europe, improving the existing housing stock in Albania is

considered to be the highest potential contributor to the energy-saving targets of the National Energy Efficiency Plan (Energy Community, 2011), given the fact that the building sector is the second largest energy consumer in Albania, accounting for over 40% of total carbon emissions (Energy Community, 2015; Global Buildings Performance Network, 2015). Even more, reducing energy use in buildings is considered essential to increase the energy security of the country (Energy Charter Secretariat, 2013; Republika e Shqiperise, 2015).

On the other hand, there is a need to increase the thermal comfort in the existing homes in Albania. Most homes are the product of a quick and cheap construction strategy prompted by the housing shortage during the communist regime and followed by the rapid urbanization that happened after the 1990s, which had no focus on the quality of life of their occupants. Even more, Albania's economic situation makes it difficult for occupants to consume the energy needed to provide adequate thermal comfort in their houses. At least 25% of the population cannot afford to pay for energy and 95% of those with access to electricity say it is too expensive to use (Fankhauser and Tepic, 2005). The existing housing stock is in a poor condition, which is also due to a long-term lack of renovation, mainly because of a lack of financing for this purpose.

However, in recent years, many new buildings are being insulated because of the high competition emerging within the construction sector. First initiatives are also taken to improve the existing buildings, even though there is a lack of good practices and research (Islami, 2016). Although several retrofitting programs have been developed in different European countries, lessons have to be transferred to national and local contexts, because what works well in one country may not work in another (UNECE, 2013). Therefore, energy retrofitting programs should be carefully designed considering not only the economical and technical issues of retrofits, but also social and cultural aspects and focusing also on thermal comfort, indoor air quality as well as health and elimination of poor fuel (Gupta *et al.*, 2015a).

3.2.1. Energy consumption of residential buildings in Albania

The building sector in Albania is responsible for over 40% of total GHG emissions (Energy Community, 2015), 30% of total energy consumption and over half of the total electricity consumption (EU built Energy Efficiency, 2012) (See Figure 5). Most of this energy, about 40%, is used for space heating (Shehi, Gjoka and Schweizer, 2011) and the average electricity consumption per household per year is 4,600kWh (International Energy Agency, 2008)

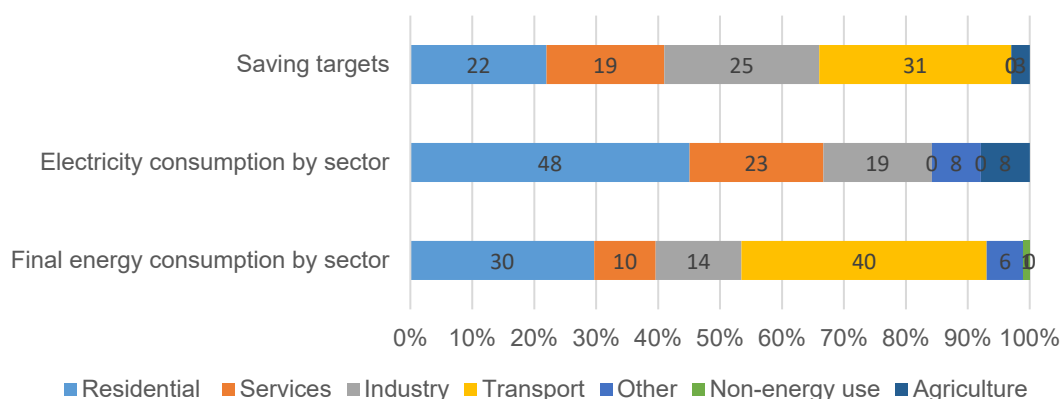


Figure 5: Energy consumption and energy-saving targets by sector in Albania

Source: (Republic of Albania, 2011; AKBN, 2012; Energy Community, 2015)

Because Albania is not yet gasified, electricity is widely used for space heating in winter and cooling in summer. Furthermore, electricity is the main fuel for heating water, at approximately 86% (International Energy Agency, 2008). Although fuelwood is extensively consumed, particularly in rural and mountainous areas, it is typically consumed inefficiently mainly because of the low-efficiency stoves and poorly insulated houses (International Energy Agency, 2008). LPG is another form of energy on the rise in consumption in Albania because of its flexibility and coverage to a broad range of users. According to INSTAT (2012), heating systems in Albania consist mainly of separate equipment like stoves, which were owned by 63.3% of households, or split systems (reverse air conditioners) and electric heaters, while only 3.2% of households owned central heating systems within the building (See Figure 6). Firewood is the main type of heating for 57.5% of households, followed by gas at 20.8% and electricity at 15.4%.

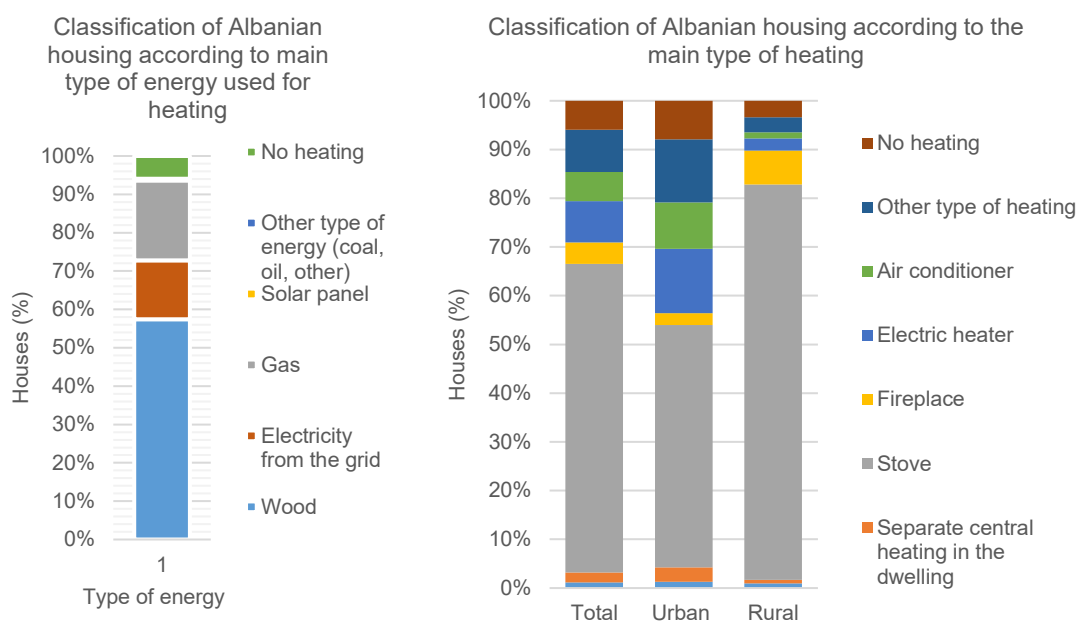


Figure 6: Albanian housing stock by the main type of energy used for heating (left) and main type of heating (right)

Source: (Instat, 2012)

However, because Albania relies on hydropower for over 90% of its electricity production, it emits the lowest amount of CO₂ in the Western Balkans and its GDP is less CO₂ intensive (International Energy Agency, 2008). Nevertheless, energy security is a critical concern for the country (Energy Charter Secretariat, 2013). Therefore, it is explicitly recognised by the Albanian authorities that energy efficiency and renewable energy have the potential to both reduce carbon emissions and make a contribution to the security of supply (Islami, 2012; Energy Charter Secretariat, 2013). Retrofitting existing buildings is gaining much more importance (EU built Energy Efficiency, 2012), offering the greatest potential for energy savings and rapidly cutting GHG emissions (Pellegrini-Masini *et al.*, 2010).

3.2.2. Residential stock in Albania

In Albania, there are 598,267 residential buildings containing 1,012,400 dwellings in total (Instat, 2012). The housing stock has been developed in line with the political, social, and economic phases of the country. Houses built before 1945 were mainly 'self-built' (United Nations, 2002) and are being progressively replaced by new constructions. With the start of the socialism era, over 62,000 houses were inherited, and one-quarter of them were damaged or destroyed, creating a national housing crisis (Aliaj, 1999). Therefore, to meet the high demand for housing, 185,000 new houses and apartments were built from 1945 to 1970 (Aliaj, 1999), following the slogan 'Let's build quickly, good

and cheap' (Simaku, 2014). This shortage of housing led to a production rate of over 10,000 units a year (United Nations, 2002), which were mainly prototype designs prepared by the National Institute of Studies and Designs in Albania. Later, as much as 46.5% of the housing stock pre-1990 was built from 1971 to 1990 and was mainly prefabricated buildings in urban areas and one-two-storey houses in the countryside (Aliaj, 1999). Although over 80% of the population were accommodated in houses built during the socialism era, they were minimalist, demonstrating the power of the system over people's life and space. The approved standards were 4-6 m² per person (United Nations, 2002). On the other hand, the size of households was large since more than one generation shared the same dwelling (Aliaj, 1999) mainly because of cultural reasons and strong traditional values relating to marriage and family.

In the 1990s, with the change of the political system to democracy, there was a massive and uncontrolled flow of population from rural to urban areas, causing a high rate of unpermitted developments in cities. From 1992 to 1996, as many as 60% of all houses built by the private sector were informal (United Nations, 2002). The control over these constructions and building regulations was non-existent because the central and local institutions were powerless and weak (United Nations, 2002). Corruption and the lack of respect for institutions were also at the highest levels. This rapid urbanization was inevitable, as Albania inherited from communism the lowest number of houses in European countries in transition, with only 219 dwellings per 1,000 people and also the lowest surface area per person of only 8m² (United Nations, 2002). Therefore, the biggest intent was to build bigger houses at a low cost, with no concern for either the design or energy efficiency.

The inner cities also underwent a radical change, especially in Tirana, where most of the existing villas were demolished to make space for newly built 10-storey, or taller, mixed-use apartment buildings at high densities (Pojani, 2010) (See Figure 7).



Figure 7: Tirana's urban development after 1991

Source: (Wikimedia Commons, 2005; Pojani, 2010)

Likewise, to satisfy the rapid demographic and economic growth of the city, many new high-rise apartment buildings were packed in the spaces between existing ones (Deda, 2003). Alterations to existing buildings were commonly undertaken, such as new sections or floors and the enclosure of existing balconies and porches, to achieve new and better living spaces, with no concern for outdoor public space. On the other hand, illegal large settlements outside the city boundaries were constructed. All these developments have contributed to the housing stock being the most evident social-economic problem today in Albania (Nepravishta, 2004).

Overall, there can be defined three periods in the development of Albanian housing stock, related to the economic, political, and social development of the country, with characteristics summarised in Table 4. Figure 8 is an overview of the housing stock in Albania by built form and year of construction.

Table 4: Physical and socio-economic characteristics of periods of housing construction in Albania

Period	Construction characteristics	Socio-economic characteristics
Pre 1960	• 'self-built' • generally single-family units • low standards • poor infrastructure	• rural society • little industrialization
1961-1990	• A distinction between urban and rural housing: flats in urban areas and self-built in rural ones. • Low-rise blocks of flats (six floors max). • Typically, loadbearing brick construction or prefabricated elements. • Prototype designs. • Insufficient and low-quality housing. • Limited space standards. • High technical standards due to strict controls.	• Immigration was controlled by the communist government. • No housing markets. • Big families in small houses. • Low-cost buildings. • Buildings of this period supported the 'collective' aspect of communism ideology. • 'Let's build quickly, good and cheap' slogan.
Post-1990	• Many ground-floor flats were converted to non-residential use. • The most common construction is concrete frames with brick or block in-fill. • Limited building controls. • Illegal and informal constructions.	• Rapid and massive free movement from rural to urban areas. • Overpopulation of cities. • Most of the public stock was privatized. • Most new housing has been produced by the private sector. • Illegal occupation of vacant land and informal houses. • Individualist society.

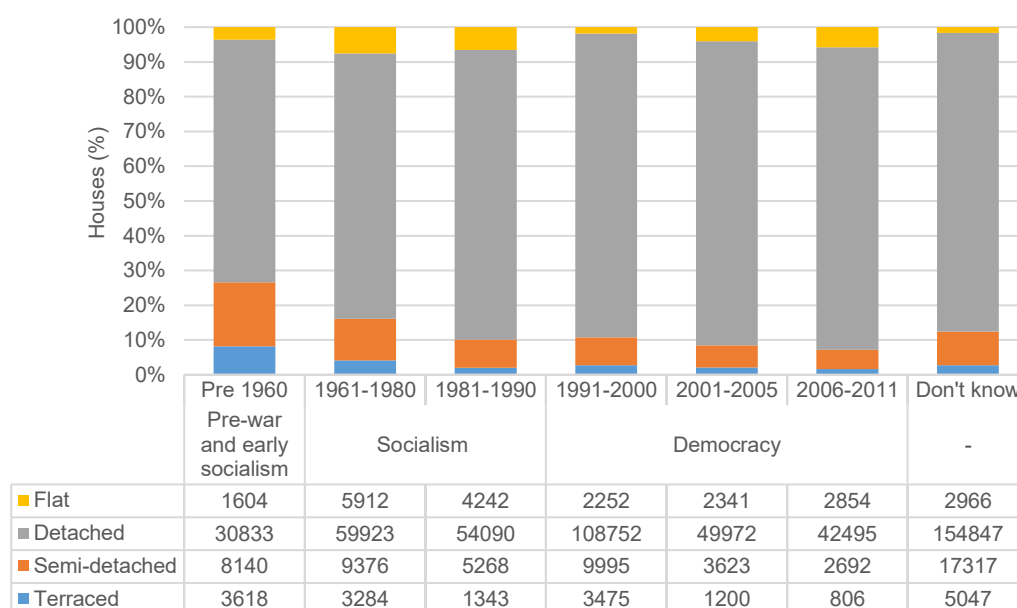


Figure 8: Albanian housing stock by typology and year of construction

Source: (Instat, 2012)

From the last large survey of population and housing in Albania undertaken by INSTAT (2012) of the 598,267 residential buildings, 80% were one-storey detached houses, with only one dwelling. A total of 4% were apartment buildings, of which 31.3% were in the capital city, Tirana (see Figure 9). Most of them were mixed-used with shops on the ground floor and residential on the other ones. However, 35% of the dwellings were in apartment buildings, which makes this typology very important in the Albanian housing stock. According to (Instat, 2012), at least 57% of all residential buildings in Tirana were built between 1991 and 2011, and the most common number of rooms in dwellings was three, 43.8% had a density of about 14sqm per occupant; 86% of houses in Albania were constructed with brick and stone (Instat, 2012) (see Figure 9).

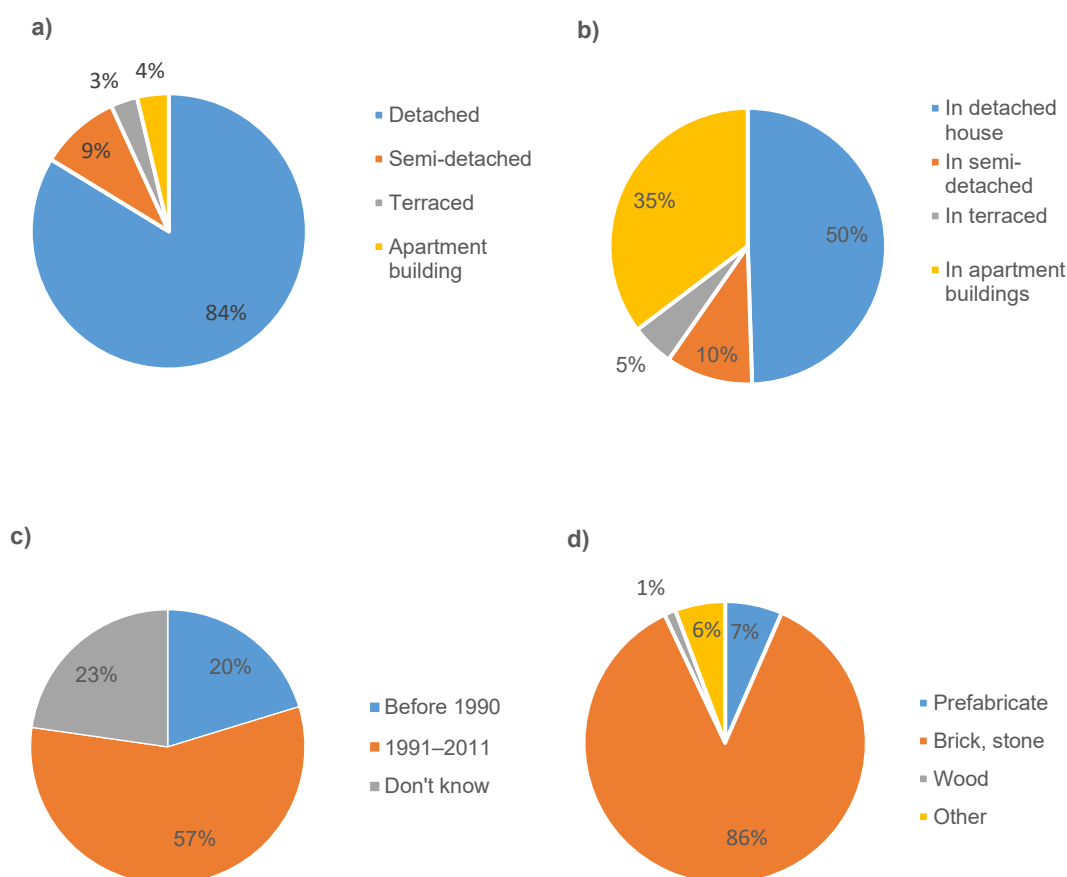


Figure 9: Residential buildings in Albania, by building type (a), dwellings in each type (b), by the period of construction (c); and construction material (d).

Source: (Instat, 2012)

Today, most of the residential buildings in Albania are not energy efficient mainly because of the lack of thermal insulation, high levels of infiltration and lack of adequate maintenance, providing very low levels of thermal comfort. Moreover, although the

Building Code was revised in 1989 and the Energy Building Code came to life in 2003, the latter was rarely implemented. Therefore, most of the residential buildings in Albania are uninsulated and built with no concern for energy efficiency.

3.2.3. Housing typologies

A deeper knowledge of existing building stock is needed to evaluate the most suitable and efficient energy-saving measures (Theodoridou, Papadopoulos and Hegger, 2011a), and to create sustainable policies for managing the existing housing stock (Kohler and Hassler, 2002; Theodoridou, Papadopoulos and Hegger, 2011a; Kaasalainen and Huuhka, 2016). However, the building stock is complex and vast, making it a challenging research object (Kohler and Hassler, 2002) due to the variety of building's architectural, structural and operational characteristics (Theodoridou, Papadopoulos and Hegger, 2011a). Therefore, to limit the number of analysed objects, 'representative building types' are applied as a research method by many authors (Theodoridou, Papadopoulos and Hegger, 2011a; Theodoridou, Papadopoulos and Hegger, 2011b; Gupta and Gregg, 2012a; König and De Cristofaro, 2012; Gulotta *et al.*, 2021). To address energy renovation needs in the existing housing stock, many countries, including Germany, Switzerland, Denmark, England, Italy and Greece, have classified their residential buildings by building type and year of construction (Theodoridou, Papadopoulos and Hegger, 2011a).

In Albania, there are no specific methods and indicators used for categorizing residential building stock for energy performance (Energy Community, 2012; Simaku, 2014). The only reliable available statistic per building is from the last population and housing census in 2011, where there are seven main classifications of Albanian housing:

- Location (urban and rural).
- Climatic zones (A the mildest, along the seacoast, with 36% of all residential buildings; B, the medium zone with 48% of all residential buildings; and C, the coldest, in the mountainous area, with 16% of all residential buildings).
- Building type (detached, semi-detached, terraced, and flat).
- Year of construction (pre-1960, 1961-1980, 1981-1990, 1991-2000, 2001-2005 and 2006-2011).
- Number of stories (1-storey, 2-storeys, 3-5 storeys, 6-10 storeys and 11+ storeys).
- Number of dwellings in the building (1, 2, 3-4, 5-8, 9-15 and 16+ dwellings).
- Main construction material (prefabricated, brick, block, wood and other).

However, categorization is needed for energy purposes based on the characteristics listed above but related to energy regulation and legislation. Energy Community (2012) recommends the use of 'reference buildings' to classify residential buildings to undertake a rough assessment of the potential for energy savings in the Energy Community Contracting Parties for the scope of EPBD. EPBD and EUROSTAT have recommended that the categorization and subcategorization of residential buildings in the building inventory be:

Table 5: *Categorization of residential buildings according to EPBD and EUROSTAT*

Main Category	Subcategory
1. Family houses	One dwelling Two dwellings
2. Apartment buildings	Low (up to 5 floors) High-rise
3. Residences for communities	

Source: (Energy Community, 2012)

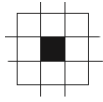
Nevertheless, when the information regarding building stock for energy purposes is missing, it is recommended to develop the first version of reference buildings based on the existing information and then adjust it based on the information collected in the new building stock inventory (Energy Community, 2012). (Gulotta *et al.*, 2021) also states no subdivision for age can be considered when many data are missing.

In terms of legislation for buildings, the Building Code was revised in 1989, however, the Energy Building Code came to life in 2003, but it was rarely implemented until recent years, when more restrictions have been put in place to grant planning permission for new buildings. Therefore, most of the residential buildings in Albania are uninsulated and built with no concern for energy efficiency. Within this context, the proposed stock cohorts for energy purposes are based mostly on the available statistics and the change in construction techniques in Albania:

- Pre-1960
- From 1961 to 1990
- From 1991 to 2011
- Post-2011

Notwithstanding, the buildings built post-2011 are less likely to undergo further improvements in the close future due to the relatively new construction. For this reason, they are not considered in this analysis. Based on the above analysis, there are 12 defined archetypes based on built form and period of construction, and at least 15 sub-archetypes including the construction material, given in Table 6.

Table 6: Defined Albanian housing archetypes

Built form		Period of construction	Main construction material
	Detached	Pre 1960	Brick/stone
		1961-1990	Brick/stone
		Post-1990	Brick/block
	Semi-detached	Pre 1960	Brick/stone
		1961-1990	Brick/stone
		Post-1990	Brick/block
	Terraced	Pre 1960	Brick/stone
		1961-1990	Brick/stone
		Post-1990	Brick/block
	Flat	Pre 1960	Brick
		1961-1990	Brick
			Silicate brick
			Prefabricated
		Post-1990	Hollow brick
			Hollow brick + insulation

Drawn by author

3.3. Legislation on energy in Albania and related legislative/institutional framework in the EU

The decarbonisation of buildings, especially in developing countries, is constrained by multiple barriers, obstacles and limited flow of finance, as well as the lack of institutional capacity and appropriate governance structures (IPCC, 2022b). A reduction of up to 90% in carbon emissions in the building sector can be achieved by 2050 (EU built Energy Efficiency, 2012). The 2050 Roadmap (European Commission, 2012) was developed to build a plan to meet this long-term target by achieving the objective of Directive 2010/31/EU (EPBD recast), developing a strategy for the sustainable competitiveness of the construction sector and encouraging investments in renovation (EU built Energy Efficiency, 2012; European Commission, 2012), as well as making the obligation for all new buildings built from December 31, 2020, to be nearly ZEB. The revised directive in EPBD (EU, 2018) adds new elements, including cost-optimal minimum energy performance requirements for new buildings and for retrofitting existing ones. The European countries are required to transpose the EPBD into their national law and application. Although Albania is not in the EU, it has committed to reducing 11.5% CO₂ emissions by 2030, compared to the baseline scenario of 2016 (European Commission, 2016), and has prepared the National Energy Efficiency Action Plan (NEEAP) (Republic

of Albania, 2011) for this purpose. However, this represents the first attempt at a long-term energy efficiency plan for Albania (Islami, 2014). In addition, not much work is happening currently because of the legal barriers associated with its implementation. Furthermore, there is a huge gap in Albanian building regulations and legislation because of the rapid urbanization after the 1990s. A new law on Energy Efficiency (Law no 124/2015), based on the EU energy efficiency legislation, was approved in 2015 by the Parliament of Albania. Aims to create regulation and policies for uptake and promoting energy efficiency, to reduce energy consumption and increase energy security, as well as minimising barriers to energy trade. This law aims to determine the national objectives in relation to energy efficiency, as well as increase the competitiveness between energy operators (Republika e Shqiperise, 2015). There are five main energy efficiency policies developed in this law:

1. National policies of energy efficiency to develop institutional and financial incentives as well as the appropriate legal framework to overcome any existing barriers to improving the energy efficiency of the country.
2. Energy efficiency national policies that aim to provide the maximum benefits from energy efficiency throughout the whole cycle of energy use, including energy production, transformation, deposition, transmutation, distribution, and energy consumption in various ways.
3. National policies for efficient use of energy should consider: normal operation of the energy market; promoting energy efficiency through various financial incentives; transforming the public sector into an example of efficient management of energy; raising information and awareness of energy efficiency; ensuring co-operation between consumers, manufacturers, energy suppliers and public subjects; supporting research and adopting new technologies in collaboration with scientific and university institutions in the field of efficient energy use; promoting private initiatives and the development of cost-effective services of energy efficiency; avoiding negative impacts on the environment and respecting social priorities in promoting energy efficiency on the basis of technological, cultural and/or economic changes; as well as ensuring co-operation with other countries in the field of energy efficiency and the fulfilment of commitments and obligations of the country under any treaty or international convention to which Albania is a party.
4. During the drafting of energy efficiency policies and programmes are taken in consideration the characteristics of each region of the country and their expectations for a stable economic development

5. The ministry responsible for energy, with support from the Agency of Energy efficiency, drafts national policies for energy efficiency, as well as monitors their implementation

Notwithstanding its value as the main step into the development of energy-efficient policy, this law solely provides an overall insight into the energy efficiency in Albania as a whole country. Detailed policies should be developed and promoted to achieve the objectives of this law. For this reason, the government of Albania has created the Agency of Energy Efficiency, which is the institution created to be responsible for promoting and ensuring the implementation of energy efficiency policies.

An overview of the key Albanian legislation regarding energy in buildings is given in Table 7. However, according to (Simaku, n.d.), the main problem in Albania is not the lack of regulations, but the lack of implementation. Therefore, the Secondary Legislation for the implementation of energy efficiency measures must be revised and developed.

Table 7: A picture of the key Albanian legislation regarding energy in buildings (drawn by the author)

Law/decision	Aim/objectives
Decision No. 584 'on energy-saving and heat conservation in buildings' (02/11/2000)	Defines the obligation to design central or individual heating systems for all new buildings and they must not use electric power (Republika e Shqiperise, 2010).
Law No. 8937 'on Heat conservation in Buildings' (12/09/2002)	- Aims to establish the necessary legal basis for setting up the rules and making mandatory actions for the conservation of heat in buildings. - Defines the necessary technical parameters for conservation and efficient use of energy (Republika e Shqiperise, 2010).
Decision No. 38 'on the Technical Norms of Heat Saving in Buildings' (16/01/2003)	- It is based on Law No. 8937 'on Heat conservation in Buildings' and it is the Governmental Decree for the Energy Building Code. - Aims to define the technical norms of heat saving in buildings. - Charges the institutions responsible for the implementation of this decision (Republika e Shqiperise, 2010).
Law No. 9379 'on Energy Efficiency' (28/04/2005)	- Establishes the legal framework for the promotion and improvement of the efficient use of energy within the whole Albanian energy sector. - Defines the most economic use of energy sources, and how to reduce the environmental impacts of the electricity supply infrastructure (Republika e Shqiperise, 2005).
Law No.10113 'on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances' (09/04/2009)	- Transposes the requirements of directive 92/75/EEC. - Defines the obligations to publish information on consumption of energy and other essential resources, particularly through labelling and information about the product, as well as additional information concerning certain types of household appliances, allowing the consumer to choose more energy-efficient appliances for home use. (EEA, 2011; Energy Charter Secretariat, 2013).
Decision No. 619, 'on approval of national action plan for energy efficiency 2011-2018' (07/09/2011)	Approves the National Action Plan for Energy Efficiency 2011-2018 (Republika e Shqiperise, 2011).
Law No. 138 'on Renewable Energy Sources' (02/05/2013)	- Complies with the new EU Directive 2009/28/EC 'on promoting energy usage from renewable sources, and changes and repealing of directives 2001/77/EC and 2003/30/EC'. - Focused mainly on the generation of electricity from renewables (Hido, 2012).
Law No. 124/2015 'on Energy Efficiency' (12/11/2015)	Aims to create regulations and policies for uptake and promoting energy efficiency, saving energy consumption and increasing energy security, as well as minimising the barriers to energy trade. Furthermore, this law aims to determine the national objectives for energy efficiency, as well as increase the competitiveness between energy operators (Republika e Shqiperise, 2015).

3.4. Case studies of retrofitting in Albania

Little research has been undertaken on residential buildings in Albania in terms of their energy and thermal performance and retrofits. Similarly, limited studies have used comprehensive building simulation models to assess the energy performance and investigate potential retrofitting strategies in buildings in the context of Albania (Dervishi *et al.*, 2022). Rexhepi and Mahdavi (2010) investigated the thermal performance of a traditional housing typology in Kosova, known as Kulla, using measurements on-site and parametric simulation of improvement scenarios. They found that there is no need for cooling in this typology due to the high thermal mass that the external walls provide and thermal insulation of the building envelope would reduce the heating energy requirement by up to 70%. Belba and Dervishi (2018) found similar results for the climate of Kukes, a city in North Albania, after investigating energy performance and thermal comfort in five buildings using energy simulation. Due to the thermal mass properties of thick external stone walls, there was no cooling required in the summer, while the improvement of the building envelope offered the potential of up to a 35% reduction in annual energy consumption. Resuli and Dervishi (2015) focused their study on cultural Heritage Italian houses built in the 1920s, exploring seven scenarios of improvement of thermal properties of the building envelope. They found that the thermal improvement of the walls, roof and double glazing could reduce the heating loads by up to 38%. More recently, Dervishi *et al* (2022) have explored the energy performance of traditional buildings in three different cities in Albania, characterised by different climatic conditions. Seven scenarios focusing on improving the building envelope have been investigated using computer simulations. They found that wall insulation could achieve an energy consumption as low as 44.5%, while thermal insulation of all building envelopes would achieve up to a 52.9% reduction in annual energy consumption. On the economic side, the payback period of the measures would be from 7.9 to 18 years, depending on the measure and house location.

On the other side, Albania is also taking the first steps in the form of pilot projects initiated by local communities and public authorities as well as international organizations with a reduction target of up to 50% (see Table 8). In these case studies, there was no survey or monitoring undertaken before or after the retrofit, meaning that there is no real feedback on the in-use performance of the retrofits. However, the homeowners have acknowledged that although they achieved some reduction in energy consumption, the increased thermal comfort was the main benefit of the interventions (Islami, 2016). The investment costs are found as the main barrier to undertaking such improvements, and

it is recognised that applying these projects on a larger scale would be impossible without real financial and legal policies from the government (Islami, 2016). Moreover, in the case of apartment buildings, a fundamental change in their management must be applied to provide continual maintenance of the building and avoid the quick amortization of the applications. Because almost all the investment costs are covered by government structures, these kinds of interventions do not propose a great model for encouraging homeowners to retrofit their houses. Co-financing schemes between the homeowner and the government would offer a better solution to this matter (Islami, 2016). Individuals have also started implementing other small-scale retrofits, mainly by improving the building fabric and installing solar water heating systems. However, they are not widespread and often there is a lack of integrity among building elements and systems as a result of the lack of knowledge and skills of the construction team. The new law on Energy Efficiency (Law nr 124/2015) has proposed an Energy Efficiency Fund, which aims to provide financial support to all stakeholders, including energy consumers, on projects aiming to improve the energy efficiency of their homes (Republika e Shqiperise, 2015).

Table 8: Case studies of retrofitting residential buildings in Albania

Project	Photo	Size	Investment costs	Measures	Estimated energy savings	Outcomes	Source
Prefabricated apartment building Fier, Albania		30 dwellings	84,500€	• 50mm external wall insulation • 60mm roof insulation • Double glazing • Blinds	30-40%	• No data regarding energy reduction. Homeowners receive a slight reduction in electricity consumption. • Evident improvement of thermal comfort.	(Shehi, Gjoka and Schweizer, 2011; Islami, 2016)
Three stories apartment building built in 1960 Lezhe, Albania		24 dwellings	100,330€	• External wall insulation • Double glazing	50%	• No data regarding energy reduction. • Improvement of thermal comfort.	(Islami, 2016)
Five-storey apartment building built in 1974 Korce, Albania		15 dwellings	76,365€	• 100mm external wall insulation • 80mm terrace insulation • Double glazing	50%	• No data regarding energy reduction. • Improvement of thermal comfort.	(Islami, 2016)

3.5. Barriers to energy retrofit in Albania

Although the potential benefits of energy efficiency measures and retrofitting are acknowledged to be beyond energy and emission reduction (including energy security, sustainable development, competitiveness, employment, comfort and climate change mitigation) (Energy Charter Secretariat, 2013; Christensen et al., 2014), there still exist many interrelated barriers for retrofitting the existing housing stock. Owners and investors see energy retrofits as an investment involving high risk due to evidence of a high discrepancy between predicted and actual performance in energy consumption, as well as being costly and inconvenient, and its benefits not being transparent (Francis, 2014). Although the high upfront capital cost of retrofitting strategies appears to be one of the main economic barriers (Crosbie and Baker, 2010; Pelenur and Cruickshank, 2012; Fawcett, 2014; Islami, 2016; Streicher et al., 2021), different researchers have shown that the claim “investment will pay off through lower fuel costs” will not overcome it (Jones, Lannon and Patterson, 2013; Fawcett, 2014; Galvin, 2014b). Instead, increased comfort (Blackhurst *et al.*, 2011; Consumer Focus, 2012; Christensen *et al.*, 2014; Fawcett, 2014; Simpson *et al.*, 2016) and ‘affordable warmth’ (Jones, Lannon and Patterson, 2013) are identified as very important drivers for retrofitting. Building Performance Institute Europe (BPIE) identified four main categories of barriers to retrofitting through an extensive survey across all European Member states (BPIE, 2011): 1) financial; 2) institutional and administrative; 3) awareness, advice and skills and 4) separation of expenditure and benefit. Similar categories of barriers were also identified by other studies including the UK Department of Energy and Climate Change (DECC, 2014) as well as (Weiss, Dunkelberg and Vogelpohl, 2012; Alam *et al.*, 2019). Because retrofitting existing buildings is a complex process characterised by a high number of barriers (BPIE, 2011; DECC, 2014; Marquez, McGregor, & Syme, 2012), overcoming these barriers requires the design and implementation of effective strategies that can promote energy efficiency investments and actions (Alam et al., 2019).

However, high upfront capital costs and financing energy retrofits in Albania are the main issue as poverty affects 18.5% of the population (in the year 2005) and it has the lowest per capita income in the Western Balkan region, with inefficient consumption of energy by vulnerable households absorbing more than 20% of their revenues (International Energy Agency, 2008). Therefore, Albanian families lack funds to implement house improvements (International Finance Corporation, 2014). On the other hand, low-cost financing and funding from the government is missing (Islami, 2016), even though it is found that “investments in energy efficiency are cheaper than investing in new energy production capacity” (UNECE, 2013). In addition, in transition countries, including

Albania, there is a lack of opportunities for credit or third-party service-provider investments to fund resource-saving measures or energy service contracts (UNECE, 2013). High rates of unemployment and financial crises have also stepped the individuals back from undertaking retrofits. In the Albanian market, energy efficiency is not a top priority and a property's value is not affected by its energy performance. Energy performance certification (EPC) of buildings in Albania is missing, so transparency over the energy performance of the buildings is lacking. The training of the first energy auditors to produce EPC has only been completed in 2020 (Ministria e Infrastruktures dhe Energjise, 2020).

An overview of the barriers identified and observed by the author in the Albanian context and supported by existing literature is given in Table 9. They are classified into five groups based on the type of barrier. In each category, the higher the barrier is on the list the more prevalent it has been found to be in literature and in discussions that the author has had with professionals and residents in Albania.

The lack of legislation and instruments that encourage energy efficiency interventions are also among the main barriers in Albania at the moment (Islami, 2012; Simaku, n.d.). Even when they do exist there is a lack of clarity, transparency and uncertainty in them that raise uncertainty among people and developers. There is a lack of clarity on energy norms and standards for buildings, while energy efficiency has only recently been added as a criterion for obtaining planning permission for new builds.

Table 9: Assessment of the impact of the identified barriers in Albania (drawn by the author)

BARRIERS	
Economic	High upfront capital costs of retrofit
	Low incomes
	Uncertainties over financial gains
	Long payback periods
	Lack of low-cost financing and funding
	High interest of loans
	Lack of competitive funding method
	Risk and uncertainty involved with the investment
	Unemployment
	Financial crises
	Additional costs associated with retrofitting
	Lack of incentive to invest in retrofits by homeowners
	Miscalculation of energy savings
	Lack of feed-in tariff
	Lack of incentive to invest in retrofits by suppliers and installers
	Property value is not affected by its energy performance
	Lack of EPC
	Energy bills are still affordable
Political/ institutional	Lack of clarity, transparency, and uncertainty in policies
	Lack of legislation
	Lack of implementation strategies
	Lack of energy norms and standards for buildings
	Planning permission requirements
Education and skills/ information and people's perceptions	Limited/no implementation network
	Lack of information/awareness/marketing approach
	Little/no understanding of retrofitting
	Lack of trust in the strategies
	Lack of trust in suppliers
	Lack of training
	Lack of skills (tradesmen, surveyors, designers)
	Lack of multi-skilled experts
Technical	Lack of motivation
	Lack of demand for retrofitting measures
	Uncertainty in the performance of the measures
	Lack of warranties of the measures
	Lack of reliable suppliers available
	Lack of coordination and cooperation between industry and people
	Lack of management support
	The technical complexity of the process and maintenance requirements
	The need to undertake a house survey
	Disruption
Social/cultural	Time involved
	Little/no intention in the design and aesthetical issues
	Lack of trust in new technologies
	Ability to change and adapt
	Customs, habits and relevant behavioural aspects
	Lifestyle and involvement with the community

On the other hand, there is an evident lack of information, awareness and marketing approach regarding energy retrofits in Albania. This happens mainly because Albania has just started to consider improving the quality of its housing stock after the massive process of urbanization that has happened in the last 30 years. Even when there is information, suppliers, tradesmen, surveyors, and designers are not trusted because of a lack of training and skills. People are also not confident about the success of retrofitting strategies in terms of energy savings, as well as the intended performance in the long term. Usually, there is a lack of maintenance and warranties from the construction companies after construction, making people less motivated to undertake retrofits. Furthermore, many technologies that can be applied when retrofitting existing housing are not yet available in countries with economies in transition (UNECE, 2013). Disruption, time involved in retrofitting homes and aesthetic issues are not seen as primary barriers in Albania, due to the priority people have in spending less on energy bills and improving thermal comfort in their homes.

Another barrier to implementing the retrofits, especially to apartment buildings, is multi-ownership and the lack of implementation of the Law No. 10112 date 09.04.2009 on '*Administration of ownership in residential buildings*' (Islami, 2016). These barriers, and many more, strengthen each other when interacting with the Albanian lifestyle related to the Mediterranean climate and culture. A strong connection between people the nature exists in Albanian lifestyle, making it difficult to change it to make the most of the retrofitting.

3.5.1. How deep to retrofit in Albania?

Various retrofitting options are available to homeowners, including improvement of the building envelope, options for space heating and hot water systems, lighting, appliances and equipment, as well as renewable energy generation (Feng et al., 2020; Prabatha et al., 2020). The recast Directive 2010/31/EU (EU, 2010) and the revised EPBD 2018/844 (EU, 2018), discuss the need for 'deep renovations', and different pilot programmes underline the benefits of a whole-house approach to energy-efficient refurbishments (National Energy Foundation, 2014) that combine several strategies to optimise the overall performance of the building.

When considering the energy retrofitting of existing residential stock, the impact of the national climatic, physical, and socio-economic context must not be underestimated. Thanks to its geographical position, Albania belongs to the Mediterranean climate belt with hot dry summers, long days of sunshine and mild winters with abundant rainfall (Ministria e Infrastruktures dhe Energjise, n.d.). The average temperatures in the

lowlands are 7°C in winter and 23.5°C in summer. While in the inland areas, the temperatures are influenced by differences in elevation and the Continental air mass that dominates the weather in Eastern Europe, causing lower temperatures than in the lowlands. However, maximum, and minimum temperatures registered are more extreme than averages. The highest record registered since 1963 is 40.8°C in August 2017 and the lowest temperature registered was -9.7°C in January 2017 (Worlddata, 2021). Moreover, Albania benefits from long hours of sunshine from five to 18 hours per day in winter and summer respectively, which has shaped the strong connection that people have with nature. This is reflected in their behaviour towards the building by extensively opening windows and doors.

On the other hand, rapid urbanization has created many social/cultural barriers associated with people's behaviours and lifestyles. According to (Poiani, 2010), relationships between neighbours are now more anonymous, and individuals are less motivated to socialize due to increased feelings of independence, making community ties seem unnecessary.

Moreover, the lack of information and awareness might reduce the uptake and effectiveness of retrofitting strategies. Indeed, it is determined (Janda, 2011) that only half of the energy used in the house depends on the characteristics of the house and its equipment, while occupants and their behaviours influence the rest (Schipper *et al.*, 1989), producing a variation of 300% in energy consumption for similar houses. Therefore, energy efficiency savings cannot be guaranteed without the cooperation of occupants (Crosbie and Baker, 2010; Gupta and Chandiwal, 2010). Making the cooperation of occupants, raised awareness, education and information vital instruments for successful results, behavioural change will need to be a significant part of the retrofitting process. Although behaviour change does not need huge capital investments, awareness and commitment among the occupants could be challenging to obtain. (Prabatha *et al.*, 2020). Research on US households has estimated that 20% of their emissions could be saved by implementation of 17 different behavioural actions (Dietz *et al.*, 2009), while only in-home energy consumption can be reduced by 5-12% based on studies of daily or continuous energy-use feedback (Dietz *et al.*, 2009).

Notwithstanding that it would be interesting and of great interest to investigate the highest potential that Albanian residential stock has in reducing carbon emissions, and using the net-zero energy retrofits as a standard for retrofitting, it imposes a radical change in technical, economical and cultural levels (Kapsalaki and Leal, 2011; Butera, 2013). Moreover, it is recommended that in transition countries energy-efficiency measures should not always try to meet the highest building performance standard but focus on achieving the greatest energy savings while keeping investment costs at a reasonable

level (UNECE, 2013). For these reasons, this level of retrofit is not considered within the scope of this thesis, however, in the longer term, it will be a sustainable solution and should be set as a target for energy efficiency standards to guarantee the development of good solutions (Laustsen, 2008).

The availability and the possibility of applying several single strategies and their combinations will be considered for the Albanian context considering the average economical situation of the Albanian households. Notwithstanding the danger of the 'lock-in' effect, there is a need for the people in Albania to experience the benefits of retrofitting deeper their homes. Moreover, additional support, mainly in terms of investment strategies and awareness programmes, is required to uptake deep retrofits. Furthermore, deep retrofitting would mean that the houses would be more airtight and would need the right occupant behaviours to be successful. Considering the Albanian lifestyle, raising awareness and information about occupant behaviours is primary. Although some of the strategies, such as fabric improvements, can be very effective in terms of energy efficiency, in the Albanian climate special consideration should be given to minimise unintended consequences, such as overheating in summer. Moreover, even though Albania has a Mediterranean climate with a high number of sunny days, the lack of various effective support mechanisms, such as feed-in tariffs (FiT) and other instruments for encouraging renewable energy, is a barrier to the application of low/zero-carbon technologies as it makes them less profitable.

For these reasons, single energy retrofitting measures should be seen as the first step towards the longer term of uptaking deeper energy retrofits in Albania.

3.6. Summary

This chapter drew a picture of the case study of this study, including energy consumption, residential building stock and housing typologies. Moreover, an investigation of legislation and barriers was undertaken, listing the most prevalent barriers in the Albanian context. From this in-depth literature review, the following points were underlined to be addressed in this study:

Firstly, there is a need to retrofit in Albania, not only for energy savings but also for the improvement of thermal comfort in homes. Therefore, an evaluation of the current energy and thermal performance of existing homes is essential before proposing improvement strategies and scenarios.

Secondly, there is a lack of a classification of Albanian housing stock for energy performance studies and research. A classification based on archetypes is needed to limit the complexity and high variety of the housing stock for energy investigation, following good practices in other European countries like Germany, Italy, Greece, Denmark and England.

Thirdly, a poor legislation framework on energy efficiency and retrofits in residential buildings was made evident in the country's in-depth literature review. Therefore, recommendations for policymakers to develop tailored policy programmes are in urgent need in Albania.

Fourthly, case studies of retrofitting in Albania exposed a lack of comprehensive and holistically research and investigation of retrofitting projects, with no focus on occupant behaviour, nor consideration of the performance gap throughout the process of retrofits from the pre-retrofit stage to the in-use evaluation. Attempts to tackle it are non-existent.

Fifthly, the investigation of the barriers to retrofit in Albania unveiled a complex interrelation of multi-nature barriers, including economic, institutional, educational, technical and social ones. Furthermore, they were found to be interconnected on various levels, including occupant and household to the developer and governmental levels. Therefore, tailored recommendations need to be addressed.

Finally, various levels of retrofits should be investigated.

Such findings imply that outcomes of energy retrofit programs should take into account the economic development, legislative and institutional frameworks, the history and practices of the housing sector, and climate (UNECE, 2013), and must be reframed to focus on outcomes wider than energy or CO₂ reduction, such as comfort, indoor air quality, health and elimination of fuel poverty (Gupta *et al.*, 2015a). This recommendation is especially important when it comes to applying retrofitting strategies in developing countries like Albania.

CHAPTER 4

Methodology

4.1. Introduction: Chapter outline

This chapter explains the methods used to obtain and process relevant and valid data to address the overall aim of the thesis. Section 4.2 gives a general outline of the methodological approach, following a description of the investigative methods that supported data gathering to its depth in Section 4.3, and an explanation of the analysis undertaken in section 4.4. A detailed illustration of the RetrofiTEA framework proposed for future retrofitting projects is given, explaining how the individual methods are used to assess technical and economic feasibility, followed by an evaluation of acceptability.

4.2. The overall methodological approach

The literature review revealed the complexity and the interrelated nature of barriers to energy retrofits of residential housing stock and the need for a tailored framework considering not only technical aspects of energy savings but also social and cultural implications. A mixed method approach combining qualitative and quantitative research methods is used to provide a more comprehensive understanding of the topic under investigation, and to investigate and achieve a more complete answer to the research aim. Furthermore, the study adopted a socio-technical perspective to holistically investigate the most effective energy retrofitting strategies in residential buildings, where homeowners have been involved and have participated in every stage of the field studies so they would be at the centre of the decision-making process of the retrofits to be applied in their homes. The energy retrofitting strategies were investigated using dynamic computer simulations on a 'real reference building', which is an existing building in the sample representing the most typical building in a special category, called 'archetype' in this study. To minimise the performance gap between the estimated and actual energy consumption, the baseline energy model has been informed by empirical data collected during the field studies, including building and occupant surveys, on a sample of 49 dwellings that were chosen to be in-depth analysed and monitored. Improvement scenarios, including single and combined energy retrofitting strategies, were investigated in terms of energy savings and improvement of thermal comfort using the validated baseline models for each archetype considered in this study. Economic feasibility was tested for each improvement scenario in each archetype through cost-

benefit analysis using Net Present Value (NPV), the Internal Rate of Return (IRR) and Payback Period (PP) to determine the most affordable choices. The results were tested afterwards with the homeowners through semi-structured interviews to evaluate their acceptability and factors affecting their acceptance. Based on the overall analysis and results, recommendations on successful energy retrofitting were provided to policy makers, housing providers/developers and homeowners.

4.3. Data collection methods

Various type of data from different sources has been collected using a multi-disciplinary mixed-method approach to data collection. An overall illustration of the data collection design is illustrated in Figure 10.

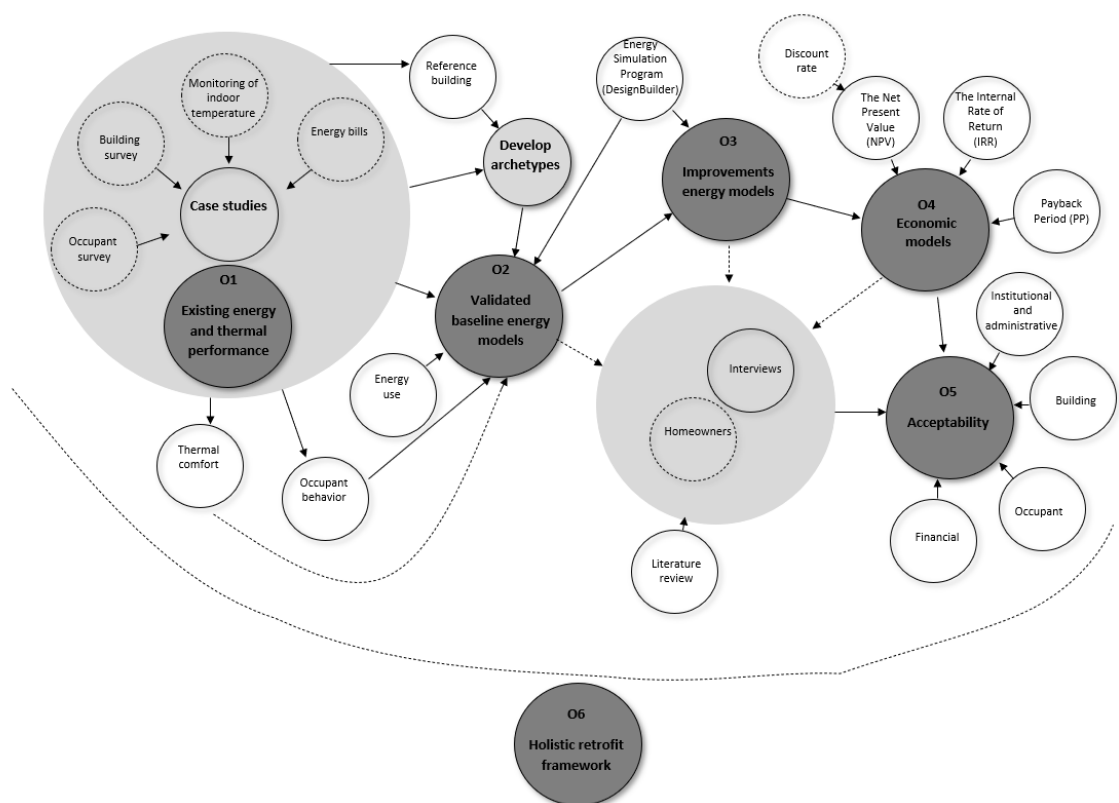


Figure 10: Overall design of data collection methods

4.3.1. Selection of case studies

Ethical approval from the Ethics Committee of Oxford Brookes University was granted to perform the three field studies designed for this study. A wide range of households was considered in this research, including with/without children; old/young; living in the house recently/living in the house since it was built; families with different incomes and education levels, etc. Therefore, multiple approaches are considered in the recruitment

of the participants to secure this diversity of the cases. In all cases, the researcher used a trusted community member who helped introduce her to the survey participants.

The researcher approached:

- Administrative of Polytechnic University of Tirana
- Administrative of Social Security Institute, Tirana
- retired households through the retirement office
- different local coffee shops.

Recruiting houses through local coffee shops was particularly successful due to their popularity and different people attending them. An initial screening was conducted through an invitation letter (Appendix 2), containing 10 questions regarding the type and year of construction of the houses, and the type and size of the participant's household, and it was circulated by the secretary of the Polytechnic University; receptionist of the Social Security Institute; receptionist of the retirement office; and manager of coffee shops staff respectively. A total of 800 invitations were sent. There were 75 positive responses from which 16 participants withdrew from the field study, leaving 49 cases in total.

However, it was found that achieving a response rate of lower than 10% was particularly low due to social and cultural barriers. Most of the participants expressed some hesitation regarding the confidentiality of the information they were giving, and the reliability of the instrument used, even after a detailed description of the research and its objectives from the researcher was summarised in the information sheet attached to the invitation letter (Appendix 3). Based on dwellings statistics, the sample chosen for monitoring is proportionally representative of Tirana's housing apart from semi-detached houses, which are under-represented (See Table 10). However, detached houses (representing 49.5% of the Albanian housing stock) and flats (a fast-growing typology in the last three decades) are the two most popular and important housing typologies in Albania.

Table 10: Statistics of residential buildings in Tirana

Type	Dwellings - Albania		Dwellings - Tirana		Sample	
	Frequency	%	Frequency	%	Frequency	%
Detached	501,138	49.5	88,804	33.9	17	34.6
Semi-detached	101,240	10	25,666	9.8	1	2
Terraced	50,620	5	14,142	5.4	2	4.1
Flat	359,402	35.5	133,291	50.9	29	59.3
Total	1,012,400		261,903		49	

Drawn by the author based on (Instat, 2012)

The sample is relatively small and is not statistically representative of the housing stock in Albania. However, it does contain the various types of dwelling forms and age bands prevalent in the Albanian housing stock. Moreover, the investigation in this study is based on archetypes, which are typical residential buildings and will be represented by a real case study in the sample. Treating the example dwelling as case studies and in-depth analysing them, would allow a holistically investigation of the performance of each energy retrofitting scenario. In addition, this research is based on the archetypes to define different strategies for improving their energy performance rather than creating a statistical conclusion. Although representative houses for all main typologies were recruited, there does exist a wide range of building forms and layouts within each typology, mostly due to alterations made over the years to accommodate better living requirements.

The study was undertaken in Tirana, the economic and political capital of Albania and where the focus of future retrofitting measures could be.

In-depth investigation and analysis of the case studies through building surveys, occupants' surveys, monitoring and energy use through energy bills was felt to be the most appropriate approach to access a great wealth of details and receive direct feedback from the households that have served as the main data sources for developing and validating baseline energy models.

4.3.2. Building surveys

A detailed survey of each dwelling in the sample was undertaken from June to July 2016, to gather information on the buildings' properties and energy use: Quantitative data were collected through appliances, lighting and walkthrough templates involving observations on the location (orientation, surroundings, etc) and on the buildings' technical characteristics (building type, number of storeys, building materials and construction, floor area window openings, etc). Information regarding appliances and lighting was also

collected to allow for a detailed picture of energy use and behaviours within the home. Appliances, lighting and walkthrough templates used are given in Appendix 4.

Monthly metered energy use readings were also obtained for 36 out of the 49 dwellings selected for this study.

4.3.3. Occupants' survey

Occupants' surveys were conducted in June to August 2016 and January to February 2017 to cover the two extreme seasons of Albanian climate: summer and winter respectively. A pilot survey with five households was conducted before the actual surveys, to ensure the validity of the content, to test the understanding of terms and the flow of questions, as well as to ensure that the projected completion time was achievable. The participants' comments and feedback led to some modifications to improve the clarity of the questionnaires. The surveys aimed to gather socio-demographic information, as well as to get an insight into how and when the house is used, occupants' attitudes and habits, and other everyday practices in their homes. The study adopted the method of questionnaire-guided interviews as the most appropriate technique for gathering all essential information in its full range and depth, as well as for getting insights into occupants' behaviour. Furthermore, it provided the researcher with control over misinterpretations due to the possible lack of knowledge and awareness of the topic. The questionnaire design process involved several considerations, including question types and wording, as well as finding the most suitable words to explain the new information the homeowners did not know of. The questionnaire comprised of close-ended, partially closed-ended, and open-ended questions.

The survey also incorporated a subjective evaluation of the thermal environment in the selected homes in this study using a seven-point ASHREA scale for the thermal sensation evaluation and a five-point scale for thermal preference.

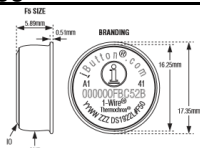
Only one occupant per dwelling participated in the survey to provide consistency across the research. The template of the questionnaire-guided interview is given in Appendix 5.

4.3.4. Continuous monitoring of indoor and outdoor temperature

Indoor temperature was measured continuously in the living room and main bedroom of the same sample for six weeks in summer (June 30 to August 12, 2016) and six weeks in winter (January 5 to February 16, 2017) for 30-minute intervals to assess the indoor environment in the house. Outdoor temperature was monitored simultaneously to assess any correlation between indoor and outdoor conditions. A total of 45 dwellings out of 49 monitored during the summer were secured for the winter monitoring. iButtons, with an

accuracy of ($\pm$)0.5°C and a measurement range of -10°C to +65°C (specifications are presented in Table 11), were used to record the indoor temperature every half hour to allow for seasonal variations. The instrument was selected because of its minimal interference and upset of occupants' activities and life, as well as cost. Data loggers were placed by the researcher in secure places in the living rooms and bedrooms away from external walls, direct solar radiation and devices that generate heat or air conditioning devices, therefore there was no outside effect on the conclusive results.

Table 11: Technical specifications of iButtons data loggers

iButton Temperature Logger DS1922L-F5	Measurement range	Accuracy
	-10°C to +65°C	$\pm$ 0.5°C

Source: (Maxim Integrated, 2016)

4.3.5. Semi-structured interviews with homeowners

The third and final field study has been designed to collect data using semi-structured interviews with the same homeowners who participated in the first two field studies, from which only 31 were able to participate. All the interviews were undertaken in June to July 2019. Interviews were selected over other qualitative research methods because they can generate a rich understanding of occupants' beliefs and behaviours, as well as explore their perspective on the factors associated with the implementation of energy retrofitting measures. Homeowners were selected over other stakeholders because the aim was to investigate the willingness to accept, or not, each of the proposed strategies that are fundamental in this study, while other stakeholders' opinions could be subjective. The interviews were conducted in the national language and thereafter data were transcribed and translated.

The interviews started with a five-minute presentation of the research topic and objectives of the research and the interview in particular, followed by a 45 to 50-minute discussion with questions covering financial, social and cultural aspects of barriers to retrofitting as well as drivers and strategies to overcome them. They were asked about their intentions to implement any more energy retrofitting strategies and the reasons behind their decision. The interview did not include questions about the demographic background of the homeowner, given that they provided this information in the first field study and that information was able to be cross referenced. The interview template is given in Appendix 6.

4.4. Data analysis

Data collected in various stages of the study has been analysed using various methods, including:

4.4.1. Statistical analysis using SPSS Statistics 24

Various statistical tests have been performed for different parts of the analysis, including: *Spearman correlation analysis* to check the strength of the relationship between the estimated annual heating/cooling energy use and dwellings' and households' characteristics, including housing typology, size, construction as well as household size, using data collected from the electricity bills for the selected dwellings, as well as information secured during the building and occupants' surveys.

Descriptive analysis using SPSS Statistics 24 has been used to analyse the indoor temperature recorded in living rooms and bedrooms during the field studies. Furthermore, daily, and hourly temperature profiles have been produced during summer and winter during the occupation times in living rooms and bedrooms to investigate the indoor environment. Descriptive analysis has also been used to analyse the results from the subjective evaluation of thermal sensation and thermal preference using a seven-point ASHREA scale and a five-point scale respectively. The line of the best fit, together with the 95% interval of confidence of the means is also produced to check the regression of the association between the indoor temperature and thermal sensation in both seasons.

Regarding the analysis of the thermal performance of the selected dwellings using data secured from the field study, some limitations to the data collection that have been identified are:

1. The survey has not been designed as a field study of thermal comfort. Occupants are questioned about how they feel at the moment of the survey (indoor temperature was recorded at the same time), as well as how they feel in summer and winter respectively.
2. Only one (ambient air temperature) out of six factors (ambient air temperature, mean radiant temperature, relative humidity, air velocity, metabolic rate, and clothing level) predict the occupants' overall satisfaction with the thermal environment expressed by the Predicted Mean Vote (PMV) has been collected during the survey.
3. The small sample of dwellings.

However, this analysis does not intend to make a statistical conclusion, nor it is focused on momentary determinants of thermal comfort. It aims to tell a story and look at factors that are associated with the way people feel in their homes. The focus should be on different occupants' behaviours related to comfort to understand the energy consumption of households (Gill *et al.*, 2010; Gram-Hanssen, 2010). And indeed, according to the adaptive principle, the behavioural reaction of people occurs because of thermal discomfort and tends to restore their comfort (Humphreys and Nicol, 1998). Even more, it is essential to understand the relationship between people and the indoor-outdoor environment (Shove *et al.*, 2008).

Because indoor temperatures influence the energy consumption and thermal comfort in homes, *Hierarchical multiple regressions* have been performed using three sets of variables in blocks, including building-related factors (such as construction and building type), temperature-related factors (such as instant and average indoor temperature) and heating/cooling related factors (cooling type and night cooling), to evaluate their contribution to the prediction of, and variance in, thermal sensation votes in summer and winter respectively.

Chi-square tests and *one-way ANOVA tests* for categorical and continuous variables respectively have been used to describe clusters for both summer and winter by testing the differences in several buildings and socio-demographic and occupant behaviours' factors. When the results are statistically significant (>0.05) this shows that there is a significant association between that building/socio-demographic/behaviours factor and the clusters. However, the Chi-squared test only provides an association or not between the two variables but does not give the strength of the association. For this, the phi coefficient can be used. However, because of larger tables than two by two, Cramer's V will be used in this analysis (Pallant, 2013).

4.4.2. Development of indoor temperature profiles

Hierarchical cluster analysis of the monitored indoor temperature has been performed using SPSS Statistics 24 to determine the most typical profiles of indoor temperatures in Albanian homes that are used afterwards to extract essential information (setpoint temperatures for summer and winter, as well as heating and cooling durations) as input for baseline energy models, as well as for the further investigation of proposed retrofitting measures and packages to improve the energy and thermal performance of Albanian homes. Clusters have been created based on the centralised temperatures, meaning

that the average of each data point measurement is calculated for each day and then across the six weeks for each dwelling across summer and winter. Weekdays and weekend clusters were created to identify any difference in temperature patterns between them. The hierarchical cluster analysis was performed using an agglomeration schedule and Ward's method, which uses the F-value (like in ANOVA) to maximise the significance of differences between clusters. Because the dataset is made of interval data, Square Euclidian Distance is chosen as the distance measure. Last, variables (each day of the week, or day of the weekend) are standardised to Z scores, so they all contribute equally to the distance or similarity between cases. Cluster analysis is a statistical analysis method used in previous studies to determine occupancy and heating profiles (Guerra Santin, Itard and Visscher, 2009; D'Oca and Hong, 2015; Liang, Hong and Shen, 2016; Pan et al., 2017; Laskari et al., 2020), as well as indoor temperature profiles in living rooms (Huebner et al., 2015). There are two main cluster analysis methods, k-means and hierarchical. Hierarchical analysis was chosen over k-means because it is mostly used for small datasets, and the number of clusters created is determined after plotting the distances between each data point. In contrast, k-means is used more for large datasets and the number of clusters is decided before plotting the dataset. For hierarchical clustering, other studies suggest that a minimum of 10 observations in each cluster should be considered (Norušis, 2011; Huebner et al., 2015; Laskari et al., 2020)

4.4.3. Development of Archetypes

Archetypes of the existing building typologies to develop energy-efficiency measures have been created using the tool of 'Reference building', as previously used in many studies (Dascalaki *et al.*, 2011; Famuyibo, Duffy and Strachan, 2012; Gupta and Gregg, 2012b; Loga, 2012; Ballarini, Corgnati and Corrado, 2014; Schaefer and Ghisi, 2016). It is a common practice to design archetypes of the existing building typologies to develop energy-efficiency measures (Ali *et al.*, 2020; Hong *et al.*, 2020). 'Reference buildings' is a tool used in many studies (Dascalaki *et al.*, 2011; Famuyibo, Duffy and Strachan, 2012; Gupta and Gregg, 2012b; Loga, 2012; Ballarini, Corgnati and Corrado, 2014; Schaefer and Ghisi, 2016; Gulotta *et al.*, 2021) as the first evaluation of thermal and energy balance in buildings. It is an accepted and proven approach, which has been applied to various case studies (Ballarini, Corgnati and Corrado, 2014; Tuominen *et al.*, 2014; Nik, Mata and Sasic Kalagasidis, 2015; Carnieletto *et al.*, 2021) and an acknowledged approach in support of policy and research developments. It is used to represent the typical and average building stock for which the baseline energy performance is calculated, as well as to select effective improvements based on calculations on the

energy performance of choosing sets of energy retrofit measures to be applied to them (Ballarini, Corgnati and Corrado, 2014; Kragh and Wittchen, 2014). The 'reference' building is defined in Annex II of the Directive recast EPBD 2010/31/EU (EU, 2010) as a characteristic and representative building of the functionality and geographic location of building stock, including internal and external environmental conditions. The largest and the most known datasets for reference buildings are the cross-typology USA Department of Energy database (Deru *et al.*, 2011) and the European residential typology matrix developed by the TABULA project (Tabula, n.d.).

Although there is no standard regarding the process to determine reference buildings (Schaefer and Ghisi, 2016), European Commission Guidelines (EU, 2010) recommend that reference buildings can be established in three ways:

1. Example Reference Building: when the researcher does not have survey data available and the model is determined from literature data, such as manuals, standards, etc., or the knowledge of experts in the field.
2. Selection of a Real Reference Building; an existing building in the sample representing the most typical building in a specific category (cluster).
3. Creation of a 'virtual building', developed from the combination of the most representative features of its category, including the most commonly used materials and systems, coming from statistical analysis.

It is possible to combine different approaches for different building categories (Ballarini, Corgnati and Corrado, 2014; Schaefer and Ghisi, 2016; Gulotta *et al.*, 2021), however the choice between the options depends on statistical data availability and expert enquiries. In the case of Greece (Dascalaki *et al.*, 2011) and Italy (Loga, 2012), the 'real examples' have been considered to represent 'typical' buildings as a result of the lack of official national data with the required level of detail. Because of the lack of detailed statistical data for residential buildings in Albania, the same approach has been used in this study. However, even though one real example is chosen to represent the most typical building in a specific category, named 'archetype' in this study, a large variety of floor areas, forms and designs are available for each archetype, especially in detached houses and flats built after 1991. Eight 'real reference' buildings have been chosen from the sample of 49 dwellings analysed in this study, which are considered to best represent each of the archetypes defined for this study.

The main source for statistical data regarding residential buildings in Albania is the 2011 Census , which groups residential buildings into four building types:

- detached
- semi-detached

- terraced
- apartment buildings.

And into five construction periods:

- Pre-1960
- 1961-1980
- 1981-1990
- 1991-2000
- 2001-2011.

However, some considerations have been taken for this study, which are to not calculate the baseline energy consumption of residential stock in Albania, but to investigate the effectiveness of a list of energy retrofitting measures and scenarios in real reference buildings that represent the main building types in existing housing stock in Albania. Therefore, for this reason, buildings of the same building type, built during periods with no changes in terms of energy regulations as well as construction principles, have been grouped and represented by only one real reference building. However, various constructions within the same period have been considered, such as prefabricated, red bricks and silicate bricks, for flats built pre-1990. The same principle is also followed in other studies (Hong *et al.*, 2020; Gulotta *et al.*, 2021), the period used to categorize different architectural typologies in terms of energy efficiency has been the timeframe of building construction and implementation of regulatory standards. As mentioned before in this study, construction principles as well as building materials used have mainly changed after 1991, when new building techniques and materials started to be introduced in Albania as part of a new open market.

On the other hand, residential buildings built after 1991 are all represented by real example buildings that are not insulated, as that was the most common building technique, even though building codes existed but were very weak and not sufficiently strict (Novikova *et al.*, 2015).

For these reasons, there are only two building periods considered in this study: pre-1990 and post-1991. Residential buildings built before 1960 have not been considered in this study for three main reasons:

1. Most of them are in degraded conditions, hence the cost balance between retrofitting and replacing them should be considered. Many of them have been demolished and replaced by new buildings, mainly apartment buildings in urban areas and new houses in rural areas.

2. Some of the buildings built before 1960 are part of the cultural heritage, which would require special considerations during retrofitting, therefore are not included in this study.
3. Only a very small proportion (7%) of the existing building stock was built before 1960.

On the other hand, real reference buildings were not able to be secured for semi-detached houses built pre-1990 and terraced houses built post-1991. Therefore, only one real reference building is investigated from these two categories, and the final archetypes considered in this study are:

- detached pre-1990
- detached post-1991
- semi-detached post-1991
- terraced pre-1990
- flat pre-1990
- flat post-1991.

However, considering the construction material, three sub-archetypes have been considered for the flats pre-1990:

- flat pre-1990 with full red brick construction
- flat pre-1990 with silicate brick construction
- flat pre-1990 with prefabricate panels construction.

Making eight archetypes in total to be considered in this study.

Notwithstanding that the main archetypes have been defined, there does exist a large variety of houses within the typology, mainly by the number of storeys, layout and different alterations carried out during the last 30 years to accommodate better living requirements.

4.4.4. Energy modelling

The baseline energy models for each archetype of Albanian homes have been constructed using EnergyPlus V8.5 with DesignBuilder V5 as a user-friendly interface which allows the dynamic thermal evaluation of heating, cooling, lighting, ventilating and other energy consumptions as well as thermal comfort, shown in annual, monthly, daily, hourly or sub-hourly intervals. Various sources of data have been used as input information into the models, including data obtained from previous studies, field studies undertaken in this study, as well as from building regulations in Albania. Afterwards, the baseline models have been validated using the information, including real energy use through energy bills gathered during the field studies undertaken in summer and winter in Albanian dwellings. Electricity consumption used for heating and cooling as well as

indoor temperature in living rooms and bedrooms have been investigated and analysed based on the results of the validated baseline energy models for each archetype.

Both single energy retrofitting measures and combinations of them in packages have been tested for each archetype, using the validated baseline models developed for this study. Thereafter, energy savings and improvements in indoor temperature have been analysed, resulting in the list of the most effective retrofitting strategies in terms of technical feasibility.

4.4.5. Cost-Benefit Analysis

The economic feasibility of the proposed energy retrofitting measures was tested through Cost-Benefits analysis to assess their cost-effectiveness using three indicators: The Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback Period (PP).

The Net Present Value (NPV) – is a financial metric that seeks to capture the total value of a potential investment opportunity. It looks to assess the profitability of the initial investment by comparing the difference between the present value of cash inflows and the present value of cash outflows over a while. In this study, the period is taken 30 years as the average lifespan of the retrofitting measures (European Commission, 2014; Belaïd, Ranjbar and Massié, 2021). The NPV relies on a discount rate (considered 4% in this analysis) that may be derived from the cost of the capital required to invest, in compliance with the European Commission recommendations (European Commission, 2014). The discount rate expresses the net gain or loss of an investment over a specified period of time, expressed as a percentage of the investment's initial cost.

A positive NPV indicates that the project benefits will exceed the project costs, while a negative NPV indicates a net loss.

$$NPV(\tau) = -I_0 + \sum_{i=1}^{\tau} \frac{CF_i}{(1+d)^i} \quad (1)$$

Where: τ -the calculation period, I_0 -the investment cost of the retrofitting strategies considered, CF_i - the net cash flows of year i , and d - the discount rate.

The Internal Rate of Return (IRR)- measures the attractiveness of the project and it is used to compare projects with different lifespans or amounts of required capital. It is similar to NPV except that the discount rate is the rate that reduces the NPV of an investment to zero. In other words, the IRR aims to estimate the equivalent annual rate of return that would be received if proceeding with the investment. If the IRR is superior to the discount rate, the project is profitable.

$$0 = -I_0 + \sum_{i=1}^{\tau} \frac{CF_i}{(1+d)^i} \quad (2)$$

A Payback Period (PP) is a simpler alternative to NPV and it calculates how long will it take for the initial investment to be repaid. However, this method fails to account for the time value of money and does not allow us to measure the profitability of the project. Moreover, it has a greater potential for inaccuracy. However, contrasting both NPV and PP is a good way to compare different retrofitting projects based on the criterion of cost-effectiveness. PP refers to the amount of time it takes to recover the cost of an investment and it is calculated as the cost of the initial investment divided by the annual cash flow (annual energy gains). The shorter the payback period, the more desirable the investment.

$$PP = \frac{\text{Initial investment}}{\text{Annual cash flow}} \quad (3)$$

Based on the results of the Cost-Benefit Analysis undertaken for each archetype, the most cost-effective strategies in terms of Payback Period and Net Present Value have been established.

4.4.6. Coding using NVivo 12 qualitative analysis software package

Thirty-one interviews were undertaken with homeowners of the same sample used in the previous stages of the study. The interviews were conducted in the national language and thereafter data were transcribed, translated, and coded within NVivo 12 qualitative analysis software package. A thematic approach to data analysis was adopted to develop a coding framework until saturation was reached and no new codes and themes were being generated (Bryman, 2015). Various themes of factors of financial, occupant, building and institutional and administrative nature affecting acceptability of energy retrofitting have been identified and then combined in categories and sub-categories and further groups depending on the nature of the theme, to further facilitate the analysis. It is important to note that an interaction between the factor themes and the sub-categories exists due to the effect that some of the factors have on various phases of the retrofitting project.

4.5. Proposed RetrofiTEA framework

Notwithstanding that retrofitting residential stock offers great potential in achieving national energy reduction targets and benefits the people in many ways, a disparity between predicted and outcomes is often found because of many factors in different stages of the retrofits' delivery process. The study developed a conceptual framework named RetrofiTEA (Retrofit: Technical, Economic and Acceptability), to connect all stages of the study, with interrelated methods components employed. The framework is developed by combining methodological approaches and tools to assess both technical and social aspects of the energy retrofitting to minimise the performance gap and uptake retrofits. Following the proposed framework, the retrofit projects will pass the assessments for technical and economic feasibility as well as be accepted by the homeowners before being undertaken. Pre-design building and occupants' surveys are essential for validating the baseline energy models and producing results that are close to reality. The research will focus on a representative archetype developed to assess energy performance and will be conducted in three inter-connected stages, each of them associated with an objective. Figure 11 illustrates the breakdown of the RetrofiTEA framework. The structure of the thesis also follows this line of action, ending with valuable recommendations for homeowners as well as policy makers and housing providers/developers for achieving successful energy retrofitting projects and programmes in the future.

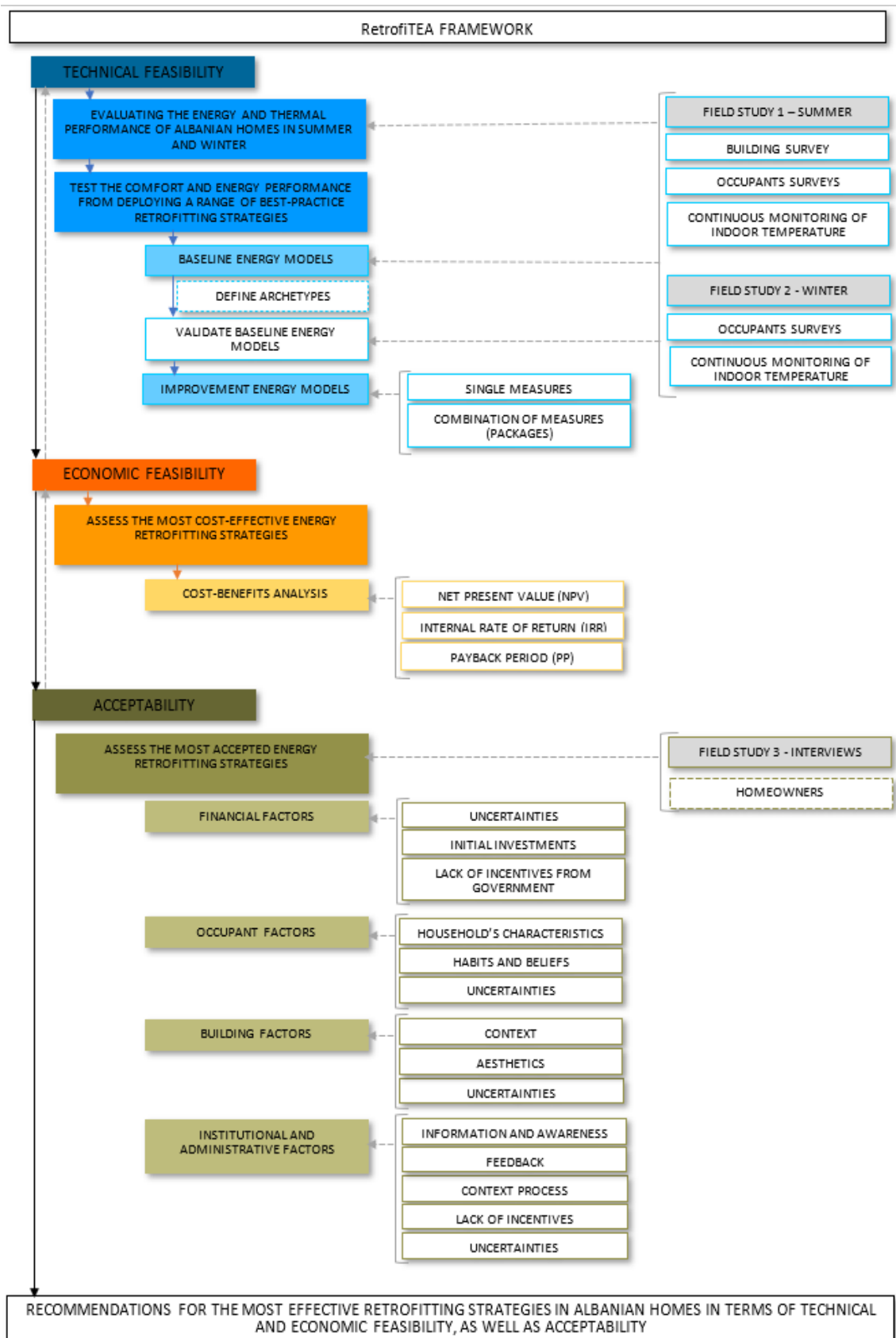


Figure 11: Breakdown of RetrofiTEA framework

There are three main stages of the framework:

1. technical feasibility
2. economic feasibility
3. acceptability.

Beyond evaluating the technical and economic feasibility of different retrofitting strategies for residential buildings, the framework aims to identify the barriers associated with whether they are accepted or not by the homeowners in terms of financial, occupant, building and institutional and administrative factors. Integrating qualitative and quantitative methods of collecting, analysing, interpreting and presenting data has generated a dynamic development and analysis of the research. It has applied an Interactive Sequential Mixed Design (Teddle and Tashakkori, 2009), as the phases of the study will occur in chronological order, with one strand emerging from the other. The first stage aims to investigate the retrofitting strategies that provide the most energy savings as well as the most improved indoor environment. The cost-effectiveness of the energy retrofitting strategies has been assessed after assessing the technical feasibility. Lastly, the proposed energy retrofitting strategies have been assessed for the level of their acceptance through interviews with the homeowners, using the results from the first two stages: technical and economic feasibility. Finally, the inferences of all three phases will contribute to creating meta-inference related to the recommendations regarding the most effective retrofitting strategies for Albanian homes.

To achieve the overall aim and objectives listed in section 1.2, the overview of methods used is given in Table 12:

Table 12: Map of the methods used to achieve the objective

OBJECTIVES	METHOD	EXPECTED OUTCOMES
Evaluating the energy and thermal performance of selected Albanian homes in summer and winter and cross-relating with people's prediction of their indoor environment, to inform the energy models (<i>Technical feasibility</i>)	• Building survey • Occupant's survey • Continuous monitoring of indoor temperature in living rooms and main bedrooms of Albanian dwellings	Providing data that can be analysed to evaluate the energy and thermal performance of various archetypes of Albanian housing stock
	• Literature review	
	• Statistical analysis using SPSS Statistics 24 • Cross-relating with people's perceptions	Evaluation of the actual energy and thermal performance of the dwellings.
	• SPSS Statistics 24	Valuable information for constructing accurate baseline energy models
Develop the baseline energy models for the selected Albanian archetypes. Afterwards, test the comfort, and energy performance from deploying a range of best practice retrofitting strategies in representative archetype dwellings in Albania, using validated dynamic thermal simulation models. (<i>Technical feasibility</i>)	• Literature review • Analysis of the case studies	Determine the most representative archetypes of Albanian housing stock
	• Dynamic simulation models using Design Builder • Building surveys • Surveys with occupants • Energy use data (energy bills) • In-situ monitoring of indoor temperature for 6 weeks in summer and 6 weeks in winter	Evaluate the actual thermal and energy performance of Albanian housing stock Have more accurate simulation models Minimising the performance gap
	• Dynamic simulation models using Design Builder	Investigation of the thermal and energy performance of various retrofitting strategies
Assess what are the most cost-effective solutions using Cost-Benefits Analysis (Economic feasibility)	• Excel spreadsheet NPV + IRR + PP	Determine the economic feasibility of the strategies
	• Excel spreadsheet	Find the most affordable retrofitting strategies for the Albanian context
Assess the most accepted energy retrofitting strategies in terms of financial, occupant, building and institutional and administrative factors, with the homeowners' interviews (Acceptability)	• Literature review	Determine the importance of integration of acceptability in the energy retrofitting program's framework
	• Interviews with homeowners	Test and determine if the investigated retrofitting strategies will be accepted by Albanian homeowners
	• Interviews with homeowners • NVivo 12	Find the most acceptable retrofitting strategies by the homeowners for the Albanian context
Using the findings, provide guidance and recommendations to homeowners and policymakers, as well as designers, and housing providers, for undertaking effective energy retrofits	• Recommendations	Recommendations for homeowners and policy makers regarding the most effective energy retrofitting strategies for Albanian homes

4.6. Summary

This chapter discussed an interdisciplinary socio-technical approach to holistically investigate the most effective energy retrofitting strategies in terms of technical and economic feasibility as well as to be accepted by the households. The research design interconnects the research objectives with methodological approaches of data collection and analysis, supported by a conceptual approach named RetrofiTEA, which aims to link quantitative and qualitative approaches in all stages of the investigation. The proposed framework is developed in three main stages that require both on-site data collection and external data sources and offers the greatest potential for energy savings if it is applied to in-depth case studies. Data collection methods, including building and occupant surveys, monitoring and interviews with homeowners, were explained. The sample selected for the investigation was discussed, also explaining limitations regarding the representation of the residential building stock in Albania. An overview of statistical analysis using various statistical tests, depending on the type of data available was given, as well as an explanation of the energy modelling and cost-benefit analysis undertaken in this study. The thematic analysis to conclude the investigation of energy retrofitting strategies in terms of acceptability has provided the main themes, sub-categories and further groups of factors affecting homeowners' acceptance of various retrofitting scenarios.

CHAPTER 5

Energy and thermal performance of existing houses in Albania

5.1. Introduction: Chapter outline

This chapter presents the findings derived from the analysis of the data collected in 49 dwellings in Tirana, Albania, and it is an essential part of this study for two main reasons:

First, it is vital to understand the energy and environment performance, together with the thermal conditions of the existing homes in Albania, through real data collection and investigation. For this, an overview of the selected sample is given in the first section, followed by an in-depth analysis of the energy consumption, temperatures and thermal comfort in summer and winter for the chosen sample, using SPSS 24 as the means for the statistical analysis of the data collected.

Second, the analysis will make it possible to define any implication for modelling the energy baseline models, including heating and cooling profiles. Hierarchical cluster analysis is undertaken to develop the most typical indoor temperature profiles in dwellings in Albania and the methodology and results are given for both summer and winter. Statistical analysis was undertaken to determine the strength of association between the clusters and contextual factors related to the building, household, and occupancy.

The chapter closes with some essential findings, as well as information that will serve for the development of energy baseline models.

5.1.1. Characteristics of the sample deduced from buildings and occupants' survey

Forty-nine households have been chosen in Tirana to represent, as far as possible, the Albanian archetypes explored previously in Section 4.4.2 of Chapter 4. However, as the sample was small, it was difficult to be exactly representative of the Albanian housing stock. Notwithstanding the selected sample is not statistically representative, it does contain the various types of dwelling forms and age bands prevalent in the Albanian housing stock. Differences in construction techniques in buildings built pre-1990 and post-1991 have also been reflected in the sample. All the dwellings built post-1991 have been constructed using a concrete structural loading scheme with no-loading hollow

bricks or blocks in the external walls. Prefabricated panels and solid brick walls were very common constructions during the communist regime of pre-1990, while insulation has only started to be applied in the last 15 years. However, the date of construction of dwellings in the sample ranged from 1950 to 2013. Electricity was the most common type of energy used for space heating, mainly due to the lack of infrastructure or security for using other types such as gas and wood. On the other hand, only three households did not use air-conditioning during the summer, which means that electricity is massively used for cooling during the hot season. Moreover, electricity is massively used for providing hot water. Table 13 presents the main dwelling characteristics in the sample.

Table 13: *Frequency of different characteristics in the sample*

Category	Description	Frequency	%
Building form	Detached	17	34.6
	Semi-detached	2	4.1
	Terraced	1	2
	Flat	29	59.3
Year of construction	Pre-1991	16	32.7
	After 1991	33	67.3
Number of storeys	1 storey	9	18.4
	2 storeys	9	18.4
	3-4 storeys	5	10.2
	5 or more storeys	26	53.1
Number of bedrooms	1	12	24.5
	2	24	49
	3	9	18.4
	4	2	4.1
	5	2	4.1
Construction type	Solid brick/stone external walls	8	16.3
	Prefabricated	3	6.1
	Silicate brick	5	10.2
	Concrete blocks	3	6.1
	Hollow brick	24	49
	Insulated walls	6	12.2
Ventilation / cooling scheme	Natural ventilation	3	6.1
	Mixed ventilation (natural + air conditioning)	46	93.9

On the other hand, focusing on the households' characteristics, they were from various parts of Tirana. What is interesting in Albanian families is that very commonly children live with their parents even after they are married and have children of their own. This culture was reflected in this sample as well, with 33 out of 49 households formed of three generations living together. Only two households were formed of only one occupant: a student and a retired woman. Most of them were well-educated, with only one household having only elementary education. Incomes for households ranged from 180€ to over 2,000€ per month, with most earning between 400€ and 700€ per month. These findings

suggest that there is a high diversity of the sample in terms of occupancy and its characteristics (See Table 14).

Table 14: Sample by household characteristics

Category	Values	Frequency	%
Highest education level	Elementary	1	2.0
	High school	15	30.6
	University	33	67.3
Households' type	Single	2	4.1
	Couple	6	12.2
	Family with children	8	16.3
	Family with children and grandparents	33	67.3
Households' income (monthly)	0-300€	8	16.3
	301-500€	16	32.7
	Over 500€	25	51.0

From the group of 49 dwellings, 29 (59%) had undertaken at least one of the energy-saving strategies shown in Figure 12. None of the dwellings built before 1990 had any kind of fabric improvement, apart from three dwellings that had double glazing. Notwithstanding their not-so-good thermal conductivity, double-glazed windows with aluminium frames were the most commonly used in the sample. Single-glazed windows with aluminium frames were largely used after 1991 in Albanian homes (Novikova *et al.*, 2015), and even when they were replaced with double glazing, the frame was still aluminium, which presents a big problem today regarding heat transmittance. Whereas wall insulation consisted of 5-8mm expanded polystyrene (EPS) placed on the outside (retrofitted) or in the cavity of the external walls (when it was built; six in total), while all the other dwellings consisted of a single layer wall plastered on the inside and rendered on the outside. Floor and roof insulation were less often applied than wall insulation, however, in all apartment buildings built after 1991, extruded polystyrene is used in floors separating the storeys to minimise their weight, improving the thermal properties of the floors and ceiling as well. Hot water pipe insulation is not practised in building construction in Albania.

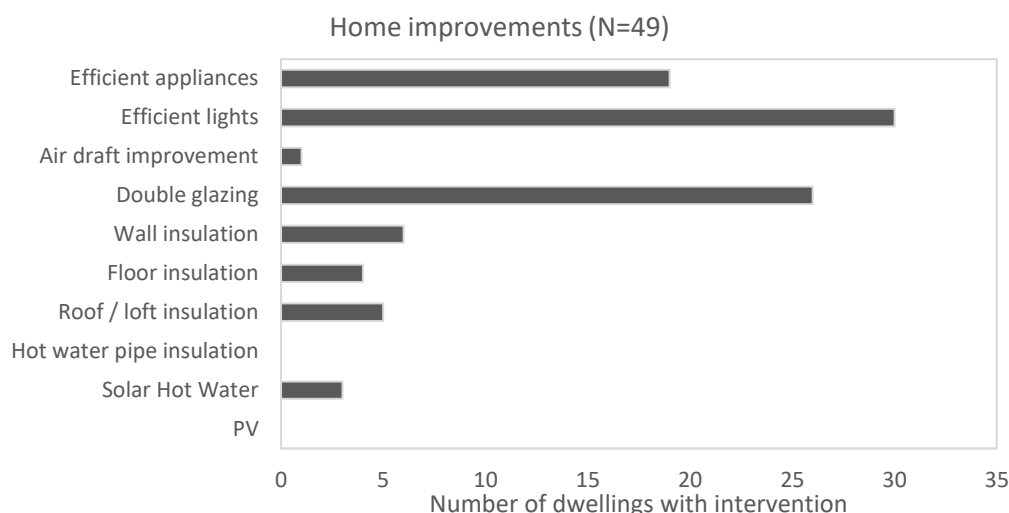


Figure 12: Frequency of energy-saving strategies in the sample

Although Albania has favourable climatic conditions of long hours of sunshine (up to 3,000 hours/year), solar energy is not used on a great scale, mainly because of financial issues and installation issues, especially in apartment buildings. Only three dwellings used solar hot water systems, and no one used PV to generate energy.

On the other hand, efficient lighting, including LEDs, was the most popular, mainly because of its low cost compared to the other interventions. However, not all could afford to replace incandescent lights. Financial issues prevented some of the homeowners from continuing to replace the lights with efficient ones. One participant stated:

“...I started to replace the old lights with the new efficient ones, but at the end of their life I could no longer afford to buy efficient lights again.”

Likewise, there is a tendency to replace the old appliances with more efficient ones, mainly due to the recent strong campaigns made by the main appliances suppliers (Simaku, 2014). This fact has been identified in the sample as well, where 42 (85%) out of 49 households have admitted to checking the energy label before buying new appliances as shown in Figure 13.

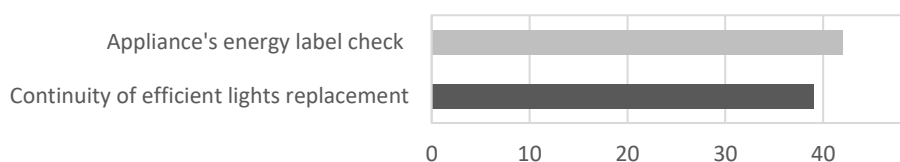


Figure 13: Frequency of occupant practices regarding efficient lights and appliances

5.2. Energy consumption

There are four main types of energy source in Albania, as shown in Table 15. Electricity is used for all categories of use, while wood and Liquid Petroleum Gas (LPG) are used for heating and cooking only. Notwithstanding that LPG is considered one of the most important energetic productions to replace electrical energy being consumed mainly for heating and cooking, there are still safety concerns regarding its use for heating the house. In the sample considered in this study, only five dwellings used LPG for heating, however, it was considered as a secondary energy source in these households. In Albania, and consequently in this sample, electricity is the only energy used for lighting. Albania has the highest electricity consumption for lighting in Europe and 95% of the hot water services are performed by electric heater boilers (ERE, 2009). Likewise, in this sample, electricity is used for running appliances and hot water, except for one dwelling that used solar thermal.

Table 15: Summary of categories of energy use in the sample

Category of use	Energy source			
	Electricity	Wood	LPG	Solar
Space heating	√	√	√	
Space cooling	√			
Hot water services	√			√
Cooking	√	√	√	
Lighting	√			
Appliances	√			

Table 16 gives the frequency and the percentage in the sample for various categories of heating and cooling as well as hot water services.

There was no form of collecting data for energy use by other types of energy apart from electricity consumption, which was secured by actual monthly bills for 36 out of 49 dwellings. Therefore, the analysis below will be based only on electricity consumption

Table 16: *Type of energy used in the sample for various categories*

Category	Description	Frequency	%
Main energy used for heating	Wood	3	6.1
	Electricity	34	69.4
	LPG (Liquefied Petroleum Gas) + electricity	5	10.2
	Wood + electricity	7	14.3
The main type of heating	Heat pumps	25	51
	Electric heater	6	12.2
	Wood stove	4	8.2
	Air conditioning + electric heater	2	4.1
	Air conditioner + gas heater	4	8.2
	Air conditioner + wood stove	6	12.2
	Electric heater + gas heater	1	2
	Central heating with electricity	1	2
	No cooling	2	4.1
Type of cooling	Air conditioning	29	59.2
	Electric cooler	7	14.3
	Air conditioning + electric cooler	11	22.4
	No cooling	2	4.1
Main energy used for hot water services	Electricity	48	98
	Solar	1	2

5.2.1. Electricity consumption

Until 2015, electricity was priced based on two main consumption blocks to discourage consumers from using it for heating or cooling the space. It was calculated by the Albanian Energy Regulator Authority (ERA) (ERE, 2009) that the minimal energy consumption needed to perform the main daily activities, without heating or cooling the space, was 300kWh and it was observed that 55.5% of the families with a connection to the grid consumed up to 300kWh. Therefore, the price for every unit of electricity consumed up to 300kWh within the month was set at 7.7 lek (€0.06) and over 300kWh was 13.5 lek (€0.1). The block has been removed and now, a single price is applied. At the time of the survey, the electricity price was 9.5leke (€0.07). It increased in July 2021 to 10.48lek/kWh (ERE, 2021).

Figure 14 shows the actual electricity consumption plotted by actual monthly bills for 36 dwellings together with the average and baseline electricity consumption in homes in Albania. In almost all dwellings, electricity consumption increases during the winter months (November to March) with its peak in January, and the summer months (June to September) in July, indicating the use of electricity for space heating and cooling respectively in winter and summer in most of the dwellings.

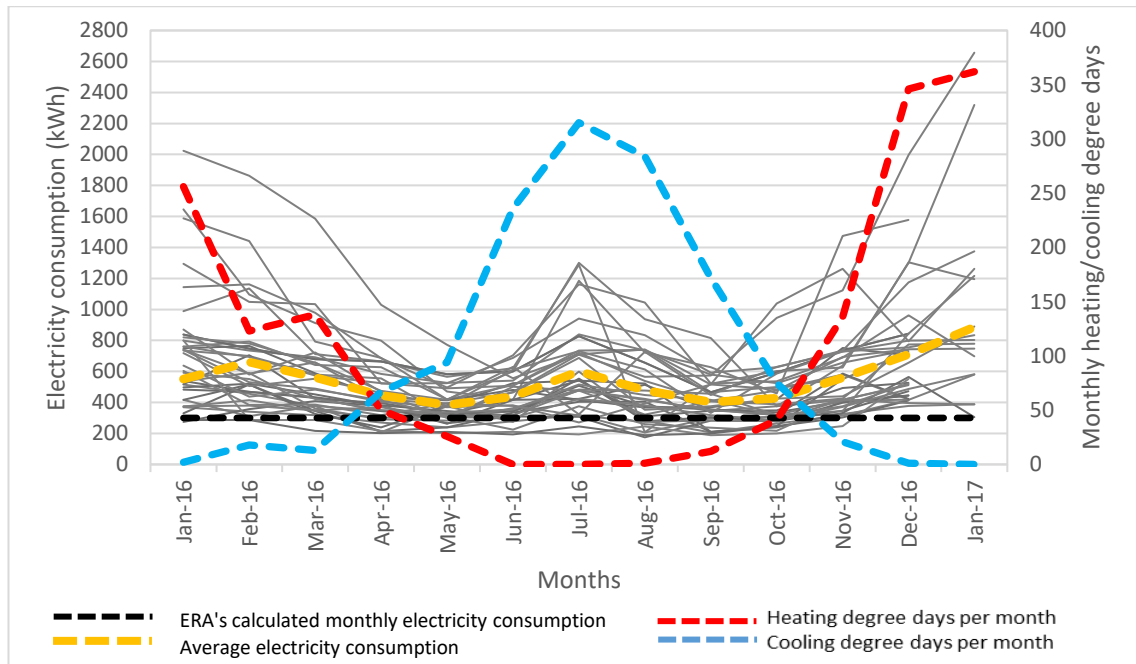


Figure 14: Electricity consumption from January 2016 to January 2017 for 36 dwellings, together with average and baseline electricity consumption in homes in Albania. Heating and cooling degree days are also included in the graph

Source of degree days: (www.degreedays.net, 2017)

According to Figure 5.3, heating in the Albanian climate is expected to start in October and last until April, to achieve a comfortable indoor temperature during the winter. Cooling is required from June to September, with its peak in July. It is important to notice that the electricity consumption increased in some of the dwellings in January 2017 compared to January 2016. This is probably because of the increase of degree days for January 2017 compared to January 2016. A degree day is a measure of the difference between the baseline and the actual outdoor temperature multiplied by the number of days (Carbon Trust, 2004). It has a direct influence on heating and cooling load because it can provide a measure of the average outside temperature (CIBSE, 2004). The base temperature in calculating the degree days used is 15.5°C, as recommended by (Carbon Trust, 2004).

Figure 15 shows the yearly electricity consumption with the cost for each dwelling, sorted from the lowest electricity consumer to the highest one. The average electricity consumption is 6,426kWh/year. However, most dwellings consume between 4,000kWh/year to 6,000kWh/year.

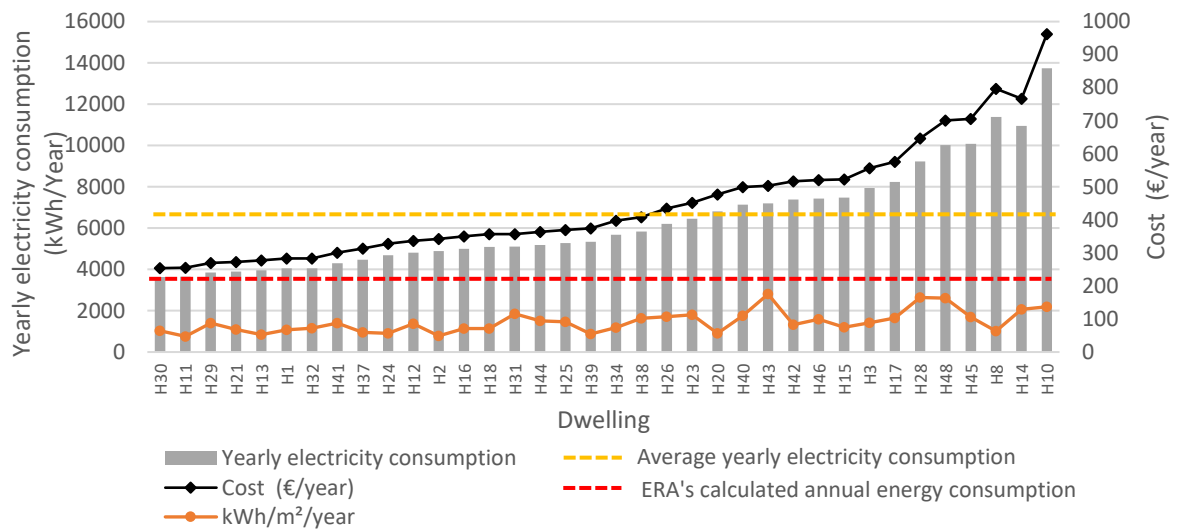


Figure 15: Yearly electricity consumption with cost

A full picture of annual electricity consumption for 36 dwellings is compiled in Table 17. Taking into account the electricity consumption needed for Albanian households calculated by the Albanian Energy Regulator Authority (ERA) (ERE, 2009) of 300kWh/month, which includes all electricity end-users except space heating and cooling, the ERA's calculated annual energy consumption (3,600kWh/year) is deducted from the total electricity consumption to give the estimated heating and cooling energy consumption for each dwelling (electricity bills were provided for 36 dwellings). The electricity consumption varies from 3,627kWh/year (dwelling H30) to 13,745kWh/year (dwelling H10) and from 47.4kWh/m²/year (dwelling H11) to 175.4 kWh/m²/year (dwelling H43). It must be noted that the estimated heating and cooling energy consumption given in this table is related only to electricity and no other types of energy that are used in some of the dwellings.

Table 17: Yearly electricity consumption and cost for each dwelling

Dwelling	Total electricity consumption		ERA's annual calculation	Heating/cooling energy consumption	Total Cost		Floor area
	kWh/year	kWh/m ² /year	kWh/year	kWh/year	€/kWh	€/year	m ²
H1	4045	67.4	3600.0	445.0	0.07	283.15	60.0
H2	4895	49.0	3600.0	1295.0	0.07	342.65	100.0
H3	7950	88.3	3600.0	4350.0	0.07	556.5	90.0
H4	-	-	3600.0	-	0.07	-	74.0
H5	-	-	3600.0	-	0.07	-	74.0
H6	-	-	3600.0	-	0.07	-	195.0
H7	-	-	3600.0	-	0.07	-	80.0
H8	11388	63.3	3600.0	7788.0	0.07	797.16	180.0
H9	-	-	3600.0	-	0.07	-	-
H10	13745	137.5	3600.0	10145.0	0.07	962.15	100.0
H11	3649	47.4	3600.0	49.0	0.07	255.43	77.0
H12	4814	86.0	3600.0	1214.0	0.07	336.98	56.0
H13	3959	52.8	3600.0	359.0	0.07	277.13	75.0
H14	10947	106.3	3600.0	7347.0	0.07	766.29	103
H15	7470	74.7	3600.0	3870.0	0.07	522.9	100.0
H16	4999	71.4	3600.0	1399.0	0.07	349.93	70.0
H17	8233	102.9	3600.0	4633.0	0.07	576.31	80.0
H18	5093	70.7	3600.0	1493.0	0.07	356.51	72.0
H19	-	-	3600.0	-	0.07	-	100.0
H20	6808	56.7	3600.0	3208.0	0.07	476.56	120.0
H21	3891	67.8	3600.0	291.0	0.07	272.37	57.4
H22	-	-	3600.0	-	0.07	-	57.0
H23	6454	113.2	3600.0	2854.0	0.07	451.78	57.0
H24	4681	56.5	3600.0	1081.0	0.07	327.67	82.8
H25	5278	91.0	3600.0	1678.0	0.07	369.46	58.0
H26	6200	106.9	3600.0	2600.0	0.07	434	58.0
H27	-	-	3600.0	-	0.07	-	70.0
H28	9236	164.9	3600.0	5636.0	0.07	646.52	56.0
H29	3856	87.6	3600.0	256.0	0.07	269.92	44.0
H30	3627	64.8	3600.0	27.0	0.07	253.89	56.0
H31	5105	116.0	3600.0	1505.0	0.07	357.35	44.0
H32	4048	72.3	3600.0	448.0	0.07	283.36	56.0
H33	-	-	3600.0	-	0.07	-	56.0
H34	5677	73.7	3600.0	2077.0	0.07	397.39	77.0
H35	-	-	3600.0	-	0.07	-	52.5
H36	-	-	3600.0	-	0.07	-	71.5
H37	4473	59.6	3600.0	873.0	0.07	313.11	75.0
H38	5833	101.9	3600.0	2233.0	0.07	408.31	57.3
H39	5344	54.5	3600.0	1744.0	0.07	374.08	98
H40	7134	109.8	3600.0	3534.0	0.07	499.38	65
H41	4300	87.8	3600.0	700.0	0.07	301	49
H42	7381	82.9	3600.0	3781.0	0.07	516.67	89
H43	7191	175.4	3600.0	3591.0	0.07	503.37	41
H44	5191	94.4	3600.0	1591.0	0.07	363.37	55
H45	10083	106.1	3600.0	6483.0	0.07	705.81	95
H46	7432	99.1	3600.0	3832.0	0.07	520.24	75
H47	-	-	3600.0	-	0.07	-	-
H48	10018	125.2	3600.0	6418.0	0.07	701.26	80
H49	-	-	3600.0	-	0.07	-	65

From a correlation analysis of average monthly salary and yearly electricity consumption per metre square, there is a strong positive correlation ($r=0.67$) between the two variables as seen in Figure 16, showing that the yearly electricity consumption is higher for the households with higher salaries. (Schaffrin and Reibling, 2015) have also found that high-income households have higher overall energy consumption, while low-income households spend a higher share of their income on energy costs. However, most households in the sample have monthly incomes of 400-600€ and yearly electricity consumption of 40-120kWh/m²/year.

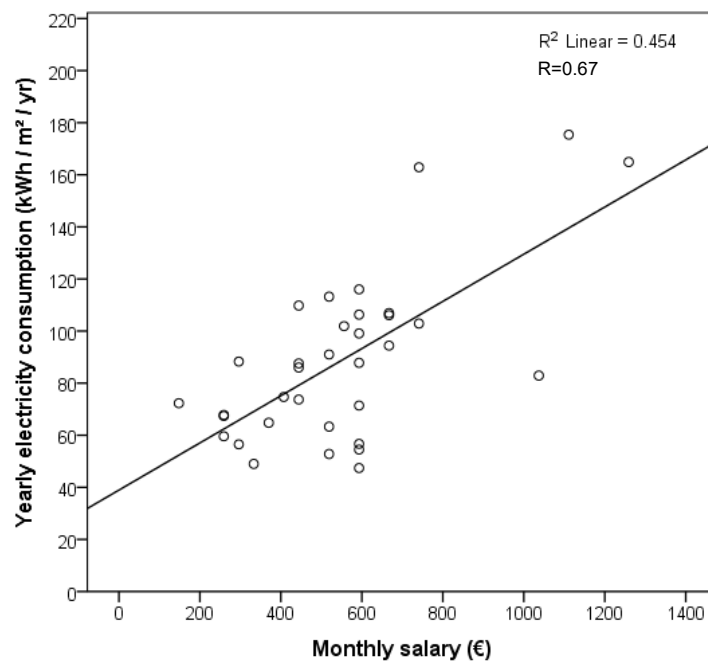


Figure 16: Linear regression of average monthly salary and yearly electricity consumption per square metre.

Spearman correlation analysis has been performed to check the strength of the relationship between the estimated annual heating/cooling energy consumption and dwelling and household characteristics. The statistically significant correlations are given in Table 18. The correlation between the estimated annual heating/cooling energy consumption and household size and monthly incomes has been among the strongest with rho equal to 0.552 and 0.525 respectively. The period the dwelling has been constructed has also had a significant correlation at 0.05 level with the annual heating/cooling energy consumption ($\rho=0.349$). All other dwellings and household characteristics have a non-significant level of correlation. However, it is interesting that the presence of an elderly person in the household has a weak negative correlation,

contrary to having children in the household, which has a weak positive correlation with the yearly heating/cooling energy consumption.

Table 18: Spearman correlation analysis results between the heating/cooling loads and dwelling/household's characteristics

		Type of house	Construction period	Main construction material	Household size	Type of heating	Type of cooling	Double glazing	The thermal sensation during the winter	The thermal sensation during the summer	Monthly salary	Presence of children	Presence of elderly people
Heating/ Cooling load	rho	-.107	.349*	-.106	.552**	.148	.070	.190	-.087	.156	.525**	.210	-.216
	Sig. (2-tailed)	.534	.037	.537	.000	.389	.684	.267	.616	.363	.001	.219	.207
	N	36	36	36	36	36	36	36	36	36	34	36	36

An example of this fact is dwelling H39, where heating was on at all times in one of the bedrooms because of a newborn in their family (dwelling H39). The graph in Figure 17 shows the daily mean temperature distribution in the living room and two bedrooms of dwelling H39.

The indoor temperature in the main bedroom, where the newborn was staying, has been noticeably lower and higher than in the second bedroom during the summer and winter respectively, indicating that this room has been constantly cooled during the summer and heated during the winter. The indoor temperature during the winter has been even higher than in the living room, where most of the other members spent most of their time during the day, showing the impact that the presence of a child has in keeping adequate thermal comfort in the home.

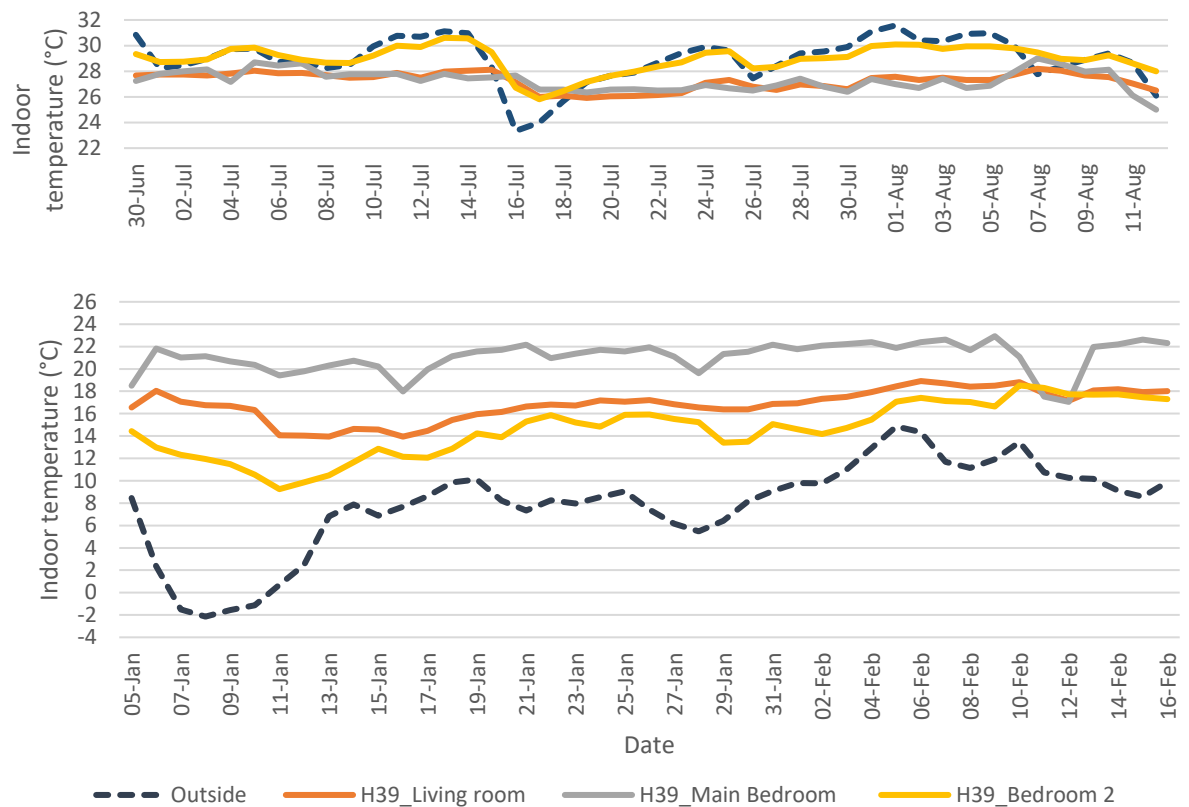


Figure 17: Daily mean temperatures in dwelling H39 during the summer (top) and winter (bottom)

Cross relating responses of participants regarding the month they start and stop heating and cooling their homes respectively, and electricity bills provided for most of the dwellings, enabled an estimation of electricity consumption used for heating and cooling the homes, which is given in Figure 18.

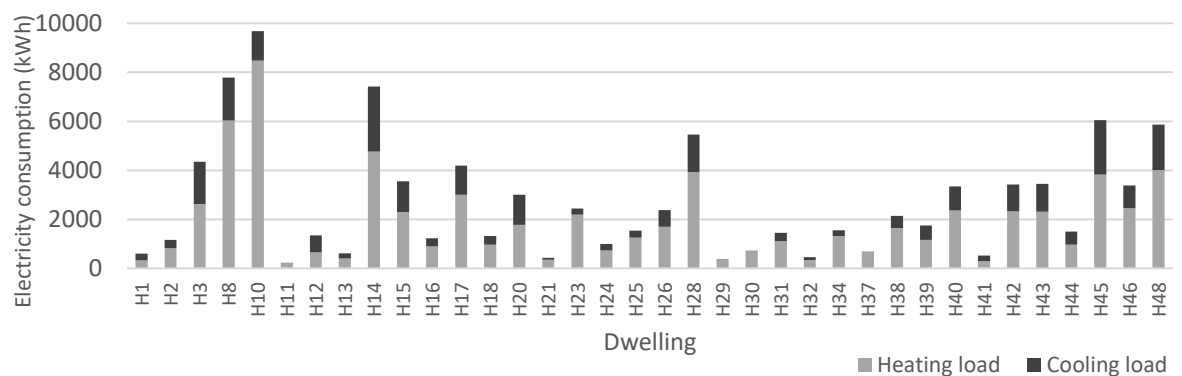


Figure 18: Estimated heating and cooling loads based on electricity bills

Notwithstanding that available energy data only includes electricity consumption, it can be noticed that most of the energy consumed over the ERA's calculated annual energy consumption needed for all activities rather than heating and cooling the space, is for heating rather than cooling the homes. Most of the households also consider heating their homes more important than cooling them (65%) (See Table 19).

Table 19: Responses of participants regarding what is more important for them: heating or cooling of their home.

	Frequency	Percentage
Heating	32	65%
Cooling	3	6%
Both	14	29%

Most dwellings are heated and cooled from November to April and June to September respectively (See Table 20). Only seven dwellings switch the heating on as late as December and only three of them switch the heating off as late as May. Two dwellings are not cooled mechanically and four of them start cooling as soon as May.

Table 20: Months when heating and cooling are switched on and off

Start heating the house			Stop heating the house		
Month	Frequency	%t	Month	Frequency	%
October	12	24.5	March	21	42.9
November	30	61.2	April	25	51
December	7	14.3	May	3	6.1
Start mechanically cooling the house			Stop mechanically cooling the house		
Month	Frequency	%	Month	Frequency	%
May	4	8.2	August	14	28.6
June	29	59.2	September	29	59.2
July	14	28.6	October	4	8.2
No cooling	2	4.1	No cooling	2	4.1

On one hand, it is important to note that 43% of the dwellings are heated for half of the year and two of them are heated for as long as eight months of the year (See table 21). On the other hand, most of the dwellings are cooled for three and four months of the year. Two participants stated that they do not mechanically cool their homes at all.

Table 21: Duration in months of heating

	Heating duration		Cooling duration	
	Frequency	Percentage	Frequency	Percentage
No heating/cooling	0	0%	2	4%
1 month	0	0%	0	0%
2 months	0	0%	5	10%
3 months	0	0%	12	24%
4 months	6	12%	24	49%
5 months	12	24%	4	8%
6 months	21	43%	2	4%
7 months	8	16%	0	0%
8 months	2	4%	0	0%
Total	49	100%	49	100%

Therefore, heating homes in Albania is more crucial than cooling them, and it is important to aim to decrease the months of especially heating in dwellings.

5.3. Temperature variations in living rooms and bedrooms over the summer

The summer field study involved the monitoring of the indoor temperature of 49 living rooms and 42 main bedrooms from June 30 to August 12, 2016, at half-hourly intervals, to cover the hottest season of the year in the Albanian climate.

After statistically exploring all datasets for normality through exploring statistics, histograms, outliers, Normal Q-Q plots and Detrended Normal Q-Q, it was decided to clean the dataset from the extreme outliers to minimise the skewness of the data distribution. Outliers were not removed from the dataset as they were not considered to be unusual for the period of monitoring. One-sample T-test was undertaken for each variable to check whether the mean temperature of each living room has statistically significantly differed before removing the extreme outliers. A statistically non-significant difference was found ($p > 0.05$) for each of the dwellings. The mean daily indoor temperature was then calculated for both the living room and the bedroom of each dwelling. The hourly mean temperature was also calculated to investigate the temperature profile during the day in monitored dwellings.

SPSS Statistics 24 has been used to perform all the analyses. Assumptions were carefully considered before undertaking each test and 95% confidence intervals have been computed from the observed data and tests have been statistically significant for $p \leq 0.05$. However, because there is a small sample (less than 100), it is important to acknowledge the possibility that a non-significant result may be due to insufficient power (Pallant, 2013).

5.3.1. Temperature distribution in living rooms and bedrooms during the summer

The outdoor temperature ranged between 19.6°C to 41.1°C, while the indoor temperature ranged from 19.5°C to 37°C in both living rooms and bedrooms. Figure 19 shows the recorded temperature variations in each monitored living room and bedroom throughout the monitoring time in summer. The indoor temperature is well above the recommended temperatures from the guidelines (23°C to 25°C) (CIBSE, 2006) and is even higher than 20°C, considered the comfortable temperature in living rooms by Albanian regulation (Republika e Shqiperise, 2010).

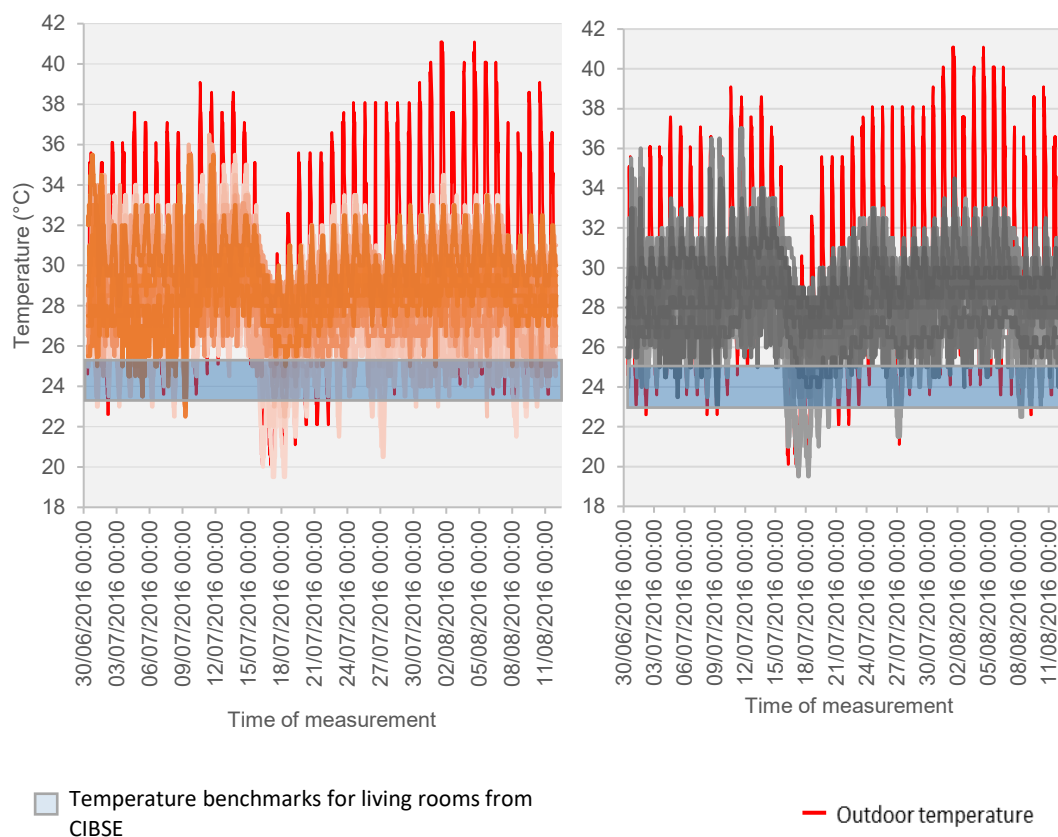


Figure 19: Measured temperatures in living rooms (left) and bedrooms (right) during the summer

Figure 20 and Table 5.10 show the boxplots and descriptive analysis of monitored indoor temperature respectively for both living rooms and bedrooms after cleaning from extreme outliers. In general, the indoor temperature distributions in living rooms and the main bedrooms are very similar, having the same mean temperature of 28.6°C, and most of the recordings are within the same range of 25 to 32°C. However, some of the dwellings have different indoor temperature distributions in living rooms and bedrooms, indicating different behaviours within the home.

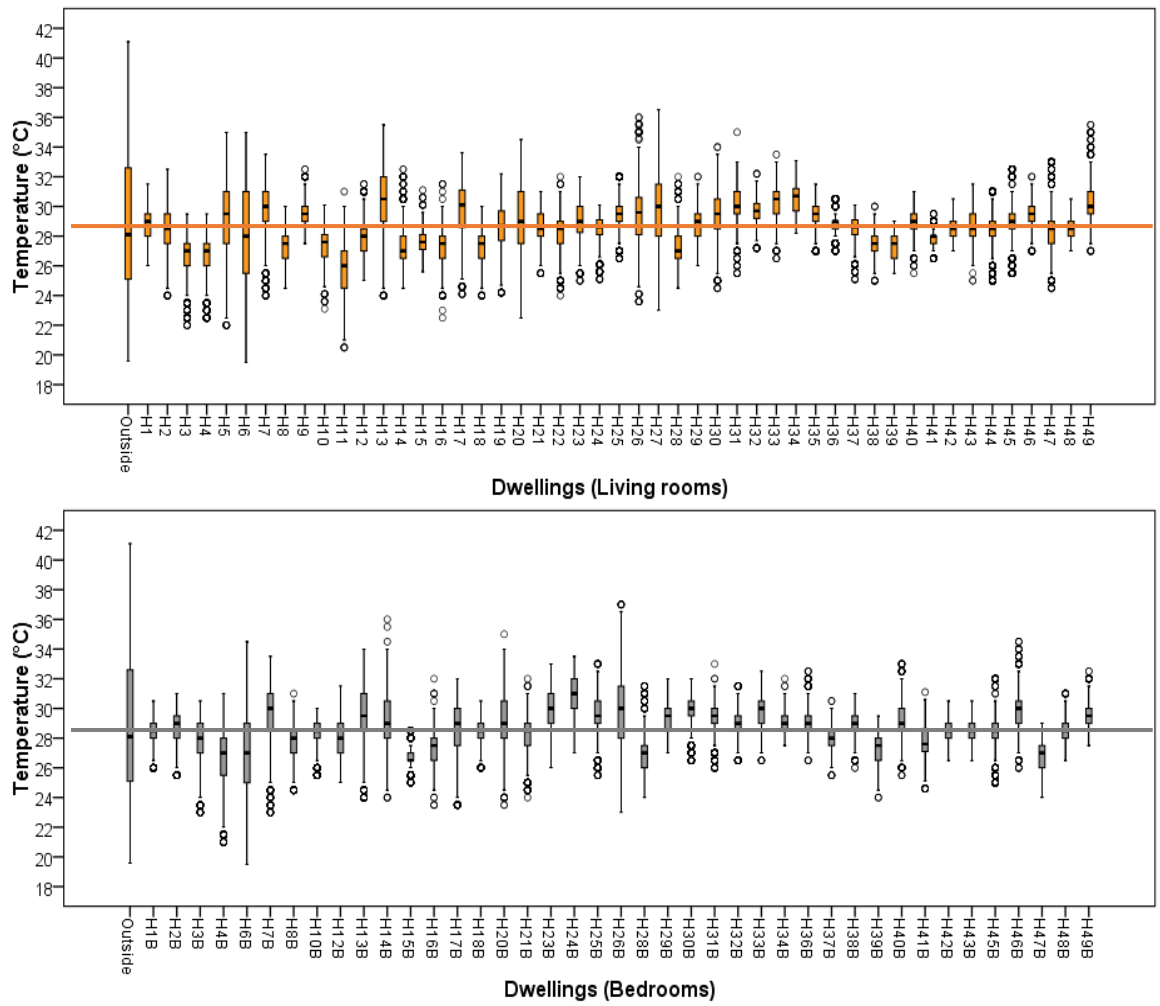


Figure 20: Boxplots of measured temperatures in monitored living rooms (top) and bedrooms (bottom) after cleaning from extreme outliers, with the line showing the mean temperature of all dwellings in living rooms and bedrooms respectively

A full picture of indoor temperatures in living rooms and bedrooms of each dwelling is given through the descriptive analysis in Table 22. The mean daily indoor temperature is above 25°C in the living room and bedroom of every dwelling, while maximum indoor temperature has exceeded 35°C in H49. Generally, deviation from the mean temperature (SD) has been higher in living rooms than in bedrooms, indicating the use of air conditioning and other cooling strategies in living rooms compared to bedrooms.

Table 22: Descriptive analysis of indoor temperatures in living rooms and bedrooms during the summer

a	Living rooms				Bedrooms			
	Mean	Max	Min	SD	Mean	Max	Min	SD
Outside	29.0	41.1	19.6	4.9	29.0	41.1	19.6	4.9
H1	28.8	31.5	26.0	1.1	28.3	30.5	26.0	.9
H2	28.5	32.5	24.0	1.5	28.8	31.0	25.5	1.2
H3	26.7	29.5	22.0	1.4	27.8	30.5	23.0	1.5
H4	26.7	29.5	22.5	1.4	26.7	31.0	21.0	2.0
H5	29.1	35.0	22.0	2.4	.	.	.	.
H6	27.9	35.0	19.5	3.4	27.0	34.5	19.5	2.9
H7	29.9	33.5	24.0	1.8	29.7	33.5	23.0	2.1
H8	27.2	30.0	24.5	1.0	27.8	31.0	24.5	1.1
H9	29.7	32.5	27.5	.8	28.3	30.0	25.5	1.1
H10	27.4	30.1	23.1	1.1	.	.	.	.
H11	25.8	31.0	20.5	1.6	28.0	31.5	25.0	1.2
H12	27.9	31.5	25.0	1.2	29.5	34.0	24.0	2.0
H13	30.2	35.5	24.0	2.2	29.1	36.0	24.0	1.8
H14	27.3	32.5	24.5	1.2	26.6	28.5	25.0	.6
H15	27.8	31.1	25.6	.8	27.3	32.0	23.5	1.1
H16	27.3	31.5	22.5	1.3	28.6	32.0	23.5	1.7
H17	29.6	33.6	24.1	1.8	28.3	30.5	26.0	.9
H18	27.2	30.0	24.0	1.1	.	.	.	.
H19	28.7	32.2	24.2	1.5	29.2	35.0	23.5	1.9
H20	29.1	34.5	22.5	2.3	28.2	32.0	24.0	1.3
H21	28.6	31.0	25.5	1.1	30.0	33.0	26.0	1.4
H22	28.2	32.0	24.0	1.3	30.9	33.5	27.0	1.2
H23	29.0	32.0	25.0	1.2	29.5	33.0	25.5	1.4
H24	28.4	30.1	25.1	.9	29.7	37.0	23.0	2.4
H25	29.6	32.0	26.5	1.0	26.8	31.5	24.0	1.0
H26	29.4	36.0	23.6	1.9	29.4	32.0	27.0	1.0
H27	29.7	36.5	23.0	2.3	30.0	32.0	26.5	1.2
H28	27.2	32.0	24.5	1.2	29.5	33.0	26.0	1.1
H29	28.9	32.0	26.0	1.1	28.8	31.5	26.5	.9
H30	29.3	34.0	24.5	1.5	29.9	32.5	26.5	1.1
H31	30.1	35.0	25.5	1.1	29.1	32.0	27.5	.7
H32	29.8	32.2	27.2	.9	29.2	32.5	26.5	.9
H33	30.3	33.5	26.5	1.1	27.8	30.5	25.5	.8
H34	30.5	33.1	28.2	.9	28.9	31.0	26.0	.9
H35	29.3	31.5	27.0	.8	27.3	29.5	24.0	1.0
H36	28.9	30.5	27.0	.7	29.1	33.0	25.5	1.3
H37	28.4	30.1	25.1	.9	27.8	31.1	24.6	1.2
H38	27.7	30.0	25.0	.8	28.5	30.5	26.5	.8
H39	27.3	29.0	25.5	.8	28.4	30.5	26.5	.9
H40	28.8	31.0	25.5	.8	.	.	.	.
H41	27.8	29.5	26.5	.6	28.4	32.0	25.0	1.2
H42	28.6	30.5	27.0	.7	29.9	34.5	26.0	1.4
H43	28.7	31.5	25.0	1.0	26.7	29.0	24.0	1.0
H44	28.5	31.0	25.0	1.2	28.4	31.0	26.5	.7
H45	28.9	32.5	25.5	1.4	29.7	32.5	27.5	.8
H46	29.6	32.0	27.0	.7	29.0	41.1	19.6	4.9
H47	28.2	33.0	24.5	1.5	28.3	30.5	26.0	.9
H48	28.4	30.5	27.0	.6	28.8	31.0	25.5	1.2
H49	30.3	35.5	27.0	1.3	27.8	30.5	23.0	1.5

Although the above analysis clearly illustrates that most of the dwellings are constantly overheated, a further investigation is essential to check the proportion of time each dwelling has been overheated during the monitoring time, as shown in Figure 21. A building is overheated when the operative temperature is over 28°C for more than 1% of annual occupied hours and over 25°C for more than 5% of the occupied hours. However, the dwellings are monitored for 12 weeks in total and not the entire year. Nevertheless, the 1% of annual occupied hours is equivalent to 21% of occupied hours during the 12 weeks of monitoring and all the dwellings have indoor temperatures over 25°C for more than 21% of the occupied hours. Even more, in 80% (39 living rooms) of the living rooms, the indoor temperatures are over 25°C almost all the time. The house with the lowest indoor temperature (H11) in the sample, still has indoor temperatures above 25°C for more than 80% of the day. Furthermore, 37 dwellings have experienced temperatures over 28°C for more than 50% of the day. This demonstrates that all dwellings in the sample are overheated during the summer.

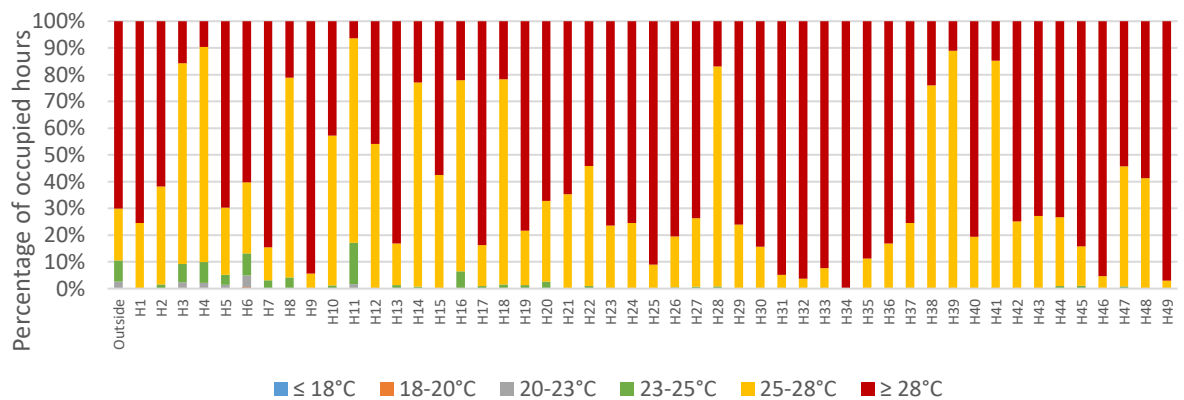


Figure 21: Temperature range during occupied hours in living rooms during the summer

5.3.2. Daily and hourly profiles of indoor temperatures in living rooms and bedrooms during the summer

Average daily indoor temperatures are assessed during the occupied hours for living rooms (07:00-23:00) and bedrooms (23:00-07:00) as shown in Figure 22. The profiles show that indoor temperatures are affected by external temperatures. For most dwellings, indoor temperatures increase as the external temperatures increase. Mean daily indoor temperatures up to 32°C have been recorded in the living rooms and bedrooms of some of the dwellings. Bedroom temperature profiles show that although the night time external temperatures range from 20.3 to 29°C, the indoor temperatures in bedrooms are at the same levels (even higher) as indoor temperatures during the day.

This suggests that most of the households in Albania do not cool the bedrooms, and do not benefit from passive cooling during the night.

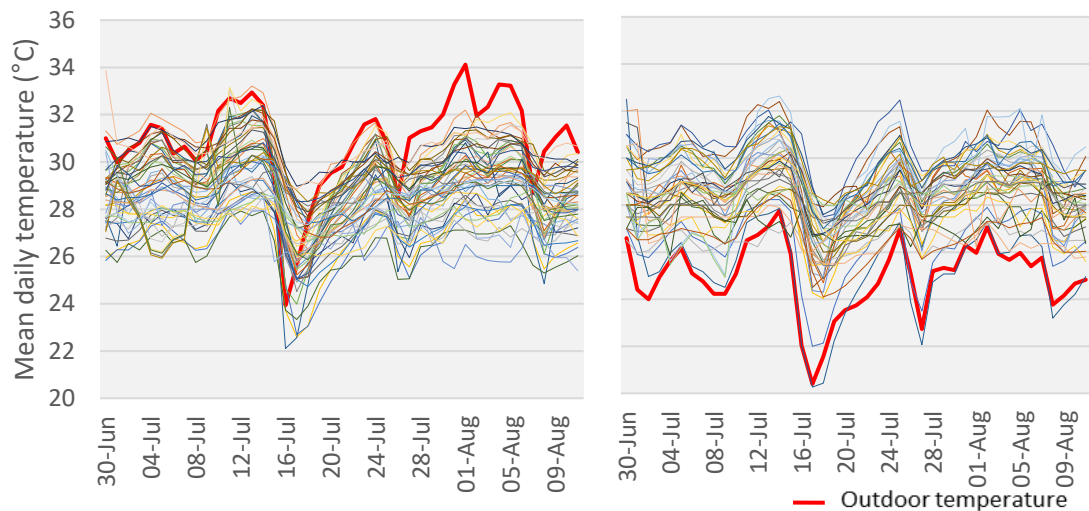


Figure 22: Mean daily temperatures in living rooms (left) and bedrooms (right) during the occupancy hours.

To investigate the temperature profile during the day, the mean hourly temperatures for living rooms and bedrooms are calculated and shown in Figure 23. Most of the dwellings have continuous mean indoor temperatures throughout the day of over 28°C, while only two dwellings have indoor temperatures below 25°C in the morning. Interestingly, in most of the dwellings, the indoor temperature daily profiles are similar in living rooms and bedrooms. However, slightly lower temperatures are noticed in the morning in bedrooms.

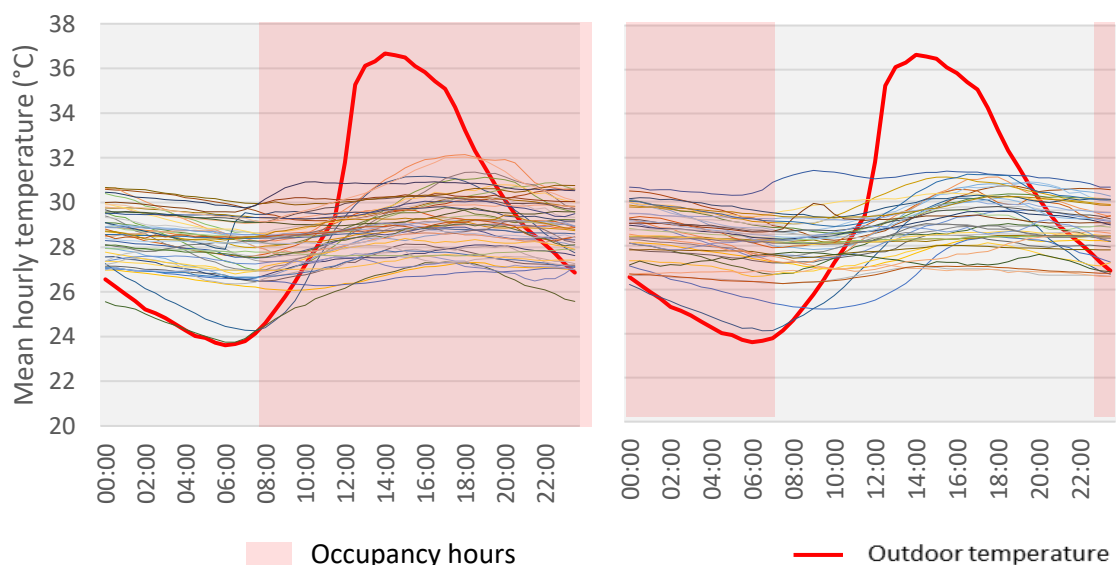


Figure 23: Mean hourly temperatures in living rooms (left) and bedrooms (right) during the summer.

5.3.3. The indoor temperature in living rooms and bedrooms by dwelling characteristics during the summer

A descriptive statistical analysis of the indoor temperatures by various dwelling characteristics is given in Table 23. Temperatures have been higher in flats and terraced houses compared to other built forms, in both living rooms and bedrooms. This could be due to less cross ventilation associated with these built forms. The highest temperatures were registered in dwellings built pre-1990, and those constructed with silicate brick and prefabricated elements (affected by poor thermal properties of the building fabric). Temperatures are higher in smaller dwellings and are generally higher for larger households, apart from households with one member, that were occupied by a student who used the flat only for sleeping and a retired woman that could not afford the heating or cooling bills and was hardly cooled or heated at all.

Table 23: Descriptive analysis of indoor temperature by dwelling characteristics during the summer

	Living room						Bedroom				
	n	Mean	Max	Min	95%	St.D	Mean	Max	Min	95%	St.D
Type of house											
Detached	17	28.1	30.2	25.8	30.2	1.3	28.1	29.7	26.7	29.7	1.0
Semi-detached	1	27.2	27.2	27.2	27.2	.	28.3	28.3	28.3	28.3	.
Terraced	2	28.9	29.1	28.7	29.1	0.3	29.2	29.2	29.2	29.2	.
Flat	29	28.9	30.5	27.2	30.3	0.9	28.9	30.9	26.7	30.0	1.1
Year of construction											
Pre-1990	16	28.9	30.3	27.2	29.6	0.6	29.4	30.9	26.8	30.5	1.0
Post-1991	33	28.4	30.5	25.8	30.3	1.1	28.3	29.9	26.7	29.7	0.9
Number of storeys											
1-storey	8	28.0	30.2	25.8	30.2	1.6	28.4	29.7	26.7	29.7	1.2
2-storeys	10	28.4	29.6	26.7	29.6	0.9	28.5	30.0	26.7	30.0	1.0
3- storeys	3	28.0	28.7	27.4	28.7	0.7	27.7	28.3	27.0	28.3	0.9
4-5 storeys	13	29.1	30.3	27.2	30.3	1.0	29.2	30.9	26.8	30.9	1.1
Over storeys	15	28.8	30.5	27.3	30.5	0.9	28.5	29.9	26.7	29.9	0.9
Main construction material											
Brick	8	28.4	29.7	27.2	29.7	0.9	28.6	30.0	26.8	30.0	1.2
Silicate brick	5	29.7	30.3	28.9	30.3	0.6	29.5	30.0	28.8	30.0	0.5
Concrete block	3	27.9	29.1	26.7	29.1	1.2	27.4	28.0	26.7	28.0	0.9
Prefabricated	3	29.1	29.4	28.4	29.4	0.6	30.0	30.9	29.5	30.9	0.8
Hollow brick	24	28.6	30.5	26.7	30.2	1.0	28.5	29.9	26.7	29.7	0.8
Block and insulation	2	27.6	27.8	27.3	27.8	0.4	27.9	29.1	26.7	29.1	1.7
Hollow brick and insulation	4	28.1	30.3	25.8	30.3	1.8	28.4	29.7	27.0	29.7	1.4
Number of bedrooms											
1 bedroom	12	29.0	30.1	27.8	30.1	0.7	29.0	30.0	27.8	30.0	0.8
2 bedrooms	24	28.7	30.5	25.8	30.3	1.2	28.7	30.0	26.7	30.0	1.0
3 bedrooms	9	28.2	29.9	26.7	29.9	1.0	28.6	30.9	26.7	30.9	1.5
4 bedrooms	2	27.3	27.9	26.7	27.9	0.8	27.4	27.8	27.0	27.8	0.6
More than 4 bedrooms	2	28.5	29.7	27.2	29.7	1.8	27.8	27.8	27.8	27.8	.
Household size											
1	2	30.1	30.3	29.8	30.3	0.4	29.3	29.7	28.8	29.7	0.6
2	7	28.4	29.3	27.7	29.3	0.6	28.7	30.0	27.8	30.0	1.0
3	13	28.4	30.1	26.7	30.1	1.0	28.6	30.9	26.7	30.9	1.3
4	14	28.7	30.3	26.7	30.3	1.1	28.5	29.9	26.7	29.9	1.2
5	11	28.4	30.5	25.8	30.5	1.4	28.7	30.0	27.3	30.0	1.0
6	1	29.1	29.1	29.1	29.1	.	.	.	.	.	.
7	1	29.6	29.6	29.6	29.6	.	28.6	28.6	28.6	28.6	.

5.4. Temperature variations in living rooms and bedrooms over the winter

The winter field study involved the monitoring of the indoor temperature of 45 living rooms and 42 main bedrooms from January 5 to February 16, 2016, at half-hourly intervals, to cover the coldest season of the year in the Albanian climate.

However, all data has been statistically explored for normality, and it has gone through a process of cleaning. Because the minimum temperature registered in January 2017 in Tirana was -5.5°C and the most common external temperature for Tirana has been -3°C , only data points that have registered temperatures above -3°C are selected for statistical analysis (4063 out of 4095 cases). This has left an independent variable with normally distributed data. The mean difference is statistically tested using a One-sample T-test, and it is found that there is not a statistically significant difference (sig. 2-tailed = 0.6) between the mean external temperatures before and after this case filter (mean difference = 0.19). Therefore, the modified dataset will not affect the results of further testing. The table shows the result of the test. In addition, all variables have been cleaned from extreme values and a non-significant difference has been found in means before and after cleaning.

5.4.1. Temperature distribution in living rooms and bedrooms over the winter

The outdoor temperature ranged between -5.5°C to 18.5°C , while the indoor temperature ranged from -6°C to 29.5°C in living rooms and -5.5°C to 29.5°C in bedrooms. Figure 24 gives the actual indoor temperatures for living rooms and bedrooms during the monitoring time. For most of the dwellings, the indoor temperature is below the recommended temperatures from the guidelines (22°C to 23°C) (CIBSE, 2006) for living rooms and (17 to 19°C) for bedrooms. Out of the dwellings monitored, 19 out of 45 did not reach temperatures 22 degrees or above. Almost the same situation is happening in bedrooms. Elevated temperature variations are observed. However, only 11 dwellings did not reach the comfort temperature guidelines of 17 to 19°C . Some of the dwellings have registered temperatures close to the outdoor temperature, meaning that they have little or no heating at all and windows could be left open during the day.

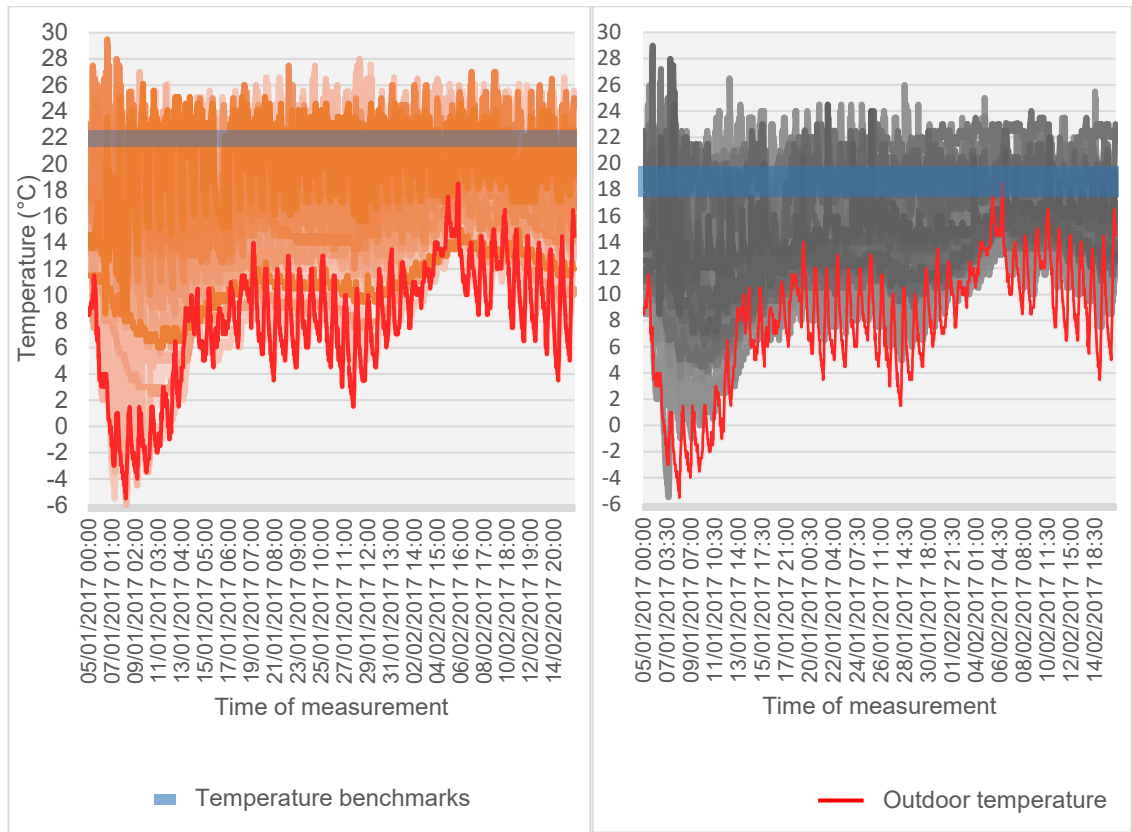


Figure 24: Measured temperatures in living rooms (left) and bedrooms (right) during the winter.

Figure 25 shows the boxplots of temperature distribution of the recorded indoor temperature for both living rooms and bedrooms after cleaning the data from extreme outliers. Overall, the indoor temperatures in living rooms are higher than in bedrooms, with a mean temperature of 15.6°C compared to 13.5°C of mean temperature in the bedrooms. However, there have been dwellings, like H17, where the indoor temperatures in bedrooms have been higher than in the living room.

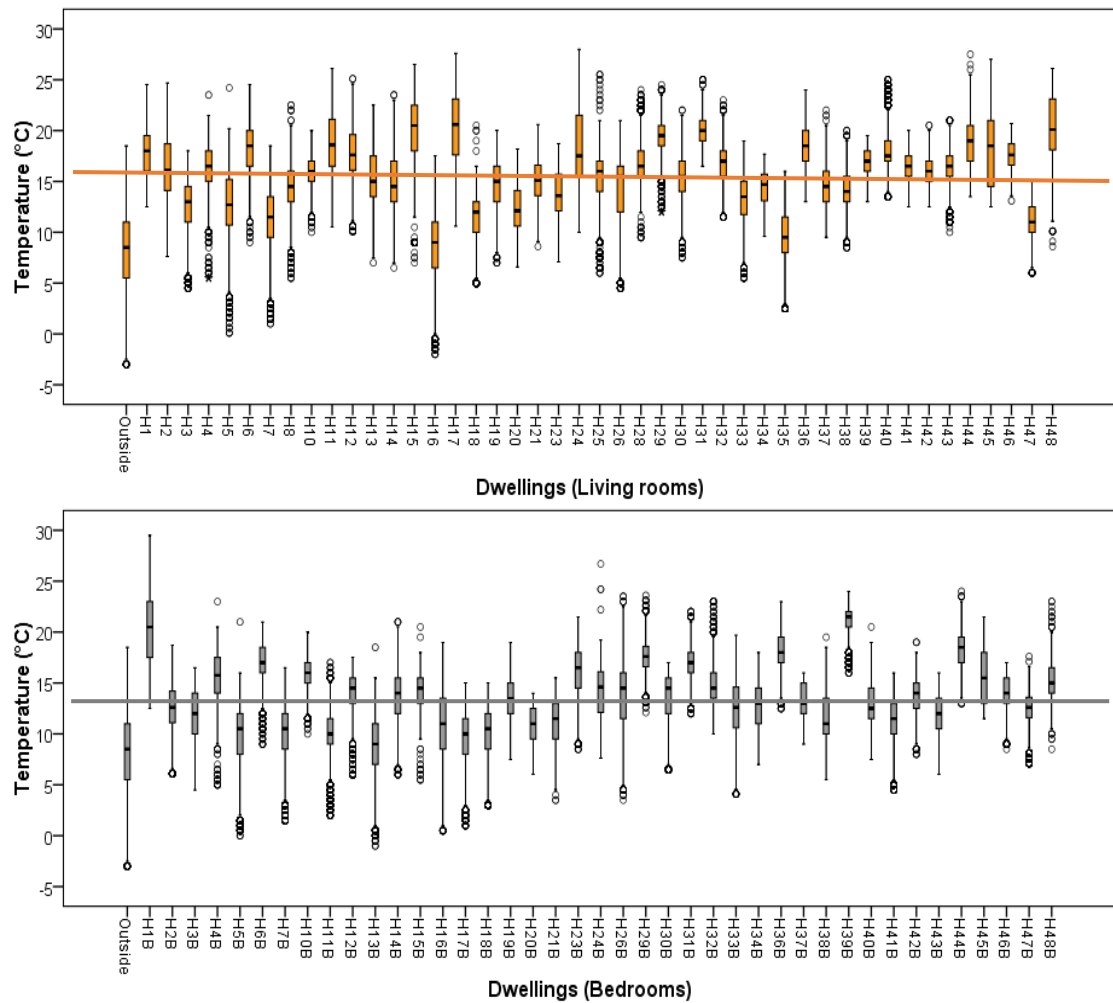


Figure 25: Boxplots of measured temperatures in monitored living rooms (top) and bedrooms (bottom) after cleaning from extreme outliers, with the line showing the mean temperature of all dwellings in living rooms and bedrooms respectively.

A descriptive analysis of indoor temperatures in living rooms and bedrooms during the winter is given in Table 24. A very high temperature variation can be noticed in living rooms; from 6.5 degrees (H39) to 24 degrees (H5), indicating a big problem in keeping adequate thermal comfort in Albanian homes in winter. Moreover, indoor temperatures as low as -2.0 have been recorded in dwelling H16.

Table 24: Descriptive analysis of indoor temperatures in living rooms and bedrooms during the winter

a	Living rooms				Bedrooms			
	Mean	Max	Min	SD	Mean	Max	Min	SD
Outside	8.0	18.5	-3.0	4.4	8.0	18.5	-3.0	4.4
H1	18.0	24.5	12.5	2.6	20.3	29.5	12.5	3.9
H2	16.2	24.7	7.6	3.1	12.3	18.7	6.1	2.7
H3	12.4	18.0	4.5	3.1	11.5	16.5	4.5	2.9
H4	16.3	23.5	5.5	2.6	15.5	23.0	5.0	2.6
H5	12.6	24.2	.1	3.7	9.6	21.0	.0	3.4
H6	18.0	24.5	9.0	2.5	16.8	21.0	9.0	2.2
H7	11.0	18.5	1.0	3.6	9.9	16.5	1.5	3.2
H8	14.3	22.5	5.5	2.6	.	.	.	.
H9	.	.	.	.	.	.	.	.
H10	15.7	20.0	10.0	1.7	15.7	20.0	10.0	1.7
H11	18.7	26.1	10.5	3.2	9.8	17.0	2.0	3.0
H12	17.8	25.1	10.1	2.6	14.0	17.5	6.0	2.3
H13	15.4	22.5	7.0	2.8	8.6	18.5	-1.0	3.4
H14	15.1	23.5	6.5	3.0	13.7	21.0	6.0	2.8
H15	19.9	26.5	7.0	3.4	14.1	20.5	5.5	1.8
H16	8.4	17.5	-2.0	4.0	10.7	19.0	.5	3.7
H17	20.1	27.6	10.6	3.4	9.3	15.0	1.0	3.2
H18	11.2	20.5	5.0	2.7	9.7	15.0	3.0	3.0
H19	14.8	20.0	7.0	2.6	13.3	19.0	7.5	2.4
H20	12.0	18.2	6.6	2.4	10.8	14.0	6.0	2.1
H21	15.1	20.6	8.6	2.1	10.8	15.5	3.5	2.7
H22	.	.	.	.	.	.	.	.
H23	13.4	18.7	7.1	2.5	16.1	21.5	8.5	2.4
H24	18.5	28.0	10.0	3.7	13.8	26.7	7.6	2.6
H25	15.2	25.5	6.0	2.9	.	.	.	.
H26	14.1	21.0	4.5	4.2	13.7	23.5	3.5	3.8
H27	.	.	.	.	.	.	.	.
H28	16.8	24.0	9.5	2.5	.	.	.	.
H29	19.3	24.5	12.0	2.0	17.6	23.6	12.1	1.7
H30	15.5	22.0	7.5	2.6	13.4	17.0	6.5	2.8
H31	20.1	25.0	16.5	1.3	16.7	22.0	12.0	1.7
H32	16.7	23.0	11.5	2.0	14.8	23.0	10.0	2.1
H33	13.0	19.0	5.5	2.7	12.1	19.7	4.1	3.1
H34	14.2	17.7	9.6	1.7	12.6	18.0	7.0	2.4
H35	9.3	16.0	2.5	3.0	.	.	.	.
H36	18.5	24.0	13.0	2.1	18.1	23.0	12.5	1.9
H37	14.4	22.0	9.5	1.9	13.2	16.0	9.0	1.9
H38	14.0	20.0	8.5	2.0	11.1	19.5	5.5	2.4
H39	16.8	19.5	13.0	1.5	21.1	24.0	16.0	1.5
H40	18.3	25.0	13.5	2.1	12.7	20.5	7.5	2.2
H41	16.4	20.0	12.5	1.5	11.2	16.0	4.5	2.6
H42	15.9	20.5	12.5	1.2	13.6	19.0	8.0	2.1
H43	16.4	21.0	10.0	1.8	11.8	16.0	6.0	2.3
H44	18.8	27.5	13.5	2.4	18.2	24.0	13.0	2.0
H45	18.3	27.0	12.5	3.6	15.6	21.5	11.5	2.6
H46	17.4	20.7	13.1	1.5	13.9	17.0	8.5	1.9
H47	10.9	15.0	6.0	2.1	12.5	17.6	7.1	2.0
H48	20.2	26.1	8.6	3.0	15.0	23.0	8.5	1.7
H49	.	.	.	.	.	.	.	.

To further investigate the temperature distribution of indoor temperatures during the winter, the time that each temperature zone has occurred has been calculated, as given in Figure 26. Only five dwellings have had indoor temperatures within the recommended levels for more than 10% of the monitoring time while very rarely have the temperatures have been over 23°C.

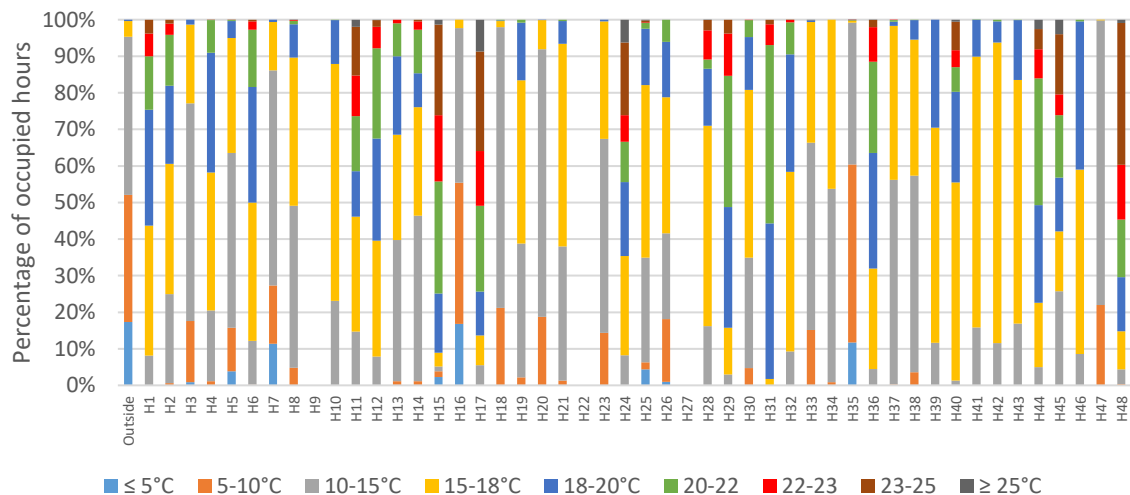


Figure 26: Temperature range during occupied hours in living rooms during the summer

Bedrooms were mainly unheated at all. In some of the dwellings, internal doors of the bedrooms that had direct access to living rooms were kept open to circulate the air. However, most of the time it was localised heating.

“We can’t afford to keep the electric oil-filled radiator on all the time. So, we switch it on only when it is very cold and we cover it with a blanket, so we heat up quickly.”

Most households turned the heating off as soon as the occupants achieved a temporary thermal comfort, to save energy. One resident said:

“We simply cannot afford to keep the air conditioning on all the time.”

However, there were high heat losses through infiltration and the building fabric. One resident stated:

“It is unbelievable how slowly this room heats up and how quickly cools down as soon as we switch the heating off.”

5.4.2. Daily and hourly profiles of indoor temperatures in living rooms and bedrooms during the winter

Similar to summer analysis, the mean temperature is also calculated for each day of monitoring for each room to investigate the projection of temperatures over time, during the occupied hours for living rooms (07:00 to 23:00) and bedrooms (23:00 to 07:00).

2016 readings are plotted for each living room and bedroom against the mean daily outside temperature.

The graph in Figure 27 shows that daily mean indoor temperatures in bedrooms are more sensitive to the external temperature, meaning that a considerable part of dwellings heat for small periods or do the bedrooms are not heated at all. Generally, the indoor temperatures are lower in bedrooms. Although most of the living rooms are heated to some extent, it is interesting that some dwellings show mean daily indoor temperatures close to the external one, indicating that there is a strong possibility that the living rooms in these dwellings are not heated.

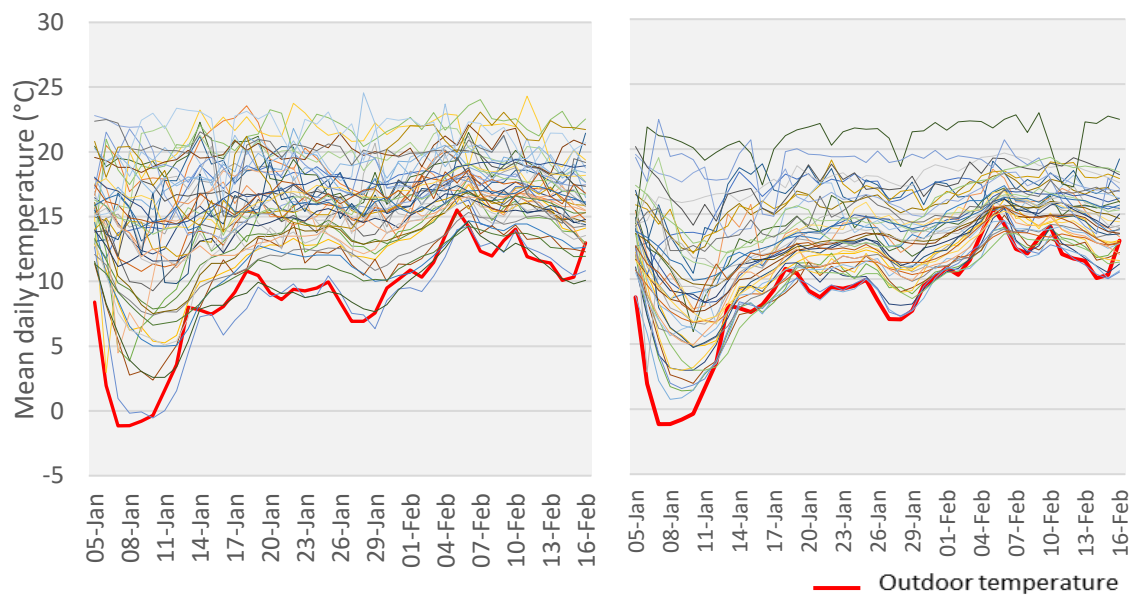


Figure 27: Mean daily temperatures in living rooms (left) and bedrooms (right) during the occupancy hours in winter.

To investigate the temperature profile during the day, the mean hourly temperatures for living rooms and bedrooms are calculated and shown in Figure 28. It can be noticed that most living rooms are heated in the evening, while there is a more constant temperature during the day in bedrooms. However, hourly profiles that have very low temperatures during the day are present, as well as profiles with temperatures over 20°C. This indicates the large variation of hourly profiles in Albanian dwellings as a result not only of different building properties but also as a result of different behaviours within the household.

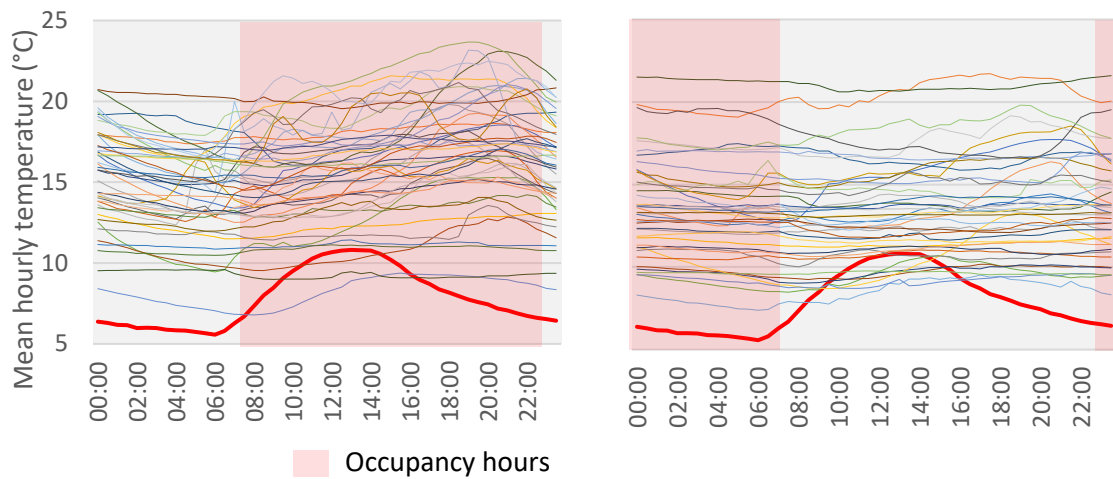


Figure 28: Mean hourly temperatures in living rooms and bedrooms during the winter.

5.4.3. The indoor temperature in living rooms and bedrooms by dwelling characteristics during the summer

An overall picture of the indoor temperatures by various dwelling characteristics is given in Table 25. The semi-detached house is the coldest of all the typologies and flats have the highest indoor mean temperatures during the winter. Interestingly, the lowest mean temperature is in the dwellings built after 1991. There was one dwelling with more than four rooms and, reasonably, it had the lowest mean temperatures in the analysis conducted by the number of rooms. The mean temperatures were relatively higher for larger household sizes (due to more incidental heat gains). More importantly, the dwellings that had applied wall insulation had higher indoor mean temperatures, which highlights the need for fabric improvement to improve thermal comfort in Albanian homes.

Table 25: Indoor temperature by dwelling characteristics

	Living room						Bedroom				
	n	Mean	Max	Min	95%	SD	Mean	Max	Min	95%	SD
Type of the house											
Detached	16	15.5	20.1	8.2	20.1	3.3	13.0	20.5	8.5	20.5	3.7
Semi-detached	1	11.1	11.1	11.1	11.1	.	9.7	9.7	9.7	9.7	.
Terraced	2	13.4	14.7	12.0	14.7	1.9	12.0	13.3	10.7	13.3	1.8
Flat	26	16.0	20.1	9.3	20.1	2.7	14.3	21.1	10.7	18.2	2.7
Year of construction											
Pre-1990	14	15.3	20.1	13.4	19.6	1.8	14.1	20.5	10.7	18.3	2.9
Post-1991	31	15.5	20.1	8.2	20.1	3.2	13.3	21.1	8.5	18.5	3.2
Number of storeys											
1-storey	8	14.3	18.7	8.2	18.7	3.6	12.0	18.5	8.5	18.5	3.6
2- storeys	9	15.3	20.1	11.1	20.1	3.4	12.7	20.5	9.2	20.5	3.6
3- storeys	3	16.1	18.0	14.7	18.0	1.7	15.2	16.7	13.3	16.7	1.7
4-5 storeys	11	16.2	20.1	13.0	20.1	2.3	14.2	17.6	11.7	17.6	2.1
Over storeys	14	15.9	20.1	9.3	20.1	3.1	14.5	21.1	11.1	21.1	3.0
Main construction material											
Brick	6	14.9	18.0	11.1	18.0	2.5	14.0	20.5	9.7	20.5	4.4
Silicate brick	5	16.9	20.1	13.0	20.1	2.9	14.9	17.6	12.0	17.6	2.3
Concrete block	3	15.4	17.7	12.4	17.7	2.7	13.0	15.5	9.4	15.5	3.2
Prefabricated	3	15.6	18.4	14.0	18.4	2.4	13.6	13.7	13.5	13.7	.1
Hollow brick	23	15.0	20.1	8.2	18.9	3.2	13.0	21.1	8.5	18.2	3.2
Block and insulation	2	17.3	19.5	15.1	19.5	3.1	16.1	18.5	13.7	18.5	3.4
Hollow brick and insulation	3	18.9	20.1	18.0	20.1	1.1	13.8	16.7	9.7	16.7	3.7
How many bedrooms?											
1 bedroom	11	16.3	20.1	9.3	20.1	3.0	15.2	20.5	11.1	20.5	3.2
2 bedrooms	22	15.4	20.1	8.2	20.1	3.2	12.8	21.1	8.5	18.1	3.1
3 bedrooms	9	15.4	19.5	10.8	19.5	2.7	13.7	18.5	9.4	18.5	2.8
4 bedrooms	2	15.2	18.0	12.3	18.0	4.0	14.1	16.7	11.5	16.7	3.7
More than 4 bedrooms	1	14.2	14.2	14.2	14.2	.	.	.	.	.	.
Household size											
1	1	16.6	16.6	16.6	16.6	.	14.9	14.9	14.9	14.9	.
2	6	15.5	18.0	14.0	18.0	1.5	13.3	20.5	10.7	20.5	3.7
3	13	15.6	20.1	8.2	20.1	4.2	13.9	18.2	9.7	18.2	3.1
4	13	15.2	20.1	10.8	20.1	2.9	13.2	18.5	8.5	18.5	2.7
5	10	16.0	18.7	13.4	18.7	1.9	14.7	21.1	9.7	21.1	3.4
6	1	12.4	12.4	12.4	12.4	.	9.4	9.4	9.4	9.4	.
7	1	20.1	20.1	20.1	20.1	.	9.2	9.2	9.2	9.2	.

5.5. Thermal comfort in summer and winter

Subjective evaluation of the thermal environment is provided for both winter and summer using a seven-point ASHREA scale for the thermal sensation evaluation and a five-point scale for thermal preference. The results are illustrated in Figure 29, followed by a descriptive analysis in Table 26. In winter, 75% of the households reported feeling colder than neutral during the winter, while 39% were feeling cold ($T_{\text{mean}}=14.4^{\circ}\text{C}$). Nearly half of them (49%) preferred to feel much warmer and 37% preferred a bit warmer. Only 12% of the participants were feeling neutral ($T_{\text{mean}}=16.4^{\circ}\text{C}$) during the winter and 4% preferred no change in temperatures. Similarly, 86% of the households reported feeling warmer than neutral during the summer, from which more than 40% of them were feeling hot ($T_{\text{mean}}=29.1^{\circ}\text{C}$). Interestingly, although 10% felt neutral ($T_{\text{mean}}=27.1^{\circ}\text{C}$) and 4% felt slightly cool ($T_{\text{mean}}=25.8^{\circ}\text{C}$), only 6% of the households required no change. Approximately 60% wanted to feel much cooler. A very strong negative correlation has been found between thermal sensation and thermal preference votes for both winter ($p=-0.8$) and summer ($p=-0.9$).

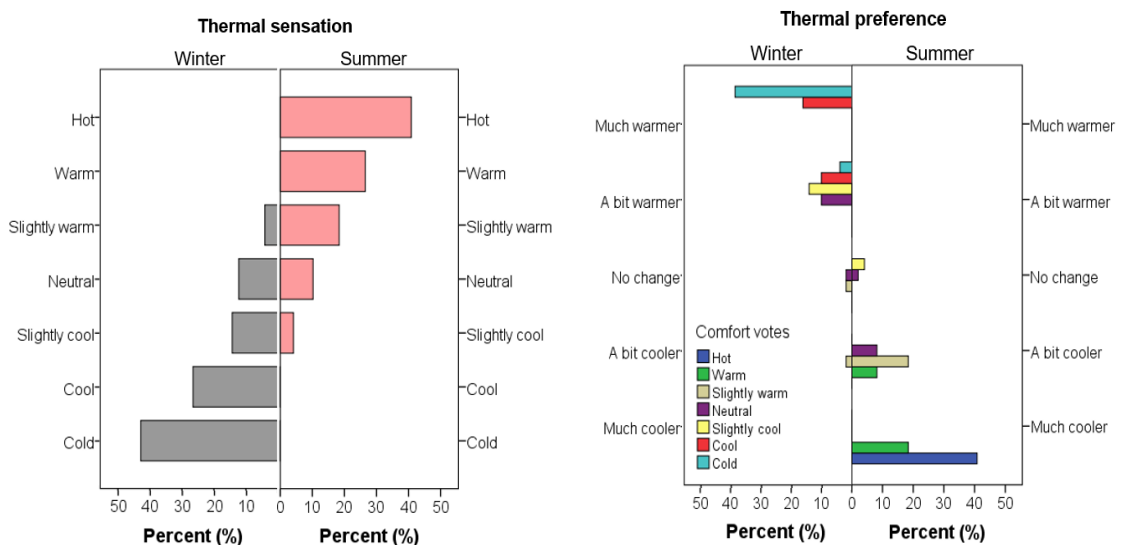


Figure 29: Thermal sensation votes in winter and summer (left) and thermal preference votes in winter and summer (right).

Table 26: Descriptive analysis of indoor temperatures in winter and summer for each comfort vote

Comfort votes		Temperature - Winter				Temperature - Summer			
ASHRAE Scale	N	Mean	Min	Max		N	Mean	Min	Max
Hot	3 0	-	-	-		20	29.1	27.4	31.7
Warm	2 0	-	-	-		13	28.2	27.2	30.2
Slightly warm	1 2	18.5	18.0	18.9		9	27.6	26.5	28.7
Neutral	0 6	16.4	11.0	18.3		5	27.1	25.7	28.2
Slightly cool	-1 7	16.0	12.0	19.5		2	25.8	25.4	26.2
Cool	-2 11	16.4	14.5	19.2		0	-	-	-
Cold	-3 19	14.4	7.5	18.2		0	-	-	-

Indoor temperature was also recorded at the same time as the response was taken. The graph in Figure 30 shows a comfort vote distribution correlated to the measured temperature in winter and summer respectively.

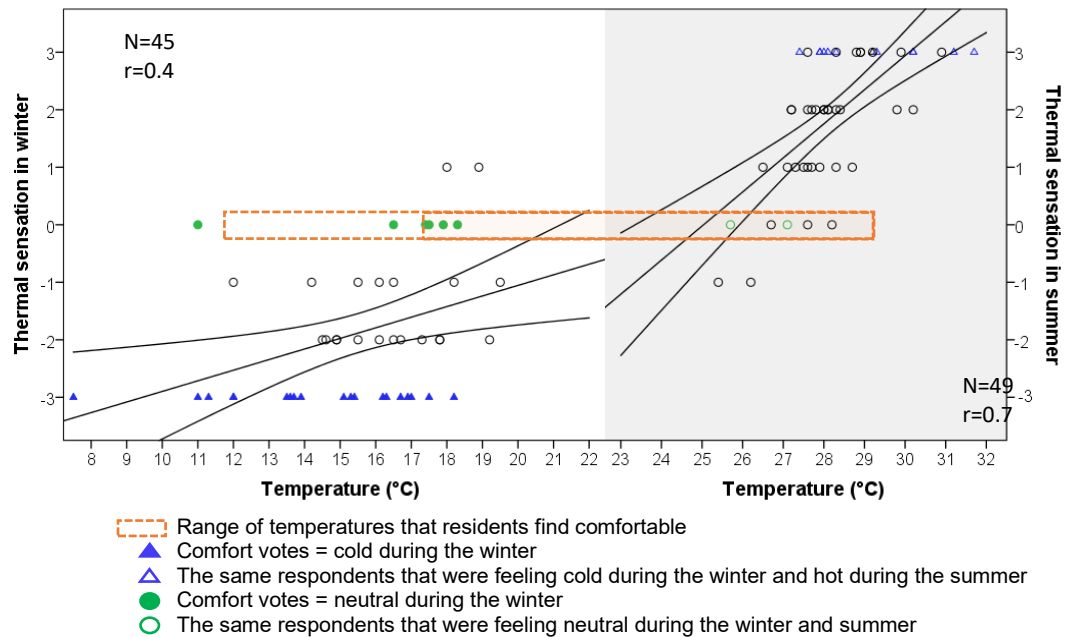


Figure 30: Thermal comfort votes in winter (left) and summer (right) with the line of the best fit line at 95% confidence of the mean.

Line of the best fit, together with the 95% interval of confidence of the means is also produced to check the regression of the association which is equal to 0.4 and 0.7 for winter and summer respectively. There is a higher temperature variance during the winter, as seen in Figure 31, which allows the comfort votes to be in a wider range. Moreover, there have been more adaptive options during the winter (several layers of clothing, blankets, localised heating, hot water bottles, etc) compared to summer. Only two respondents were feeling neutral for both winter and summer, while 60% of the respondents felt cold in winter (the lowest comfort vote) and were feeling hot in summer (the highest comfort vote). Furthermore, the temperature range where the occupants are feeling neutral is between 11°C to 28°C. However, the lower end is more probably to be close to 16°C, removing the outlier at 11°C. Moreover, all the other comfort votes during the winter are close to 16 to 8°C.

Running mean daily temperature has been calculated for summer and winter in Figure 31, to smooth out short-term fluctuations and highlight long-term trends. It is noticeable that the temperature range in summer is up to 8°C, while in winter it reaches 20°C.

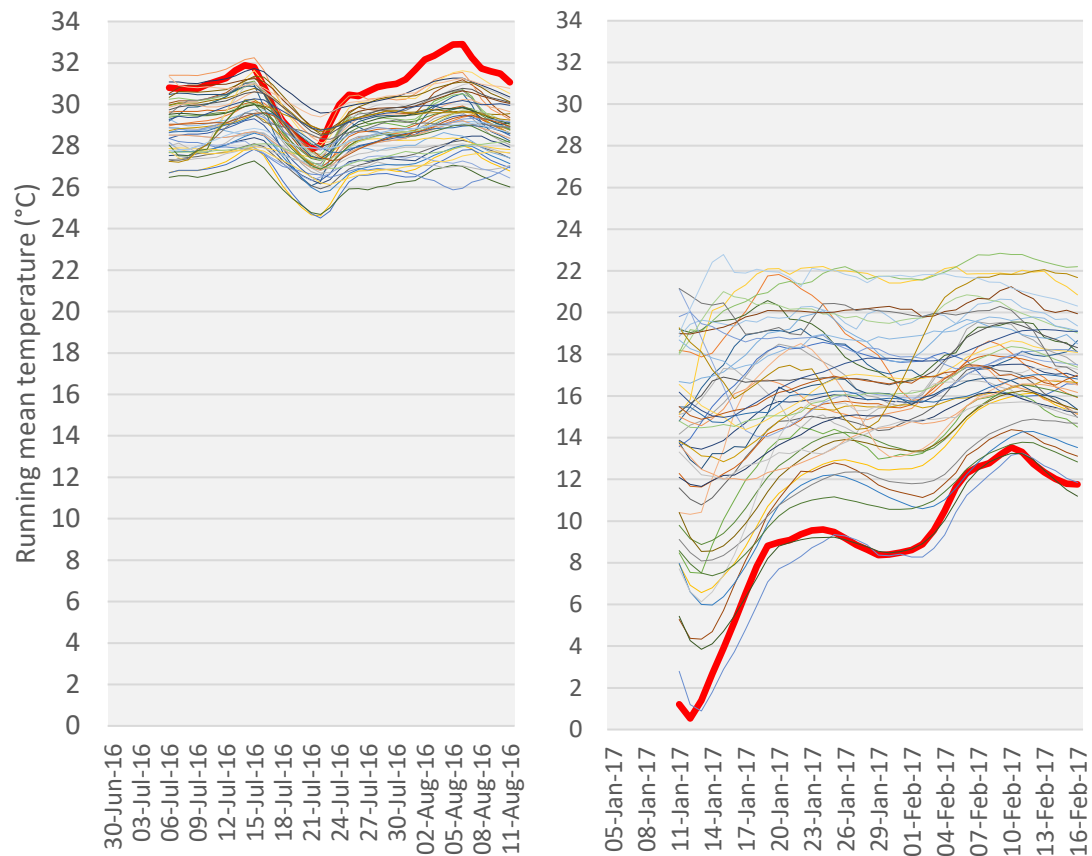


Figure 31: Running mean daily temperatures in living rooms in summer (left) and winter (right) during the occupancy hours.

In addition, a very strong correlation is found between thermal sensation votes and overall comfort in summer ($p=0.9$) and winter ($p=0.8$) respectively. From the crosstabulation of the thermal sensation votes and the overall comfort in summer and winter given in Table 27, predictably, occupants in 30 dwellings in which they were feeling hot and warm, reported having a relatively uncomfortable or uncomfortable overall comfort in summer. The two dwellings in which the occupants were feeling slightly cool had a high rate of overall comfort in summer. Moreover, for most of the occupants that were feeling slightly warm, the overall comfort in summer was acceptable. On the other hand, most of the occupants that were feeling cold during the winter found the overall comfort uncomfortable. Interestingly, the overall comfort was acceptable for most of the occupants that were feeling slightly cool.

Table 27: Crosstabulation of thermal sensation votes and overall comfort during the winter and summer

Overall comfort in summer	Thermal sensation votes in winter							Thermal sensation votes in summer						
	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Uncomfortable	0	0	0	0	0	0	14	14	1	0	0	0	0	0
Relatively uncomfortable	0	0	0	1	0	7	4	5	10	0	0	0	0	0
Slightly uncomfortable	0	0	0	0	1	4	0	1	1	1	0	0	0	0
Acceptable	0	0	0	5	5	0	1	0	1	7	5	0	0	0
Slightly comfortable	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Relatively comfortable	0	0	1	0	1	0	0	0	0	1	0	2	0	0
Comfortable	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.5.1. Determinants of thermal sensation in summer and winter

Because indoor temperatures are found to be influenced by a range of factors including regional climate, social practices, etc, the determinants of indoor temperatures will reflect the local contextual drivers (Hamilton *et al.*, 2017). On the other hand, indoor temperatures influence energy consumption and thermal comfort in homes. Hierarchical multiple regressions have been performed using three sets of variables in blocks, to assess terms of what they add to the prediction of thermal comfort in summer and winter respectively:

Block 1: Building-related factors

- Presence of double glazing
- Presence of wall insulation
- Archetype
- Main construction materials

Block 2: Temperature-related factors

- Instant indoor temperature
- Average temperature (winter and summer respectively)

Block 3: Heating/cooling-related factors

- Main heating/cooling type
- Heating/cooling during the night

The results are given in Table 28. The overall model would explain 26% and 20% of the variance for winter and summer respectively after the variables in Block 1 have been entered. However, because the sample is small, the Adjuster R Squared coefficient will be used for this analysis. Therefore, 18% and 13% of the variance for winter and summer thermal sensation votes are explained respectively by the model after variables in Block 1 have been entered. After Block 2 variables have also been included, the whole model explains 30% and 49% of the variance for winter and summer thermal sensation votes respectively. Adding the Block 3 variables has decreased the degree of explanation of variance for winter thermal sensation votes to 26%, while it has increased it for summer to 54%. The final adjuster R-value includes all the variables from the three blocks.

Table 28: Model summary of hierarchical multiple regression of three variables groups in winter and summer

	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
						R Square Change	F Change	df1	df2	Sig. F Change
Model summary winter	1	.506 ^a	.256	.181	1.118	.256	3.435	4	40	.017
	2	.629 ^b	.395	.300	1.034	.140	4.383	2	38	.019
	3	.630 ^c	.397	.263	1.061	.002	.065	2	36	.938
Model summary summer	1	.445 ^a	.198	.125	1.101	.198	2.709	4	44	.042
	2	.743 ^b	.553	.489	.842	.355	16.657	2	42	.000
	3	.783 ^c	.613	.536	.802	.061	3.137	2	40	.054

a. Predictors: (Constant), Block 1

b. Predictors: (Constant), Block 1 + Block 2

c. Predictors: (Constant), Block 1 +Block 2 + Block 3

d. Dependent Variable: Thermal sensation in winter

e. Dependent Variable: Thermal sensation in summer

R Square Change gives the additional effect of each group of variables after the effect of previous ones has been removed. It is noticed that Group 2 of variables (temperature related) explains an additional 14% and 36% of the variance in thermal sensation votes in winter and summer respectively, even when the effects of building-related factors (Group 1) are statistically controlled for. In addition, there is a statistically significant contribution of Group 1 (Sig. F Change=0.017 and 0.042) and Group 2 (Sig. F Change=0.019 and 0.000) for winter and summer respectively. However, Group 3 of variables (heating/cooling related factors) have less than a 10% contribution, which is non-statistically significant for both winter and summer.

However, the ANOVA analysis (Table 29) indicates that the model as a whole, including all blocks of variables, is significant ($F(3.3, 1.125) = 2.967, p<0.05$) and ($F(5.1, 0.643) = 7.927, p<0.001$) for winter and summer thermal sensation votes respectively.

Table 29: Model summary of ANOVA of three variables groups in winter and summer

	Model		Sum of Squares	df	Mean Square	F	Sig.
ANOVA winter ^a	1	Regression	17.180	4	4.295	3.435	.017 ^b
		Residual	50.020	40	1.250		
		Total	67.200	44			
	2	Regression	26.556	6	4.426	4.138	.003 ^c
		Residual	40.644	38	1.070		
		Total	67.200	44			
	3	Regression	26.701	8	3.338	2.967	.012 ^d
		Residual	40.499	36	1.125		
		Total	67.200	44			
ANOVA summer ^{aa}	1	Regression	13.140	4	3.285	2.709	.042 ^b
		Residual	53.350	44	1.212		
		Total	66.490	48			
	2	Regression	36.738	6	6.123	8.644	.000 ^c
		Residual	29.751	42	.708		
		Total	66.490	48			
	3	Regression	40.773	8	5.097	7.927	.000 ^d
		Residual	25.717	40	.643		
		Total	66.490	48			

a. Dependent Variable: Thermal sensation in winter

aa. Dependent Variable: Thermal sensation in summer

b. Predictors: (Constant), Block 1

c. Predictors: (Constant), Block 1 + Block 2

d. Predictors: (Constant), Block 1 + Block 2 + Block 3

Notwithstanding that the model using the three blocks of variables has been successful in explaining 26% and 54% of the variance in winter and summer respectively, there is a large share of the variance that this model is not able to explain. Other contextual factors and/or thermal preferences related to cultural norms and practices, as well as different adaptive actions, could affect thermal sensation during both winter and summer.

In the Albanian context, practices related to cultural norms for some families, especially those who live in detached houses with personal gates (where security issues are not a concern), to leave the door open for visitors and show them their hospitality, could affect the thermal sensation votes. In one dwelling a carpet was placed that prevented the door from closing (Figure 32).



Figure 32: *The use of carpet to keep the door open at all times; summer (left) and winter (right)*

Another resident living in a flat said that she kept the outside door of her flat open to provide cross ventilation in the flat. In this case, the apartment block's stairs hall served as a chimney for air movement and circulation. Opening the window was also considered an adaptive behaviour, even though the thermal preferences were very different within some of the households. One female participant said:

"I want fresh air all the time and keep the windows open all day in summer and mostly in winter. I don't care what my husband thinks or feels. He can get a blanket."

Although the sample is small, it has given some insights into indoor temperatures in different housing typologies and different occupants' behaviours.

5.6. Cluster analysis of indoor temperatures

Notwithstanding that the above analysis gives a detailed analysis of indoor temperatures, it has been difficult to determine implications for modelling energy baseline, including occupancy, heating and cooling patterns, due to the high variability in indoor temperature profiles between monitored dwellings during both summer and winter. On the other hand, partly because of the small sample, results of the simple linear regression analysis that was performed to check the significance of indoor temperature decrease as the external temperatures drop in winter and vice versa in summer for each building type, period of construction and archetypes considered in this study showed non-statistically significant difference ($p > 0.05$) for all variables in both summer and winter. This means that grouping the dwellings by their typology, year of construction, or combining them both in archetypes, would not give the most accurate representative indoor temperature profiles for Albanian dwellings. Therefore, to limit the number and determine the most typical

profiles of indoor temperatures in Albanian dwellings, from the group of all monitored dwellings (49), a hierarchical cluster analysis of the temperature dataset was conducted, which is a multivariate analysis technique, as an exploratory data tool for organizing data into meaningful groups through maximizing the similarity of cases within each cluster (high internal homogeneity) and maximizing dissimilarities between groups (high external heterogeneity) that are not previously known (Pallant, 2013). This means that the dwellings are grouped into clusters based not on the building characteristics, but on the way homes are used, and the indoor temperature profiles of dwellings within the same cluster are as similar as possible to each other. The same method was used by Huebner et al. (2015) in their study of 275 dwellings. Buttita, Turner and Finn (2017) used an approach based on a statistical clustering technique to generate representative UK occupancy profiles based on the amount of time spent at home by all occupants of the same household, resulting in 22 different occupancy profiles on weekdays and 24 on weekends, each assigned with the percentage of households with similar occupancy profiles for each dwelling type characterized by specific characteristics. They used k-means clustering as the main method of their statistical analysis in order to develop occupancy clusters, which is one of the two broad categories in which traditional clustering methods fall (Laskari et al., 2020). The other category is hierarchical clustering, used in this study, which is mainly used to develop clusters from small datasets.

Although the sample size in this research is small ($N=49$) compared to their study, it will still provide an insight into most typical indoor temperature profiles that can be used for modelling the energy consumption of homes in Albania. Moreover, hierarchical clustering is usually used for a small data set and a minimum cluster size of 10 observations shall be considered (Norušis, 2011; Huebner et al., 2015; Laskari et al., 2020). Belaïd, Ranjbar and Massié (2021) have also used Ascending Hierarchical Classification to define French housing stock profiles based on 1400 dwellings representative of the French residential sector aiming to explore the cost-effectiveness of energy efficiency implementation measures in the residential sector.

5.6.1. Cluster analysis in summer

Using the dataset from summer, three clusters have been produced with the membership as shown in Table 30. Clusters for both weekdays and weekends have been created, which do not differ much from each other in terms of membership. However, further analysis is undertaken to statistically evaluate the difference between them.

Table 30: Clusters' membership of the cases for weekdays and weekends in summer

	Weekday			Weekend		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
	H1	H3	H9	H1	H3	H7
	H2	H4	H25	H2	H4	H17
	H5	H6	H26	H5	H6	H25
	H7	H8	H27	H9	H8	H26
	H13	H10	H31	H13	H10	H27
	H14	H11	H32	H19	H11	H31
	H17	H12	H33	H20	H12	H32
	H19	H15	H34	H21	H14	H33
	H20	H16	H46	H22	H15	H34
	H21	H18	H49	H23	H16	H46
	H22	H28		H24	H18	H49
	H23	H38		H29	H28	
	H24	H39		H30	H38	
	H29	H47		H35	H39	
	H30			H36		
	H35			H37		
	H36			H40		
	H37			H41		
	H40			H42		
	H41			H43		
	H42			H44		
	H43			H45		
	H44			H47		
	H45			H48		
	H48					
Frequency	25	14	10	24	14	11

Cluster 1 represents the largest cluster with over half of the sample (49% in weekend clusters), with hourly temperatures around 29°C. Clusters 2 and 3 represent 29% and 20% of the sample (29% and 22% of the sample for weekends) with hourly mean temperatures around 27.5°C and 30°C respectively.

Figure 33 shows the daily and hourly mean temperatures of each cluster for both weekdays and weekends. It can be noticed that all three clusters for both weekdays and weekends have almost the same sensitivity but in different temperature ranges. It also can be noticed that the temperature profiles of weekends are very close to weekdays' ones. From the mean daily temperatures, cluster 3 follows very closely the mean daily external temperature profile, which indicates that these dwellings might have been cooled for small periods or not at all. While cluster 1, which represents most of the dwellings, has mean daily temperatures up to 3°C lower than external ones during the hottest days of the summer. On contrary, cluster 2, which is the second most common cluster in the sample, has temperatures lower than the other two clusters, which indicates the occupants have taken some actions to maintain a cooler indoor temperature than in other cases. Looking at the hourly mean temperatures, the indoor temperatures tend to be lower in the morning for the three clusters and they start to increase in the early

afternoon, reaching a peak in the evening for clusters 1 and 3, and in the late afternoon in cluster 2.

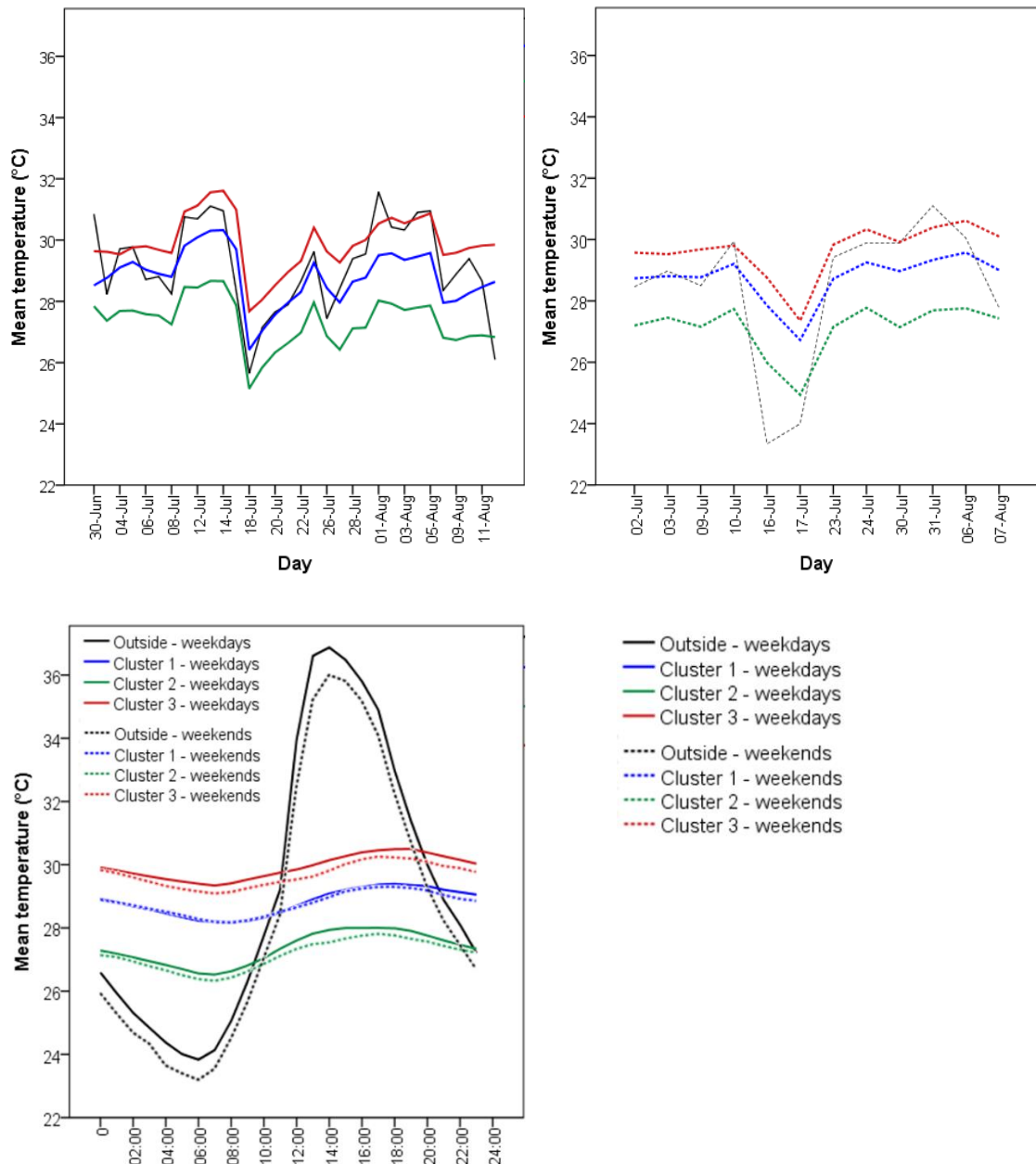


Figure 33: Mean daily temperature for weekdays (top left) and weekends (top right); and mean hourly temperature profiles for both weekdays and weekends (bottom left) of the three clusters, together with external temperature.

Statistical analysis was undertaken to determine whether the three clusters are significantly different from each other, which means that they represent three distinctive temperature profiles. To determine the type of statistical test to use (parametric or non-parametric), the assumption of the equality of variances has been tested using Levene's F-test, as shown in Table 31. The test showed non-homogeneity of variances for weekdays ($F=7.2$ and $p=0.002$) and homogeneity of variances for weekends ($F=1.4$ and

$p=0.270$). Therefore Games-Howell test (non-parametric) and Scheffe tests (parametric) will be used for post-hoc pairwise comparisons on weekdays and weekends respectively.

Table 31: Descriptive analysis of the mean temperature of each cluster based on the mean temperature of each dwelling and Levene's test results

		N	Mean	SD	F	Sig.
Weekdays	Cluster 1	25	28.3	0.4	7.230	.002
	Cluster 2	14	26.8	0.7		
	Cluster 3	10	29.7	0.3		
Weekends	Cluster 1	24	29.3	0.3	1.349	.270
	Cluster 2	14	27.6	0.6		
	Cluster 3	11	30.5	0.4		

Both Games-Howell and Scheffe tests undertaken for pairwise comparison between clusters showed significantly different mean temperatures ($p=0.000$) between clusters for both weekday and weekend profiles.

Considering that the temperature profiles are statistically different from each other, it is interesting to explore the building, household and behavioural characteristics underlying each cluster, to describe and check their association with the clusters. It has been found from previous research that these factors impact energy consumption and indoor temperatures in homes (Kelly *et al.*, 2013; Huebner *et al.*, 2015; Heubner *et al.*, 2016; Hamilton *et al.*, 2017)

Building characteristics

Seven main building-related variables were tested, as shown in Table 32. Each column gives the proportion of households for each value of the variable. Because all the building-related variables were categorical, only a chi-squared analysis has been performed, and the results are given in the table.

Cluster 2 had significantly more detached houses (64.3%) than the other two clusters (28% and 34.7% respectively for clusters 1 and 3). Moreover, the majority of dwellings in cluster 2 have been constructed post-1991, while most of the dwellings constructed pre-1990 form the membership of cluster 3. Based on the building type and period of construction, six clusters have been created for this study. Indeed, the chi-square test showed that the largest share of dwellings in cluster 2 are detached post-1991 dwellings, while cluster 3 has the largest share of flats pre-1990. On the contrary, cluster 1 has a more mixed composition, with the highest proportion of dwellings; flats built post-1991 and an equal share of detached houses post-1991 and flats pre-1990. Terraced houses and the detached pre-1990 houses are also members of cluster 1. This is a very interesting finding as it shows that most of the dwellings (cluster 1 being the largest one), including different archetypes, have middle-range performance. The largest share of

dwellings that have both wall insulation and double glazing is in cluster 2, which had the lowest indoor temperature in mean daily and hourly profiles. Generally, dwellings in cluster 1 are smaller (up to three bedrooms) in size than in the other two clusters. However, approximately half of the dwellings in each cluster have two bedrooms. Finally, most of the dwellings in each cluster are air-conditioned, however, the largest share of air-conditioned dwellings is associated with cluster 3.

Table 32: Chi-squared analysis of building variables between clusters in summer

Clusters				Chi-squared test results			Cramer's V	
Variable	Cluster 1	Cluster 2	Cluster 3	x ²	d.f.	p	Value	Approx. Sig.
Building type								
Detached	28.0%	64.3%	34.7%	13.9	6	0.030	0.38	0.030
Semi-detached	0.0%	7.1%	2.0%					
Terraced	8.0%	0.0%	4.1%					
Flats	64.0%	28.6%	59.2%					
Period of construction								
Pre-1990	32.0%	7.1%	60.0%	7.72	2	0.021	0.40	0.021
Post-1991	68.0%	92.9%	40.0%					
Archetype								
Detached pre-1990	4.0%	0.0%	0.0%	19.1	10	0.040	0.62	0.040
Detached post-1991	24.0%	64.3%	10.0%					
Semi-detached	0.0%	7.1%	0.0%					
Terraced	8.0%	0.0%	0.0%					
Flats pre-1990	24.0%	7.1%	60.0%					
Flats post-1991	40.0%	21.4%	30.0%					
Wall insulation								
No	80.0%	42.9%	80.0%	6.5	2	0.039	0.18	0.457
Yes	20.0%	57.1%	20.0%					
Double glazing								
No	56.0%	21.4%	60.0%	5.2	2	0.06	0.33	0.076
Yes	44.0%	78.6%	40.0%					
Dwelling size								
1 bedroom	32.0%	7.1%	40.0%	12.2	8	0.142		
2 bedroom	48.0%	50.0%	50.0%					
3 bedroom	20.0%	21.4%	0.0%					
4 bedroom	0.0%	14.3%	0.0%					
> 4 bedrooms	0.0%	7.1%	10.0%					
Cooling type								
No cooling	4.0%	7.1%	0.0%	5.6	6	0.465		
Air conditioning	56.0%	57.1%	70.0%					
Electric fans	20.0%	0.0%	20.0%					
Air conditioning + electric fan	20.0%	35.7%	10.0%					

χ^2 – Chi-square value d.f. – the degrees of freedom p – the probability value (the significance level)

Chi-squared test for independence showed a statistically significant association ($p < 0.05$) between clusters and building-related factors, such as building type, period of construction, archetype, and wall insulation. This means that the clusters are dependent

on these clusters. No statistically significant association was found between clusters and the dwelling's size and type of cooling.

Effect size analysis using Cramer's V was performed for building factors that had a statistically significant association with the clusters shown in Table 33. Criteria for determining the effect size are shown in the last three columns of the table. According to (Pallant, 2013), to determine which criteria to use for judging the effect size, whichever R-1 (subtracting 1 from the number of categories in the row) or C-1 (subtracting 1 from the number of categories in the column) is smaller, should be correlated to the values for small, medium or large effect.

Building type, period of construction and archetypes have a statistically significant large effect on the clusters, while wall insulation and double glazing both have a statistically insignificantly small and medium effect respectively.

Table 33: *Cramer's V test results of building variables between clusters in summer*

Information for each variable (Table)					Criteria for effect size		
Variable	R-1	C-1	Cramer's V	Sig	small	medium	large
Building type	3	2	0.38	0.030	0.07	0.21	0.35
Period of construction	1	2	0.40	0.021	0.01	0.30	0.50
Archetype	5	2	0.62	0.040	0.07	0.21	0.35
Wall insulation	1	2	0.18	0.457	0.01	0.30	0.50
Double glazing	1	2	0.33	0.076	0.01	0.30	0.50

R-1: Number of categories in the row – 1

C-1: Number of categories in the column – 1

Socio-demographic factors

Notwithstanding that several studies have shown an association between these factors and energy consumption and temperatures, no significant differences between clusters are found in this sample, as shown in Table 34, using Chi-squared tests for categorical variables. In cluster 3 there is the highest proportion of households with the highest education and single occupancy. Moreover, 70% of households in this cluster have over four members and children. The proportion of households with a retired member is higher in cluster 3 as well.

Table 34: Chi-squared analysis of socio-demographic variables between clusters in summer

Variable	Clusters			Chi-squared test results		
	Cluster 1	Cluster 2	Cluster 3	x ²	d.f.	p
Education level						
Elementary	4.0	0.0	0.0	1.76	4	0.780
High school	32.0	35.7	20.0			
University	64.0	64.3	80.0			
Household size						
1 person	0.0	0.0	20.0	13.64	8	0.092
2 people	24.0	7.1	0.0			
3 people	28.0	35.7	10.0			
4 people	24.0	28.6	40.0			
≥ 5 people	24.0	28.6	30.0			
Presence of children						
No	44.0	35.7	30.0	0.67	2	0.716
Yes	56.0	64.3	70.0			
Presence of the retired person						
No	72.0	85.7	60.0	2.04	2	0.361
Yes	28.0	14.3	40.0			

For continuous variables, one-way ANOVA, with post-hoc tests corrected with Bonferroni, was used to test for differences between clusters. The results are given in Table 35. No statistically significant difference was found in the three clusters' monthly incomes and electricity bills.

Table 35: One-way ANOVA test results of continuous socio-demographic variables between clusters in summer

Variable	Clusters			One-way ANOVA test results		
	Cluster 1	Cluster 2	Cluster 3	F	d.f.	p
Monthly incomes	521.4€	537.0€	500.0€	0.08	2	0.926
Monthly electricity bill	49.2	64.3	51.5	1.59	2	0.216

Occupants' behaviours and thermal factors

Four main variables have been tested, as shown in Table 36. However, Chi-squared tests showed that none of the variables under investigation has a statistically significant association with the clusters. Interestingly, the thermal sensation votes of households have a close association ($p=0.075$) with the clusters being statistically significant. Even though no statistically significant association whatsoever has been found between these factors and the clusters during the summer, Chi-squared tests are useful to describe the clusters relating to these variables. Most of the households for all three clusters were cooled in the afternoon, and afternoon and evening. However, cluster 2 had the largest share of households that cool the space during the night. Not surprisingly, most of the

households in cluster 2 have been feeling hot and wanted to feel much cooler. While the households that had claimed to feel neutral, are in clusters 1 and 2.

Table 36: Chi-squared analysis of occupant behaviours and thermal variables between clusters in summer

	Clusters			Chi-squared Test results		
Variable	Cluster 1	Cluster 2	Cluster 3	χ^2	d.f.	p
When do you cool the house during the day?						
No cooling	4.0	7.1	10.0	5.8	10	0.829
Mid-day	4.0	0.0	0.0			
Afternoon	32.0	35.7	40.0			
Evening	8.0	7.1	0.0			
Afternoon and evening	48.0	28.6	40.0			
All day	4.0	21.3	10.0			
Night cooling						
No	80.0	57.1	80.0	2.7	2	0.262
Yes	20.0	42.9	20.0			
Summer thermal sensation						
Hot	32.0	28.6	80.0	14.3	8	0.075
Warm	28.0	28.6	20.0			
Slightly warm	24.0	21.4	0.0			
Neutral	16.0	7.1	0.0			
Slightly cool	0.0	14.3	0.0			
Summer thermal preference						
Much cooler	48.0	57.1	90.0	7.6	4	0.105
A bit cooler	48.0	28.6	10.0			
No change	4.0	14.3	0.0			

5.6.2. Cluster analysis in winter

Three identical weekdays and weekend clusters were created by the hierarchical cluster analysis performed using the winter indoor temperatures dataset, as shown in Table 37. The same method was followed as per summer cluster analysis. Cluster 2 represents the largest cluster with nearly 45% of the sample and corresponds to the middle range of indoor temperatures around 15°C. Clusters 1 and 3 represent 33% and 22% of the sample respectively.

Table 37: Clusters' membership of the cases for weekdays and weekends in summer

Weekday			Weekend		
Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
H1	H2	H3	H1	H2	H3
H6	H4	H5	H6	H4	H5
H11	H8	H7	H11	H8	H7
H12	H10	H16	H12	H10	H16
H15	H13	H18	H15	H13	H18
H17	H14	H20	H17	H14	H20
H24	H19	H23	H24	H19	H23
H29	H21	H33	H29	H21	H33
H31	H25	H35	H31	H25	H35
H36	H26	H47	H36	H26	H47
H40	H28		H40	H28	
H44	H30		H44	H30	
H45	H32		H45	H32	
H46	H34		H46	H34	
H48	H37		H48	H37	
	H38			H38	
	H39			H39	
	H41			H41	
	H42			H42	
	H43			H43	
15	20	10	15	20	10

Figure 34 shows the daily and hourly mean temperatures of each cluster for both weekdays and weekends. Although both weekdays and weekends have the same membership of dwellings, the profiles are produced using absolute (instantaneous) temperature data, which are different between weekdays and weekends. The daily mean temperatures have been almost within the same range for both weekdays and weekends for each cluster. It can also be noticed that dwellings in cluster 1 have had temperatures above 15 °C during the coldest week of the monitoring time, while dwellings in cluster 3 follow more closely the external temperature profile, indicating that little or no heating at all has been performed in some or all dwellings included in this cluster.

Regarding hourly mean temperatures, the weekdays and weekends profiles have almost the same sensitivity as each other for all three clusters. Cluster 1 is characterised by a higher temperature throughout the day compared with the other two clusters. There is a steep rise in the temperatures at 7 am and they continue to steadily increase until 10 pm. The same is happening for the weekend profile of cluster 1. While in cluster 2, which represents most of the dwellings, there is only a small peak in the morning and, like in cluster 1, the temperatures increase gradually until evening. For the weekends of cluster 2, there is no peak in temperatures in the morning, and the profile is close to the weekday one for the rest of the day. On the contrary, cluster 3 represents the dwellings with the lowest indoor temperatures throughout the day. There is almost a flat line throughout the day for both weekdays and weekends profiles, with a small peak in the evening. This indicates that these dwellings barely heat the space during the winter.

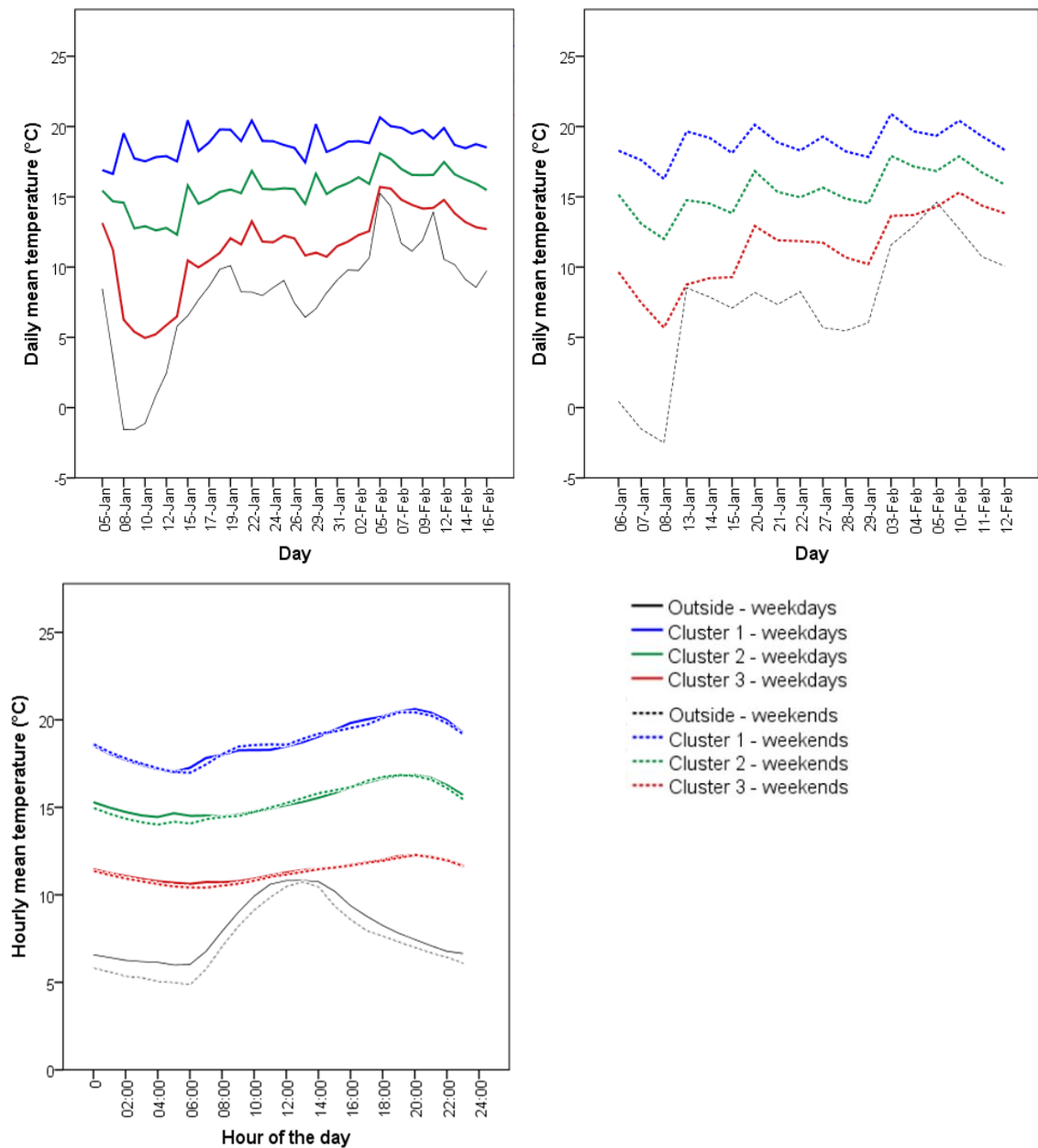


Figure 34: Mean daily temperature for weekdays (top-left) and weekends (top-right); and mean hourly temperature profiles for both weekdays and weekends (bottom-left) of the three clusters, together with external temperature.

To determine the type of statistical test to use (parametric or non-parametric), the assumption of the equality of variances has been tested using Levene's F-test. The test showed homogeneity of variances ($p > 0.05$) for weekdays and weekends ($F = 2.2$ and $p = 0.130$) and ($F = 3.0$ and $p = 0.06$) respectively. Therefore, Scheffe tests have been performed for pairwise comparison between clusters and showed significantly different mean temperatures ($p = 0.000$) between clusters for both weekdays and weekends profiles (See Table 38).

Table 38: Descriptive analysis of the mean temperature of each cluster based on the mean temperature of each dwelling and Levene's test results

		N	Mean	SD	F	Sig.
Weekdays	Cluster 1	15	18.8	1.0	2.146	.130
	Cluster 2	20	15.4	1.0		
	Cluster 3	10	11.4	1.6		
Weekends	Cluster 1	15	18.9	0.9	3.004	.060
	Cluster 2	20	15.6	1.0		
	Cluster 3	10	11.4	1.6		

Considering that the temperature profiles are statistically different from each other, it is interesting to explore the building, households' and behavioural characteristics underlying each cluster, to describe and check their association with the clusters. The same approach as per the summer analysis is followed.

Building characteristics

Chi-squared tests have been performed to describe the difference between clusters for categorical variables, and the results are given in Table 39. Each column gives the proportion of dwellings for each value of the variable. In total, seven building-related factors have been tested.

Detached houses are almost equally spread in the three clusters, while the proportion of flats in clusters 1 and 2 is bigger than cluster 3. On the other hand, semi-detached and terraced houses are members of cluster 3. Again, based on the period of construction, there is a close representation of both periods in all clusters. However, clusters 2 and 3 have the highest proportion of pre-1990 and post-1991 dwellings respectively. Furthermore, cluster 3 has more detached post-1991, compared to clusters 1 and 2, which have more flats post-1991. The highest proportion of dwellings that had wall insulation and double glazing is in cluster 1, followed by cluster 3. It is expected for cluster 1 to have more dwellings with better thermal properties. However, it is interesting that a high proportion of better thermal properties dwellings are associated with cluster 3, in which the indoor temperatures are the lowest. However, the chi-tests have shown no statistically significant association between clusters and thermal properties of the dwellings in winter. Small dwellings are associated more with clusters 1 and 2, while bigger dwellings in cluster 3, in which the indoor temperatures are very low, could be related to the high space volume to heat.

To summarise, the proportion of dwellings for most categories of each tested variable is proportionally spread between three clusters, regardless of the building factors. For this reason, chi-squared tests have not found a statistically significant association between

clusters and each of the tested building factors. This might indicate that there might be other factors that influence the indoor temperatures in dwellings in Albania in winter.

On the other hand, the small sample might have affected the results of the level of association between clusters and building factors.

Table 39: Chi-squared analysis of building variables between clusters in summer

Variable	Clusters			x ²	Test results	
	Cluster 1	Cluster 2	Cluster 3		d.f.	p
Building type						
Detached	40.0	30.0	40.0	5.9	6	0.431
Semi-detached	0.0	0.0	10.0			
Terraced	0.0	5.0	10.0			
Flats	60.0	65.0	40.0			
Period of construction						
Pre-1990	26.7	35.0	20.0	0.8	2	0.676
Post-1991	73.3	65.0	80.0			
Archetype						
Detached pre-1990	6.7	0.0	0.0	8.3	10	0.601
Detached post-1991	33.3	30.0	40.0			
Semi-detached	0.0	0.0	10.0			
Terraced	0.0	5.0	10.0			
Flats pre-1990	20.0	30.0	20.0			
Flats post-1991	40.0	35.0	20.0			
Wall insulation						
No	60.0	75.0	70.0	0.9	2	0.635
Yes	40.0	25.0	30.0			
Double glazing						
No	40.0	50.0	50.0	0.4	2	0.818
Yes	60.0	50.0	50.0			
Dwelling size						
1 bedroom	33.3	30.0	10.0	4.9	8	0.762
2 bedroom	46.7	45.0	60.0			
3 bedroom	13.3	20.0	20.0			
4 bedroom	6.7	0.0	10.0			
> 4 bedrooms	0.0	5.0	0.0			
Heating type						
Heat pumps (conditioning device)	60.0	45.0	50.0	8.1	14	0.883
Electric heater	6.7	15.0	10.0			
Wood stove	13.3	5.0	10.0			
Heat pump and electric heater	0.0	5.0	10.0			
Heat pump and gas heater	6.7	10.0	0.0			
Heat pump and wood stove	6.7	15.0	20.0			
Electric heater and gas stove	6.7	0.0	0.0			
Central heating	0.0	5.0	0.0			

Socio-demographic factors

Chi-squared tests and One-way ANOVA statistical tests were performed to test the association between clusters and socio-demographic factors for categorical and continuous variables respectively (Table 40). Households in all three clusters are almost equally educated. Cluster 2 has the highest proportion of small households of up to two members and big households of more than three members at the same time. The highest proportion of households with children is in cluster 1, with 90% of all households in the cluster's membership. In addition, the association between clusters and the presence of a child in the household has been found to be statistically significant ($p=0.016$). On the contrary, no association was found between clusters and the presence of a retired person in the household. From the occupants' surveys, this was associated with an inability to keep adequate thermal comfort because of economic reasons for these households.

Table 40: Chi-squared analysis of socio-demographic factors between clusters in winter

Variable	Clusters			Chi-squared test results			Cramer's V	
	Cluster 1	Cluster 2	Cluster 3	Value	d.f.	p	Value	Approx. Sig.
Education level								
Elementary	0.0	5.0	0.0	3.8	4	0.428		
High school	33.3	20.0	50.0					
University	66.7	75.00	50.0					
Household size								
1 person	0.0	5.0	0.0	10.8	8	0.216		
2 people	6.7	25.0	0.0					
3 people	46.7	10.0	40.0					
4 people	20.0	30.0	40.0					
≥ 5 people	26.7	30.0	20.0					
Presence of children								
No	10	60.0	26.7	8.3	2	0.016	0.429	0.016
Yes	90	40.0	73.3					
Presence of the retired person								
No	86.7	65.0	90.0	3.4	2	0.179		
Yes	13.3	35.0	10.0					

For continuous variables, one-way ANOVA with post-hoc tests corrected with Bonferroni was used to test for differences between clusters. The results are given in Table 41. As for summer cluster analysis, no statistically significant difference was found in the three clusters in the monthly incomes and electricity bills.

Table 41: One-way ANOVA test results of continuous socio-demographic variables between clusters in winter

Variable	Clusters			One-way ANOVA test results		
	Cluster 1	Cluster 2	Cluster 3	F	d.f.	p
Monthly incomes	520.9€	559.5€	498.0€	0.27	2	0.769
Monthly electricity bill	54.3	56.0	50.0	0.16	2	0.850

Occupants' behaviours and thermal factors

Four main variables have been tested, as shown in Table 42. Chi-squared tests showed that none of the variables under investigation has a statistically significant association with the clusters. However, Chi-squared tests are useful to describe the clusters relating to these variables. Because the association is not significant, this means that there is not a big difference in the proportion of households relating to each variable in different clusters.

Table 42: Chi-squared analysis of occupant behaviours and thermal variables between clusters in summer

Variable	Clusters			x ²	Test results	
	Cluster 1 (%)	Cluster 2 (%)	Cluster 3 (%)		d.f.	p
When do you heat the house during the day?						
Morning	0.0	5.0	0.0	10.7	12	0.548
Mid-day	6.7	0.0	0.0			
Afternoon	13.3	5.0	20.0			
Evening	6.7	25.0	0.0			
Afternoon and evening	13.3	25.0	30.0			
Morning and evening	46.7	25.0	40.0			
All day	13.3	15.0	10.0			
Night heating						
No	86.7	85.0	80.0	0.2	2	0.900
Yes	13.3	15.0	20.0			
Winter thermal sensation						
Slightly warm	6.7	5.0	0.0	8.1	8	0.421
Neutral	20.0	5.0	20.0			
Slightly cool	13.3	10.0	30.0			
Cool	26.7	35.0	0.0			
Cold	33.3	45.0	50.0			
Winter thermal preference						
A bit cooler	6.7	0.0	0.0	3.8	6	0.696
No change	6.7	5.0	0.0			
A bit warmer	26.7	45.0	50.0			
Much warmer	60.0	50.0	50.0			

Cluster 1, which was characterised by a daily profile of high temperatures throughout the day and two peaks in the morning and evening respectively, had most households heating the space in the morning and evening. However, more than half of the households have been turn the heating on at different times during the day, with 13.3% of them keeping the heating on all day. Almost the same situation is in cluster 2. On the contrary, most households in cluster 3 heated their home in the afternoon or later and 40% of them turned the heating on in the morning and evening, while 10% kept the heating on all day. The proportion of households turning the heating on during the night

for all three clusters was 20% or less. Contrary to the summer cluster analysis, the association of how people felt indoors has not been statistically significant with the clusters. This could be interpreted as people adapting more easily in winter, regardless of temperatures. However, an unsurprising result is that the highest proportion of households feeling cold is in cluster 3, where the indoor temperatures are the lowest among the three clusters. The proportion of households that wanted to feel much warmer is the highest in all three clusters.

5.7. Developing Albanian heating and cooling profiles for residential building simulations

Improvement of occupants' presence and action modelling in building simulations is essential to enhance the accuracy of the building energy simulation process (Yan et al., 2015). Domestic occupancy patterns have been developed in households to estimate energy demand and evaluate thermal comfort (Feng, Yan and Hong, 2015; McKenna, Krawczynski and Thomson, 2015; Aragon et al., 2017; Guerra-Santin and Silvester, 2017). Yao and Steemers (2005) claimed in their study that the number of occupants and the length of the period in which the dwelling is occupied are the main factors influencing energy consumption. Yan et al (2015) have also found that occupant-building interaction is affected by arrival, departure, and duration of absence of occupants. Also, other factors may lead to indoor temperature profiles differing from heating demand profiles (Huebner et al., 2015) and having distinct temperature profiles would indicate not only that homes are used in different ways by different occupants, but also could indicate various comfort requirements.

Ben and Steemers (2020) have developed five household archetypes based on the specific behaviours over five factors, including variables on space heating and use of appliances. Their results suggested that using these household archetypes for energy retrofits on the urban scale could save a further 20% of the annual energy costs. Gucyeter (2018) used three different occupancy patterns (Inactive Occupant, the Slightly Active Occupant, and the Active Occupant) to analyse the interaction of the occupants with the building systems in an office building. He found an excessive gain from the unpredicted metabolic heat gains due to occupants' presence, as well as excessive use of lighting. Wei, Jones and de Wilde (2014) investigated the impact of occupant behaviour change on house energy consumption by simulating three types of occupants: active heating user (AHU), the medium heating user (MHU) and passive heating user (PHU), based on the preferred value of the heating setpoint. They concluded that an

energy-efficient behaviour change could be achieved by changing from a more active user type to a more passive user type.

One of the key factors of the performance gap is the choice of the set-points and operation schedules by the building simulation modeller (Carlucci et al., 2020). Firth *et al.* (2010) found through their sensitivity analysis that the predicted energy consumption was varying widely by different input parameters, where one of the determining factors of residential space heating demand was the characteristics and usage patterns of heating systems, including the setpoint temperature and heating duration (Firth, Lomas and Wright, 2010; Hughes et al., 2013; Kane, Firth and Lomas, 2015; Jones et al., 2016; Magalhães, Leal and Horta, 2017). It has been calculated there is an increase in energy consumption of 10% for each degree of indoor temperature in a study undertaken (Tommerup, Rose and Svendsen, 2007) on single-family houses in Denmark. Dadoo, Gustavsson and Tetley (2017) also found that indoor air temperature had a significant influence on the performance of energy efficiency measures. Peng *et al.* (2012) found significant variations in building performance using three classifications of occupant behaviours based on air-conditioning operation schedule, indoor temperature preference, and household loads based on the division type. Bruce-Konuah, Jones and Fuertes (2019) have found that the physical environmental variables, including the indoor and outdoor temperature, indoor relative humidity, and solar radiation, affecting occupants' manual space heating override behaviour during the heating season. They found an average increase in space heating energy consumption of 21.5% and 13.6% on weekdays and weekends respectively. However, there is no standard method to give the heating setpoint for building simulation (Guerra-Santin and Silvester, 2017). Wei *et al.* (2017) argued that using the user's heating activity on energy simulations as active when in reality it is passive, would result in greatly overestimating of the energy saving potential of a retrofitting strategy. Chaney, Hugh Owens and Peacock (2016) and Aragon *et al.* (2017) have also claimed that the focus is on when occupants are active in the house rather than just present. Therefore, improving assumptions made about building operations is a key challenge of recent research (Kavgic et al., 2010; Aragon et al., 2017; Guerra-Santin and Silvester, 2017; Abuimara et al., 2019).

Notwithstanding the high uncertainties, default assumptions on how the homes are heated and cooled, and at what temperatures, have been used for modelling energy consumption of housing stock (Kavgic et al., 2010). Heating temperatures of 21°C have been assumed for modelling housing stock and estimating energy savings from retrofitting strategies in the UK (Anderson et al., 2002). Al-Mumin, Khattab and Sridhar

(2003) found a variation of thermostat setpoints from below 19°C to above 25°C after investigating summer air-conditioning use in residential buildings. Moreover, Peng *et al.* (2012) found that air-conditioning operations in a household varied every day. Default setpoint temperatures of 20°C and 26°C for heating and cooling respectively have been used in a study of energy retrofitting of residential stock in Albania (Novikova *et al.*, 2015). This assumption leads to energy consumption and energy saving estimations that largely differ from the actual ones (Huebner *et al.*, 2015).

Notwithstanding the effect of the heating, setpoint has been largely acknowledged as one of the main factors that affects the interaction between the occupants and the building, yet there is still no standard method to assign the heating setpoint for building simulation (Wei, Jones and de Wilde, 2014). Cluster analysis is one of the statistical analysis methods used in previous studies to determine occupancy and heating profiles (Guerra Santin, Itard and Visscher, 2009; D'Oca and Hong, 2015; Liang, Hong and Shen, 2016; Pan *et al.*, 2017; Laskari *et al.*, 2020), as well as indoor temperature profiles in living rooms (Huebner *et al.*, 2015). Buttitta, Turner and Finn (2017) used an approach based on a statistical clustering technique to generate the representative UK occupancy profiles based on the amount of time spent at home by all the occupants of the same household, resulting in 22 different occupancy profiles during the weekdays, and 24 during the weekend, each assigned with the percentage of households with similar occupancy profiles for each dwelling type characterised by specific characteristics.

Domestic occupancy patterns have been developed in households to estimate energy demand and evaluate thermal comfort (Aragon *et al.*, 2017). However, as in other studies (Chaney, Hugh Owens and Peacock, 2016; Aragon *et al.*, 2017), the focus is on when occupants are active in the house rather than just present. Occupant presence, movement and interaction with building devices and systems are included in occupant behaviour according to Yan *et al.* (2017). The occupants' surveys undertaken with the 49 homeowners in this study showed that just because occupants are at home does not necessarily mean that the heating or cooling has been on. The income level, as well as personal preferences, have been the main factors found in this study, as well as anticipated by Aragon *et al.* (2017) that may affect energy consumption - and not active presence alone. Therefore, in the context of Albanian households, the focus is to determine the heating/cooling profiles, rather than occupancy profiles, for energy modelling.

The indoor temperature profiles delivered from the cluster analysis, cross-related with the occupants' surveys in summer and winter, have been the main sources for

developing three Energy Behaviour Profiles in Albanian households that will be used in modelling the baseline energy models in this study. Heating and cooling setpoints are also related to each profile developed, as shown in Table 43. Fundamentally, these profiles will allow better energy estimations and predictions, which are closely related to occupants' behaviours. Using different heating/cooling setpoints and heating/cooling durations will enable us to determine a range of energy consumption (in the case of baseline models), rather than giving a specific target, as identified in previous studies, including Demanuele, Tweddell and Davies (2010).

Table 43: Four main overall profiles are created analysing summer and winter versions separately:

Final profiles for modelling the baseline			
Energy Saving Behaviours (No/little heating/cooling)	Living room Heating/cooling operation	Afternoon (14:00-17:00)	Morning + Evening (07:00-07:30 + 20:00-21:00)
	Bedroom Heating/cooling operation	No	No
	Heating/cooling setpoint	30°C	13°C
	Windows Operation	Morning + Evening (07:00-07:30 + 17:00-22:00)	Morning + Afternoon (07:00-07:30 + 17:00-17:30)
Energy Average Behaviours (Average use of heating/cooling)	Heating/cooling operation	Afternoon + Evening (14:00-17:00)	Morning + Evening (07:00-07:30 + 16:00-21:00)
	Bedroom Heating/cooling operation	No	No
	Heating/cooling setpoint	29°C	17°C
	Windows Operation	Morning + Evening (07:00-07:30 + 17:00-22:00)	Morning + Afternoon (06:30-07:00 + 17:00-17:30)
Energy Intensive Behaviours (Intensive use of heating/cooling)	Heating/cooling operation	Afternoon + Evening (12:00-22:00)	Morning + Afternoon + Evening (07:00-10:00 + 12:00-14:00 + 15:00-21:00)
	Bedroom Heating/cooling operation	(22:00-07:00)	(22:00-06:30)
	Heating/cooling setpoint	27.5°C	Setpoint: 21°C
	Windows Operation	Morning + Evening (07:00-12:00 + 17:00-22:00)	Morning + Afternoon (06:30-07:00 + 17:00-17:30)

Three energy behaviour profiles have been developed to be used for modelling the baseline energy models, following the graphs (See Table 43) produced from the cluster analysis, as well as the thermal comfort analysis undertaken in section 5.5. However, the temperature setpoint delivered from the cluster analysis does not statistically represent the heating and cooling setpoints of homes in Albanian homes. They might change with a larger sample of dwellings. Therefore, this analysis should be treated with caution and the focus is on methodological approach.

Each profile is characterised by different heating and cooling temperature setpoint, window operation, as well as heating and cooling operation, and represent a part of the population. This approach, therefore, addresses the performance gap by considering various behaviours and bringing them into the modelling, contributing towards a more user-centred approach to retrofits.

1. **Energy Saving Behaviour (ESB):** This profile represents those households that barely heat or cool their homes. For this reason, the cooling setpoint in this profile is set 30°C and heating setpoint 13°C. Their homes are constantly overheated during the summer and below 14°C during the winter. Furthermore, this profile is characterised by unhelpful window operation, keeping them open most of the day during the summer.
2. **Energy Average Behaviour:** This profile represents the most typical energy behaviours in the sample. Cooling was performed during the afternoon and evening to a setpoint of 29°C, still experiencing overheating. On the other hand, heating setpoint was set to 17°C with operation mainly in the morning and evening. Windows were left open for long hours during the day and bedrooms were not heated/cooled during the night.
3. **Energy Intensive Behaviour:** This profile represents those households that heated and cooled the space most of the day including bedrooms at night. Cooling setpoint of 27.5°C was delivered by the cluster analysis as well as the thermal comfort analysis of the sample. However, lower cooling setpoint could be generated using a larger dwelling sample, to avoid the risk of overheating during the summer. Window operation in this profile highlight the commonly unhelpful behaviour of keeping the windows open while heating or cooling is on.

To minimise the number of combinations, it has been assumed that people that adapt to higher temperatures in summer can adapt to lower temperatures in winter (mainly for

economic reasons). This has also been confirmed by the cluster analysis and the thermal comfort analysis in the previous chapter. While it has been assumed that people who tend to adapt in the middle range, can do so during both seasons. Indeed, by analysing the cluster membership of the middle profile, it has been found winter and summer share 50% of their membership.

It has been assumed that the main bedroom is treated (heated/cooled) only for those that tend to have higher temperatures in winter and lower temperatures in summer. This will also be the group that can afford to keep a comfortable environment throughout the year.

Heating and cooling operation times are determined by the occupants' surveys conducted during the field studies in summer and winter. However, they are also cross related with the results of the profiles delivered from the cluster analysis. The households that have lower and higher temperatures in winter and summer respectively are associated with shorter operation times. The contrary applies to those that have had higher temperatures in winter and lower temperatures in summer.

A household with four persons is used as a default occupancy profile for modelling.

In winter, it is assumed that windows are opened only half an hour in the morning and afternoon, as the most common operation profile defined from the occupants' survey in winter.

5.8. Summary

An in-depth analysis of the energy, temperatures and thermal conditions of the sample was undertaken in this chapter using data collected through two field studies conducted in June to August 2016 and January to February 2017 to cover the heating and cooling season. In-sight of energy consumption together with thermal comfort were given for both seasons. It was found that most of the dwellings in the sample performed poorly in both energy and thermal performance. Heating homes were found to be more crucial than cooling and households with children had higher annual electricity consumption. Indoor temperature was found to be higher in flats during summer and winter, due to lack of cross ventilation and less contact with the outside respectively. In terms of built period, dwellings built pre-1990 were performing worse than those built post-1991.

Furthermore, cluster analysis of indoor temperature in both winter and summer has been undertaken to determine the most typical indoor temperature profiles based on the indoor

temperature in the selected dwellings. Statistical analysis was further undertaken to determine the strength of association between the clusters and contextual factors related to the building, household and occupancy. Statistically, significant associations were found between the presence of children and the clusters in winter, but not in summer, suggesting that families with kids use more energy compared to the ones without. However, building-related factors, including building type, building age and wall insulation, were found to be statistically significantly associated with the clusters in summer.

The most typical indoor temperature profiles in Albanian homes were defined, giving an approximate trend of heating and cooling setpoints, as well as heating/cooling durations, which were thereafter triangulated with the results of occupants' behaviours. These profiles can be used for energy modelling of actual energy consumption of Albanian housing stock, as well as predicting energy savings from retrofit programs, producing more accurate outcomes, rather than using a single default heating and cooling profile. This approach would contribute to the energy industry making better predictions, as well as developing more effective policies and low energy strategies in the future.

The findings are summarised into two groups, based on the objectives of this chapter:

1. Energy, temperature, and thermal performance of the dwellings

- Energy performance
 - Electricity has been the main type of energy used for heating and cooling for households in the sample.
 - Heat pumps and air conditioning have been the main type of heating and cooling respectively.
 - In almost all dwellings, electricity consumption increases during the winter months (November to March) with its peak in January, and the summer months (June to September) in July, indicating the use of electricity for space heating and cooling respectively in winter and summer in most of the dwellings.
 - The yearly electricity consumption is higher for the households with higher salaries, household size and the presence of a child in the household.
 - Heating the homes in Albania is more crucial than cooling them, and it is especially important to aim to decrease months of heating in dwellings.

- Indoor temperatures analysis in summer
 - All dwellings in the sample are overheated during the summer with indoor temperatures over 25°C for more than 21% of the occupied hours. Furthermore, 37 dwellings have experienced temperatures over 28°C for more than 50% of the day.
 - Bedroom temperature profiles show that most of the households in Albania do not cool their bedrooms, or benefit from passive cooling during the night.
 - From the investigation of mean hourly profiles, most of the dwellings have continuous mean indoor temperatures throughout the day of over 28°C.
 - Temperatures have been higher in flats and terraced houses compared to other built forms, in both living rooms and bedrooms. This could be due to less cross ventilation associated with these built forms.
 - The highest temperatures were registered in dwellings built pre-1990, and those constructed with silicate brick and prefabricated elements (affected by poor thermal properties of the building fabric).
 - Temperatures are higher in smaller dwellings and are generally higher for bigger households.

- Indoor temperatures analysis in winter
 - A very high-temperature variation can be noticed in living rooms, varying from 6.5°C to 24°C, indicating a big problem in keeping adequate thermal comfort in Albanian homes in winter.
 - Indoor temperatures as low as -2.0°C have been recorded.
 - Bedrooms were mainly unheated at all.
 - In general, flats have higher indoor temperatures throughout the day than other built forms, and there is a small difference between flats built pre-1990 and post-1991.
 - The mean temperatures were relatively higher for larger household sizes (due to more incidental heat gains).
 - Dwellings that had applied wall insulation had higher indoor mean temperatures, which highlights the need for fabric improvement to improve thermal comfort in Albanian homes.
 - Statistically significant positive and strong correlations were found between the external temperature and indoor temperature of each archetype.

- Thermal comfort performance in summer and winter
 - The temperature range where the occupants are feeling neutral is between 16°C to 28°C.
 - There is a higher temperature variance during the winter, which allows the comfort votes to be in a wider range. Moreover, there have been more adaptive options during the winter (several layers of clothing, blankets, localised heating, hot water bottles, etc) compared to summer.
 - 60% of the respondents who felt cold in winter (the lowest comfort vote) were feeling hot in summer (the highest comfort vote).
 - A very strong correlation is found between thermal sensation votes and overall comfort in summer ($p=-0.9$) and winter ($p=0.8$) respectively.
 - The hierarchical multiple regression model developed using three blocks made of different variables related to building, temperature and heating/cooling factors, explained 26% and 54% of the variance in winter and summer thermal sensation votes respectively. Other contextual factors and/or thermal preferences related to cultural norms and practices, as well as different adaptive actions. could affect thermal sensation during both winter and summer.

2. Implication for modelling:

Cluster analysis has been performed to determine implications for modelling energy baseline, including occupancy, heating, and cooling patterns. Three statistically different clusters have been produced for both summer and winter. Statistically, a significant association has been found between the clusters in summer and building factors such as building type, period of construction, archetype, and wall insulation, but not with socio-demographic, behaviours and thermal factors. In winter, a statistically significant association has been found only between the clusters and the presence of children in the household.

These findings have the following implications for modelling:

- Different archetypes (based on building type and period of construction) will be modelled:
 - detached built pre-1990
 - detached built post-1991
 - semi-detached
 - terraced

- flats built pre-1990
- flats built post-1991.
- Different building construction
 - full bricks
 - hollow bricks
 - prefabricated.
- Based on the mean hourly profiles of clusters, three cooling and heating setpoints will be modelled:
 - cooling setpoints: 30°C, 29°C and 27.5°C
 - heating setpoints: 13°C, 17°C and 21°C.
- Heating and cooling daily profiles
 - heating: 07:00-07:30 + 20:00-21:00 (heating setpoint = 13°C)
 07:00-07:30 + 16:00-21:00 (heating setpoint = 17°C)
 07:00-10:00 + 12:00-14:00 + 15:00-21:00 (heating setpoint = 21°C)
 - cooling: 12:00-22:00 (cooling setpoint = 27.5°C)
 14:00-17:00 (Cooling setpoint = 29°C and 30°C))
- heating and cooling weekly profiles
 - heating profiles: weekdays profiles= weekend profiles
 - cooling profiles: weekdays profiles = weekend profiles
- heating and cooling yearly profiles
 - heating months: November-March
 - cooling months: June-September
- the main bedroom is treated only in the case of setpoint 27.5°C.

The next chapter will provide an analysis of the results of baseline energy models.

CHAPTER 6

Baseline energy models of the main Albanian archetypes

6.1. Introduction

This chapter presents the results of the modelled energy and thermal performance of the main archetypes representing the existing housing stock in Albania in terms of energy efficiency as previously defined. The energy models have been constructed using Energy Plus v8.5, which is validated and is one of the most recognised and used by practitioners worldwide, with DesignBuilder V5 as a user-friendly interface which allows the dynamic thermal evaluation of heating, cooling, lighting, ventilating and other energy consumptions as well as thermal comfort. 'Reference' buildings have been assigned to each archetype, associated with typological features related to geometry and construction as well as space heating/cooling system characteristics that served to validate the baseline models. Baseline energy models for each archetype are developed using input data from various sources, including literature and analysis undertaken in this thesis followed by an in-depth analysis of the simulated energy use and indoor temperatures.

6.2. Using archetypes for modelling energy consumption in residential buildings. Typological features of the archetypes and key assumptions used for the baseline energy models

From a careful and detailed investigation of existing literature, there is an acknowledged lack of studies on the energy performance of residential buildings in Albania. Moreover, no database includes all the necessary information at once. Therefore, several data sources have been aggregated and adapted to create the archetypes as thermo-physics models representing the baseline scenario. The same approach has been adopted by Schaefer and Ghisi (2016), Lavagna *et al* (2018) and Gulotta *et al.* (2021) for building representative models of European residential stock.

The main data sources for the derivation of the input information required for modelling the baseline energy models in this study include:

- a. Data obtained from previous studies.
- b. Data obtained from the analysis undertaken in this study, mainly based on the analysis of the field studies including building surveys, occupants' surveys and monitoring of 49 Albanian dwellings of different building types.
- c. Data obtained from DesignBuilder calculations, which are mainly related to the building elements' thermal properties.
- d. Data obtained from the building regulations in Albania, mainly related to typical construction features and thermo-physical properties of construction materials.

For each archetype, various aspects related to geometrical data, construction elements and materials, and space heating and cooling systems have been defined using the above sources, considering the construction age.

6.2.1. Geometrical and construction features of archetypes used for modelling

The first stage of creating the energy models is defining the geometrical features of the example reference building representing the archetypes. Although an example is chosen to represent each archetype, there is a huge variety of building sizes, forms and designs, especially in buildings constructed after 1991 in Albania. The sample of 49 dwellings used in this study is not large enough to create a synthetic building type as a weighted average of features of dwellings in the same category, so the input data related to geometry are taken from the building survey undertaken on the chosen example reference buildings in Tirana, Albania. After modelling the geometry of each building using DesignBuilder software, floor area, treated floor area, story height, surface area to volume rate, and window-to-wall area are automatically calculated for each of the example reference buildings. While typical construction systems have been selected based on the information collected from all sources.

The main remarks related to the selection of the input data regarding this data category are:

- Typical construction systems:
They have been selected taking into consideration the period of construction of the building. Load-bearing brick walls, silicate bricks and prefabricated structures have been typical construction systems for residential buildings built pre-1990,

while a concrete load-bearing structure with a single layer of hollow bricks with no insulation whatsoever is typical for residential buildings built post-1991. However, apartment buildings built pre-1990 using prefabrication technology have some insulation, as part of the sandwich wall construction (Simaku, 2014). On the other hand, almost all the dwellings until the 2000s have been built with no insulation (Simaku, 2014; Novikova *et al.*, 2015), and many buildings built after the introduction of the new building code in the 2000s did not comply with the requirements as they were not sufficiently strict enough and, as a result, they were built with no insulation.

- Elements of the building envelope, including walls, floor, roof, windows etc., for each building archetype have been modelled by combining data from available statistics and literature as well as surveys undertaken as part of this study. However, U-values might slightly differ from those in reality because of different materials' standards and properties used over the years.
- Floor height is taken as being 2.8m from floor to ceiling for all building types as the most common one during the buildings' surveys.

The geometrical characteristics and thermal properties of each archetype are listed in Table 44. Sources of data are also indicated for each data category.

Table 44: Input data for building structure

Building structureTypes	Archetypes to model							Flats post-91
	Detached pre-90	Detached post-91	Semi-detached	Terraced	Flats pre-90	Prefabricated	Silicate brick	
								
Dwelling floor area (m ²) ^{b,c}	75	92	61	106.5	45	47	57	77
Treated area (m ²) ^{b,c} Living room (Living room + bedroom)	17.8 (29.3)	25 (37)	17.5 (28.8)	24.5 (37.5)	13.7 (24.5)	16.4 (28.7)	14.3 (26.9)	21.5 (32.5)
Storey height – Floor to ceiling (m) ^{a,b}	2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Surface area to volume ratio (%) ^c	35.7	35.7	36	34	35.7	34	35.9	35.7
Window-to-wall ratio (%) ^c	0.16	0.16	0.17	0.34	0.24	0.20	0.18	0.23
Window type ^{a,b}	Single-glazed, wooden frame	Single glazed, aluminium frame	Single glazed, Aluminium frame	Single glazed, Aluminium frame	Single glazed, Aluminium frame	Single glazed, Aluminium frame	Single glazed, Aluminium frame	Single glazed, aluminium frame
Window U-value (W/m ² K) ^{a,c,d}	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Window g-value ^d	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Wall type ^{a,b,d}	Solid red brick walls (25cm) rendered both sides	Hollow brick (25cm) rendered both sides	Hollow brick (25cm) rendered both sides	Solid red brick walls (25cm) rendered both sides	Internal plaster and red solid brick (38cm)	Cast concrete and lightweight cast concrete	Internal plaster and silicate brick wall (25cm)	Hollow brick (25cm) rendered both sides
Wall U-value ^{c,d}	1.76	1.68	1.68	1.76	1.86	1.6	1.86	1.68
Ground floor type ^{a,b,d}	Cast concrete floor with hydro insulation	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles	Cast concrete with hydro insulation and ceramic floor tiles
Ground floor U-value ^{c,d}	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Roof type ^{a,b,d}	Uninsulated wooden framed roof with waterproof and clay roof tiles	Flat roof Reinforced concrete with EPS infill	Pitched roof Uninsulated wooden framed roof with waterproof and clay roof tiles	Pitched roof Uninsulated wooden framed roof with waterproof and clay roof tiles	Uninsulated wooden framed roof with waterproof and clay roof tiles	Bitumen layers, cast concrete and light cast concrete	Bitumen layers, cast concrete and light cast concrete	Reinforced concrete with EPS infill

Roof U-value ^{c,d}	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
Internal floors ^{a,b,d}	Wooden floors	Reinforced concrete with EPS infill	Reinforced concrete with EPS infill	Wooden floors	Cast concrete with concrete tiles	Light cast concrete with concrete tiles	Cast concrete with concrete tiles	Reinforced concrete with EPS infill
Internal floor U-value ^{c,d}	2.29	0.28	0.28	2.29	3.19	2.5	3.19	0.28
a- Data obtained from (Novikova <i>et al.</i> , 2015) b- Defined based on the author's analysis of case studies c- DesignBuilder calculations d- Albanian regulations (Republika e Shqiperise, 2010)								

6.2.2. Characteristics of space heating systems used for modelling

The type of space heating systems, their efficiency, and duration of use are the greatest factors that determine the energy consumption for heating. One of the main assumptions in this study is the space heating system's efficiency used for the energy models, as no statistical data are available and there are various split heat pumps traded in the market in Albania. Therefore, the heating system efficiency is assumed to be 2.2, even though other COP of heating systems can be present in Albanian homes. The main considerations of the characteristics of space heating systems used for modelling the baseline energy models are listed below, and are given in Table 45:

- Of the three most typical energy sources used for heating in Albanian homes (electricity, wood and LPG), only electricity (air-to-air heat pumps) is used for the baseline energy calculations, as the most common option in the sample chosen for monitoring and as the widest spreading type of heating (Novikova *et al.*, 2015)
- There is no statistical data available on daily heating and cooling duration in residential buildings in Albania. Therefore, results from the analysis of 49 dwellings in this study have been considered, which are also supported by discussions with active experts in the field of buildings in Albania.
- The most common heating duration in months on the surveys undertaken in this study has been November to March. Therefore, this is used to complete the annual profile of space heating in Albanian houses.
- The efficiency of the systems is taken from Novikova *et al.* (2015), as the most reliable study undertaken on residential buildings in Albania.
- Based on the cluster analysis undertaken in this study, three heating profiles have been developed. Only the Energy Intensive Behaviour profile considers that the bedroom is heated and cooled.

Table 45: Input data for space heating systems

	Archetypes to model					
Space heating	Detached pre-90	Detached post-91	Semi-detached	Terraced	Flats pre-90	Flats Post-91
Space heating system	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump
The efficiency of the system: Coefficient of performance (COP) ^a	2.2					
Heating duration in months ^b	01 Nov-31March					
The heating duration during the day ^b	07;00-07:30 + 20:00-21:00 05:00-07:30 + 16;00-21:00 07:00-10:00 + 12:00-14:00 + 15:00-21:00					
Heating at night ^b	1. Yes 2. No					
Treated rooms ^b	1. Living room 2. Living room + main bedroom					
Heating setpoint for each Energy Behaviour Profile (bedroom) ^b	13°C (-) 17°C (-) 20°C (18°C)					
a-Data obtained from (Novikova <i>et al.</i> , 2015)						
b- Defined based on the author's analysis of case studies						

6.2.3. Characteristics of space cooling systems used for modelling

Similar to space heating systems, characteristics of space cooling systems used for modelling the baseline energy models for each reference building are mostly based on findings from the analysis of 49 dwellings. Input considerations and values are listed below and in Table 46.

- The use of air conditioning in Albania is assumed to be up to 45% in climatic zones A and B and 15% in climatic zone C, and are predominantly decentralised units (split units) (Novikova *et al.*, 2015). Because most of them are reversible, they are also used for space heating. Because of the widespread use of air-conditioning, only this type has been considered in the models
- It was assumed that the most typical air-conditioning systems have a low energy efficiency rate, with a coefficient of performance of two.
- The space cooling duration during the day and months has been determined by the analysis of the 49 dwellings in this study.
- Space cooling in bedrooms has been considered only for the Energy Intensive Behaviours profile.
- Cooling setpoints are determined by the profiles derived from the cluster analysis of the indoor temperatures in 49 dwellings.

Although the temperature setpoints assumed by the standard ISO 17772-1 for calculating the thermal heating and cooling load are assumed 20 to 26°C (ISO, 2017), in this study, the lowest cooling temperatures setpoint is considered to be 27.5°C, based on the cluster analysis of the sample of dwellings selected for this study.

Table 46: Input data for space cooling systems

	Archetypes to model					
Space cooling	Detached pre-90	Detached post-91	Semi-detached	Terraced	Flats pre-90	Flats Post-91
Space cooling system ^{a,b}	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)
The efficiency of the system: Energy efficiency rate ^a	2					
Cooling duration in months ^b	1 June-31September					
The cooling duration during the day ^b	14:00-17:00 12:00-22:00 + 22:00-07:00					
Cooling at night ^b	1. Yes 2. No					
Treated rooms ^b	1. Living room 2. Living room + main bedroom					
Cooling setpoint for each Energy Behaviour Profile (setback) ^b	30°C 29°C 27.5°C					
a- Data obtained from (Novikova <i>et al.</i> , 2015)						
b- Defined based on the author's analysis of case studies						

6.2.4. Other assumptions and limitations

The selection of all data needed to develop the archetype of the Albanian residential stock has been challenging.

- In this study, the baseline calculations have been performed for the capital city, Tirana, which is within Zone A with 900-1500 Degree Days, although Albania is divided into three climatic zones.
- Data collected during the buildings and occupants' surveys have not been as detailed as required to be used for the validation of energy models. Therefore, although the geometrical and construction information regarding each example reference model is close to the real case, other input information on the energy models is determined by the most commonly used in the sample, rather than by the individual case. Therefore, it is important to handle the figures with caution, understanding that the main objective has been to create the archetype with the most typical behaviours, rather than the exact behaviour in each example reference.

6.3. Baseline data analysis

6.3.1. Baseline energy simulation and model validation

Research has shown that it is impossible to fully validate a model (Ryan and Sanquist, 2012; La Fleur, Moshfegh and Rohdin, 2017). Even the model calibration, which focuses on how closely simulated results match the metered energy data (ASHRAE, 2002), is difficult to perform in this study as the main criteria set by the guidelines is to validate the model against actual data at either monthly or hourly intervals. On the other side, it is difficult to compare the simulated results and the measures regarding electricity consumption due to estimations on monthly readings in electricity bills in Albania. Moreover, there are other uncertainties related to the measured and simulated values, as captured by de Wit and Augenbroe (2002), related to specifications (building fabric and systems), modelling (the degree of model simplification) and scenario (climate and occupancy behaviour), as a result of simplification generally made to describe a building energy model. However, the validation in this study is also determined graphically through the indoor temperature charts.

Comparing the energy use before and after implementation of the retrofits is usually used as the calculation method for determining energy savings, and they are widely predicted by a building simulation computer program. However, several studies have shown

significant discrepancies between simulation results and actual measured energy consumption in buildings. This section will present the method used for validating the baseline energy models for each archetype that represent the Albanian housing stock. The energy models are constructed using EnergyPlus V8.5 with DesignBuilder V5 as a user-friendly interface. Hourly weather data for Tirana, Albania (19.78°E / 41.33°N) are secured from Meteonorm (Meteonorm, 2017), as one of the recommended sources that supply simulation-appropriate weather data recommended for EnergyPlus calculations (EnergyPlus, 2017). It was then edited and translated so that data are compatible with DesignBuilder day-of-week results for daily, hourly, and sub-hourly output and can be used in DesignBuilder. A real example representing each archetype defined in this study has been constructed using the geometrical and construction features, developed above, and using default profiles provided by the software for each zone, and the main characteristics are given in Table 47:

Table 47: Main characteristics of the default template

Activity		Heating schedule	Cooling schedule	Window operation
Heating setpoint temperature	21/18*	1 Jan-31 Dec	1 Jan-31 Dec	WinterDesignDay
Heating setback temperature	12	00:00-05:00 50%	05:00-10:00	00:00-24:00 Off
Cooling setpoint temperature	25	05:00-10:00 100%	15:00-24:00	
Cooling setback temperature	28	10:00-15:00 50%		SummerDesignDay
		15:00-24:00 100%		00:00-07:00 Closed
				07:00-08:00 50%
				08:00-09:00 Open
				09:00-10:00 50%
				10:00-17:00 Closed
				17:00-18:00 25%
				18:00-19:00 50%
				19:00-20:00 75%
				20:00-22:00 Open
				23:00-24:00 25%

* 21°C (living room); 18°C (bedroom)

Infiltration and natural ventilation rate are automatically calculated using wind, opening sizes and operation, and crack sizes, using the EnergyPlus Airflow Network. The airtightness of the building is defined as a 'crack template', where custom crack templates can be defined and selected. Compact fluorescent lights (CFL) are used for the matter of simulations, although many households used tungsten lights. Heating and cooling are assumed to be performed using split systems as the main heating and cooling type used in Albanian housing.

To validate them, one way would be to investigate the energy consumption and comfort conditions during the unheated/uncooled periods of the year, such as May or October. But the measured indoor temperature is not available for these periods of the year and the validation could not be effective based only on the electricity consumption, as this would not consider thermal performance and would not give insights into occupants'

behaviours. Therefore, since electricity was the only energy used for cooling in summer, it would be reasonable to validate the model output by comparing them with the electricity consumption from the fuel bills and in-situ measurements of indoor temperatures measured in each representative case study dwelling.

First, it is important to compare the in-situ measured outdoor temperature with the one generated by the model. Figure 35, shows the modelled and measured mean daily outdoor temperatures for Tirana. It can be noticed that measured temperature during the summer is higher than those modelled, indicating 2016 had a hotter than average summer. Therefore, it is expected to have a higher electricity consumption for cooling during the summer than the model estimations.

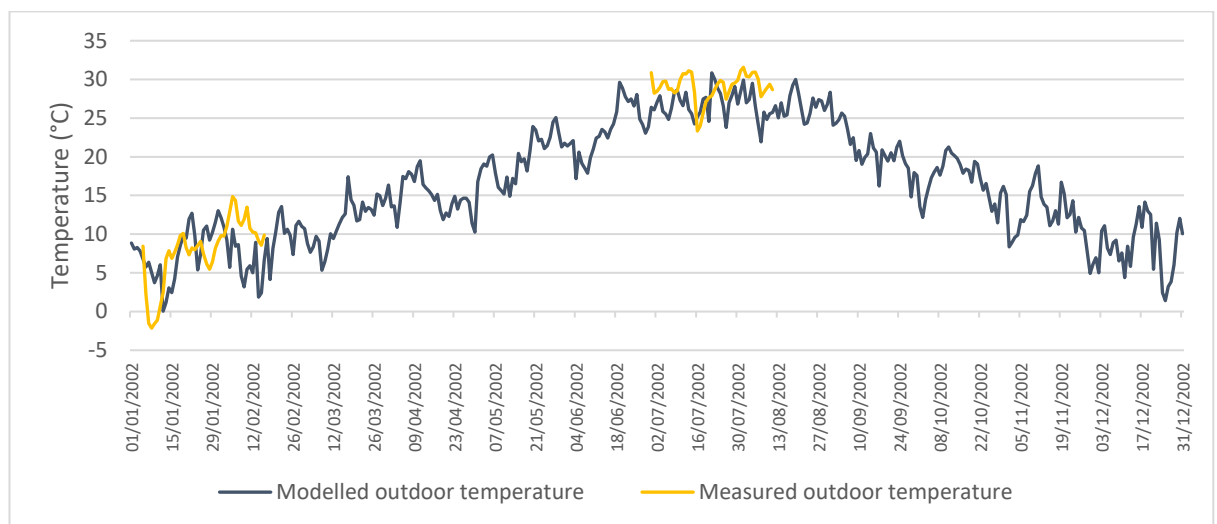


Figure 35: Daily measured and modelled temperatures for Tirana.

To further compare the two weather data sets, average temperatures during the day are calculated in Figure 36.

The same tendency is noticed, however, that modelled hourly mean temperatures are approximately 2°C lower than measured temperatures during the summer. Therefore, higher measured electricity consumption during the summer is expected compared to the modelled results.

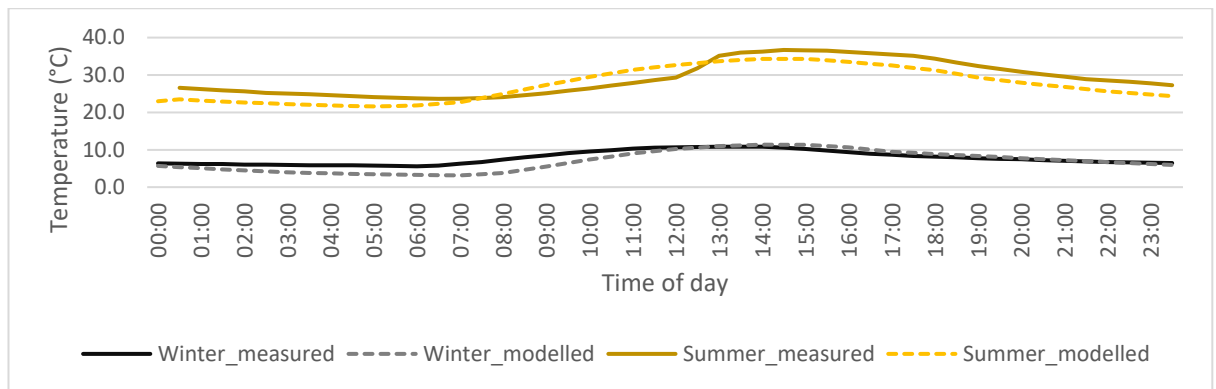


Figure 36: Measured and modelled daily temperature variation.

Thereafter, data regarding the building and actual occupants' behaviours extracted from the occupants' surveys are used as input parameters for each energy model of each reference building representing each archetype to create zoning, schedules, heating, and cooling systems. Output data is compared with the default profiles provided by DesignBuilder for residential buildings so that the effect of the validated model on minimising the performance gap from inappropriate modelling can be apparent.

Table 48: Input data for energy model using default and actual profiles:

	Default profiles	Actual profiles
Activity		
Heating setpoint temperature (°C)	21	15
Heating setback temperature (°C)	12	10
Cooling setpoint temperature (°C)	25	30
Cooling setback temperature (°C)	28	31
Occupancy	2	5
Heating schedule		
Yearly/Daily	1 Jan-31 Dec 00:00-05:00 50% 05:00-10:00 100% 10:00-15:00 50% 15:00-24:00 100%	1 Nov-30 Apr 7:00-24:00 (50%)
Cooling schedule		
Yearly/Daily	1 Jan-31 Dec 05:00-10:00 15:00-24:00	1 Jun- 30 August 17:00-19:00
Window operation schedule		
Yearly/Daily	WinterDesignDay 00:00-24:00 Off SummerDesignDay 00:00-07:00 Closed 07:00-08:00 50% 08:00-09:00 Open 09:00-10:00 50% 10:00-17:00 Closed 17:00-18:00 25% 18:00-19:00 50% 19:00-20:00 75% 20:00-22:00 Open 22:00-23:00 75% 23:00-24:00 25%	1 Nov-30 Apr 07:00-08:00 Open 1 May-30 May 07:00-17:00 Open 1 Jun-30 Aug 14:00-22:00 Open 1 Sep-30 Oct 07:00-17:00 Open

The reference dwelling representing the post-91 flat archetype has been chosen to demonstrate the validation process of the baseline energy model. Input data using default and actual profiles are given in Table 48.

The mean hourly temperatures in winter and summer, using the default and actual profiles compared with the measured indoor temperature, are shown in Figure 37. It can be noticed that the temperature variation during the day using the actual profiles fed by the in-situ surveys is very close to the actual measured indoor temperatures. On the other hand, using the default profiles would give an overestimated electricity consumption of over 50%, as shown in Table 49.

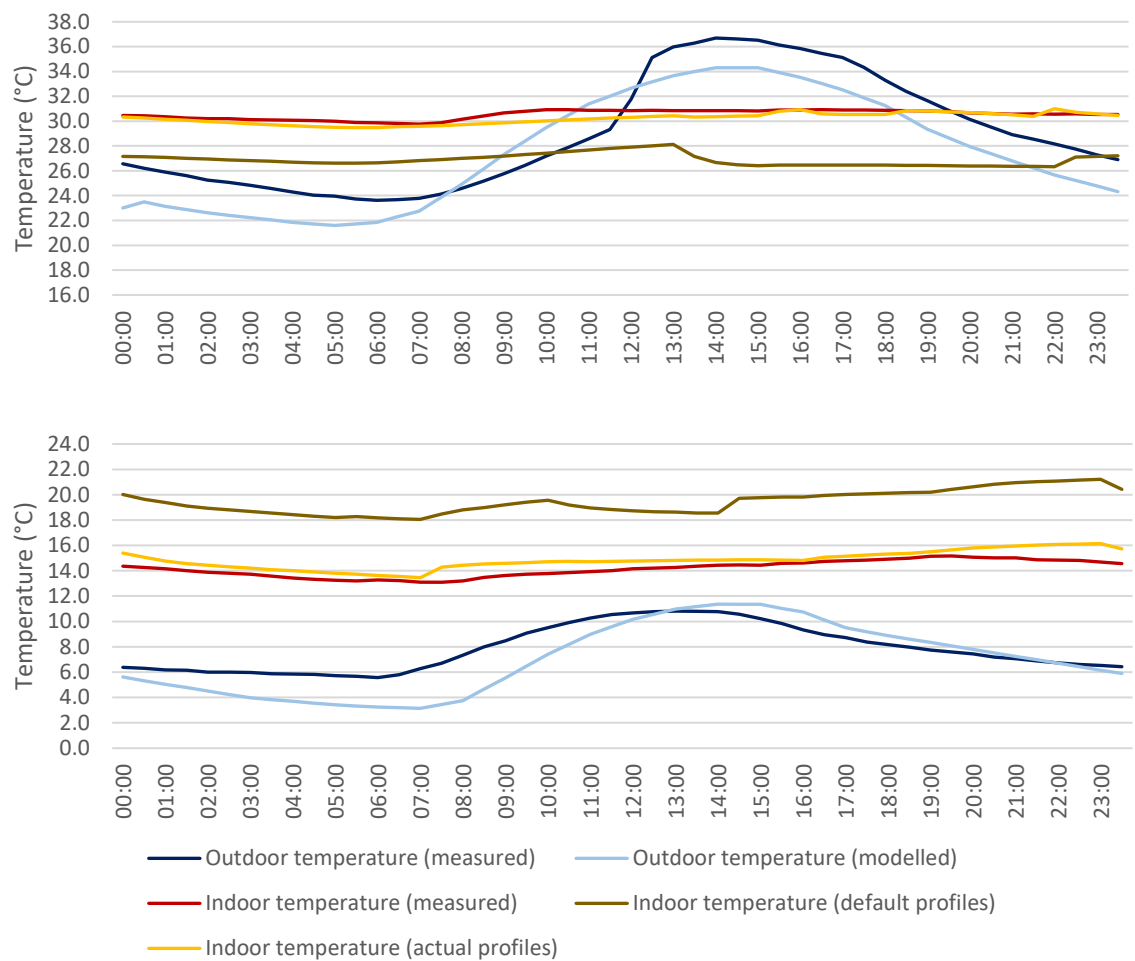


Figure 37: Average daily temperatures in summer (top) and winter (bottom).

Table 49: Actual electricity consumption compared with modelled electricity consumption using default and actual profiles as input parameters (kWh)

Month	Electricity consumption (kWh)		
	Actual electricity bills	Modelled default profiles	Modelled actual profiles
Jan	518	1164	532
Feb	502	1013	467
Mar	486	890	462
Apr	377	791	438
May	464	946	452
Jun	445	1115	488
Jul	456	1251	535
Aug	435	1215	519
Sep	481	942	443
Oct	519	839	452
Nov	459	840	443
Dec	535	1100	506
Total	5677	12106	5737

Using the actual profiles for modelling the baseline energy model, a relative deviation of only 1.04% is obtained. Although the actual profiles represent the selected case study energy behaviours, they might not necessarily represent all the occupants' behaviours in Albanian dwellings. For these reasons, three occupant behaviours have been developed in this study to minimise the uncertainties related to the energy models and to make the baseline energy calculations closer to the Albanian context. This step is very important to make sure to take into consideration occupant behaviours because the same energy retrofitting interventions would provide different outcomes for different households of the same archetype.

The validation of each reference building demonstrated that the energy model developed using DesignBuilder could be used as a reliable model for the baseline energy estimation and energy savings after applying retrofitting strategies.

6.3.2. Electricity consumption is used for heating and cooling the space

Electricity has been used as the main energy source in the modelling of baseline energy consumption and as the only energy used for heating and cooling the space in the analysis of this study. The energy consumption of the baseline scenario is highly dependent on the configuration of the existing building, as well as on the existing heating and cooling systems. The graph in Figure 38 shows the simulation results of the baseline scenario for each archetype using the three different energy behaviour profiles. It notes a very low level of electricity consumption is used for heating using the ESB profile for all the archetypes, backed up by the occupants' survey that found that this category of households tends to be very cautious regarding energy consumption, and barely used the heating or cooling. In winter, they often used hot water bottles to warm themselves,

as well as blankets and more layers of clothing. The electricity consumption used for heating using EIB is considerably higher than the other two profiles due to the higher temperature setpoint and the longer operation times. However, a larger floor area has been estimated to be treated using EIB profile compared to ESB and EAB profiles. Furthermore, keeping the house/flat cool during summer is more challenging and using air conditioning was one of the few options available. This can also be noticed with the smaller difference in modelled electricity consumption used for cooling using ESB and EAB profiles compared with the EIB one. On the other hand, electricity consumption extracted from the bills provided for each case study representing each archetype show that the electricity consumption is closer to the results of simulations using EIB profiles in most cases. This result imposes the need for behavioural change in homes.

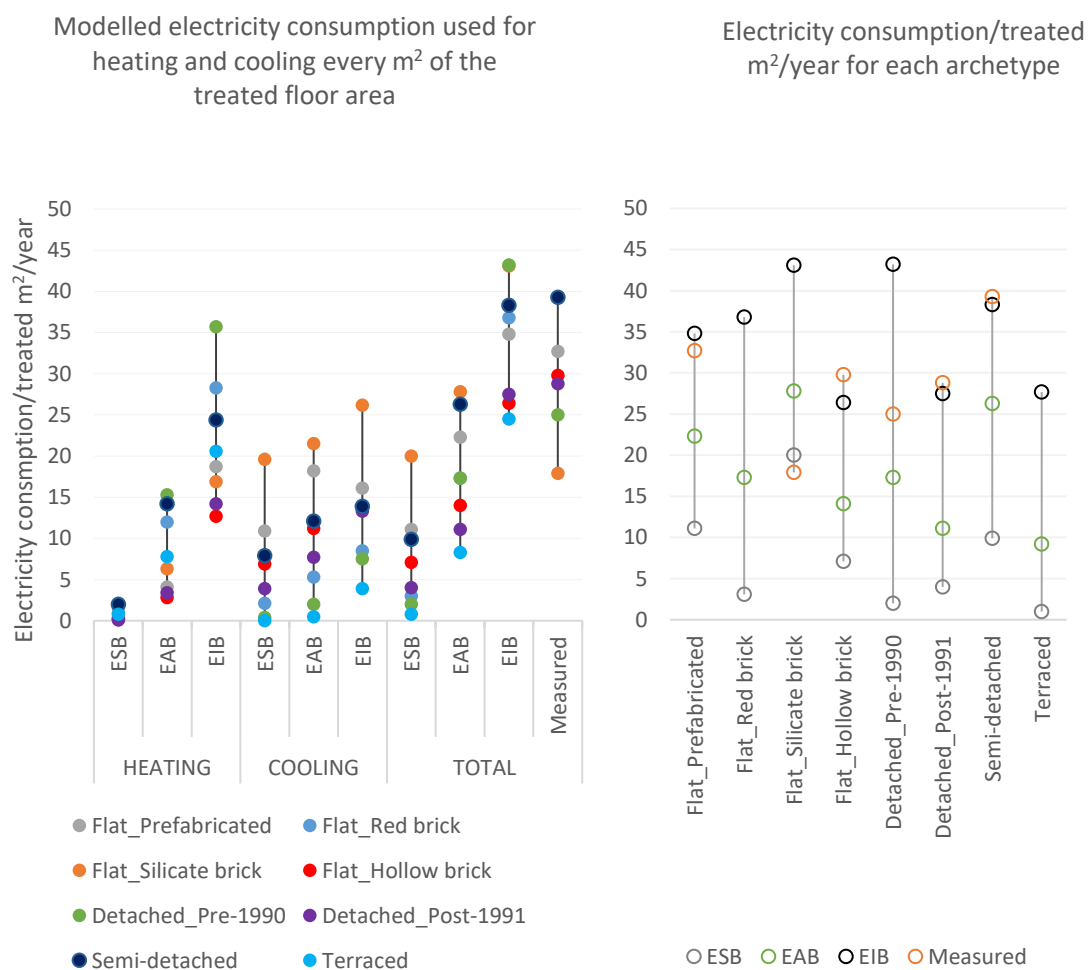


Figure 38: Annual electricity consumption used for heating and cooling separately (left) and heating and cooling together (right) from simulation results using three energy behavioural profiles compared with measured electricity consumption.

It is important to notice the effect of building materials on the external walls on the heating and cooling loads. Houses/flats built with full brick provide a high thermal mass during

the summer, resulting in considerably lower cooling loads than the other constructions. However, heating loads in the houses and flats with full brick walls have been one of the highest compared with other building materials. On the other hand, flats/houses built with silicate and hollow bricks, with the lowest thermal mass, require higher cooling loads than heating ones. This is due to the differences in heat transfer phenomena throughout the year. In winter, the heat flow direction is constantly from indoor to outdoor so that the structures with low values of thermal transmittance perform better. In summer, the optimal envelope is the one that shifts and attenuates the diurnal heat wave, so that structures with higher thermal capacity perform better than thermal resistant ones.

Based on the computer energy simulations, it has been possible to determine the range of electricity consumption used for heating and cooling for each archetype using various occupants' behaviours as shown in Figure 38 (right). It was found a variation of up to 41.2kWh/m²/year by using the same dwelling differently.

Figure 39 shows the monthly electricity consumption used for heating and cooling the space for each archetype using the three behavioural profiles defined in the previous chapter.

It notes the same sensitivity of all three profiles, with a high peak of electricity consumption during the summer, in most cases in July, which is related to cooling the space. The same trend is noticeable during the winter months with high electricity consumption during December and January, the coldest months in the Albanian climate. However, it has been found from the models that the summer peak in electricity consumption used for cooling using the Intensive Behaviour Profile is considerably higher than the other two profiles. This is closely related to the lower cooling setpoint used for this profile (27.5°C), longer operation times, as well as the addition of night cooling in the main bedroom. It is also interesting that the winter electricity consumption for heating using the Energy Saving Behaviour profile is very low, due to the low heating setpoint set during the winter in this profile, as well as the lack of heating in bedrooms.

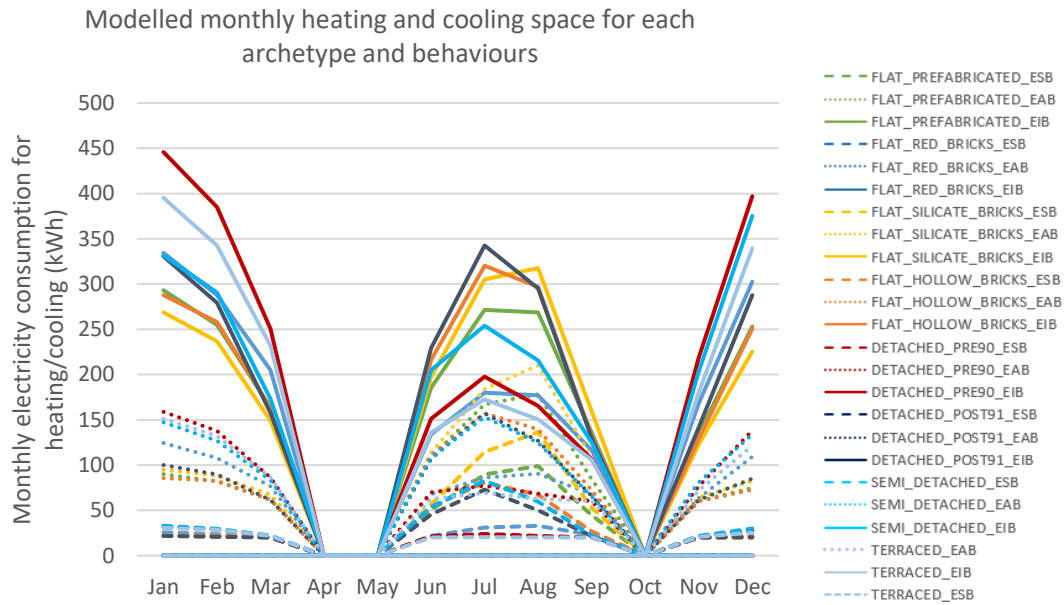


Figure 39: Monthly electricity consumption from simulation results using three Energy behavioural profiles.

In further examining the monthly electricity consumption used for heating and cooling of all archetypes, using three behaviour profiles, it can be noticed that all the archetypes with external walls with full red bricks (detached pre-1990, terraced pre-1990 and flats with red bricks pre-1990) use considerably less electricity for cooling during the summer, mainly due to high thermal mass of the external brick walls. While, during the winter, flats have lower electricity consumption used for heating compared to other archetypes, mainly due to fewer external surfaces.

The annual electricity consumption used for heating and cooling the space is noticeably higher for each archetype using the Energy Intensive Behaviour compared to the other two profiles, reaching up to 86.1% and 52.9% higher than Energy Saving Behaviours and Energy Average Behaviour profiles respectively (see Figure 40). This is mainly due to the higher heating temperature setpoints in winter and lower cooling temperature setpoints in summer, as well as the larger treated area (the main bedroom is also cooled and heated in EIB) as well as window operations during summer and winter, day and night.

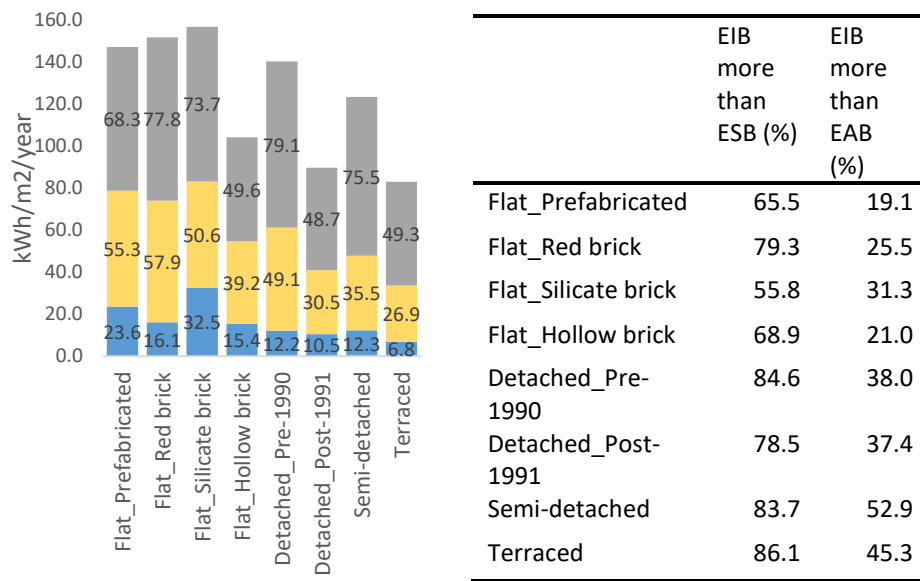


Figure 40: Modelled annual electricity used for heating and cooling the space per metre square of treated floor area (left) and the difference in electricity consumption between the Energy Intensive Behaviour profile and the other two profiles.

6.3.3. Indoor temperatures

The baseline energy models are developed for each archetype using three energy behaviours profiles developed in this study (ESB, EAB and EIB). Indoor temperatures are investigated in both living rooms and the main bedroom of each baseline model at half-hour intervals throughout the year. Figure 41 shows the boxplots of temperatures simulated during the occupation times in the living room and bedroom of each archetype, during each season (heating, cooling, no heating/cooling), compared to the external temperature.

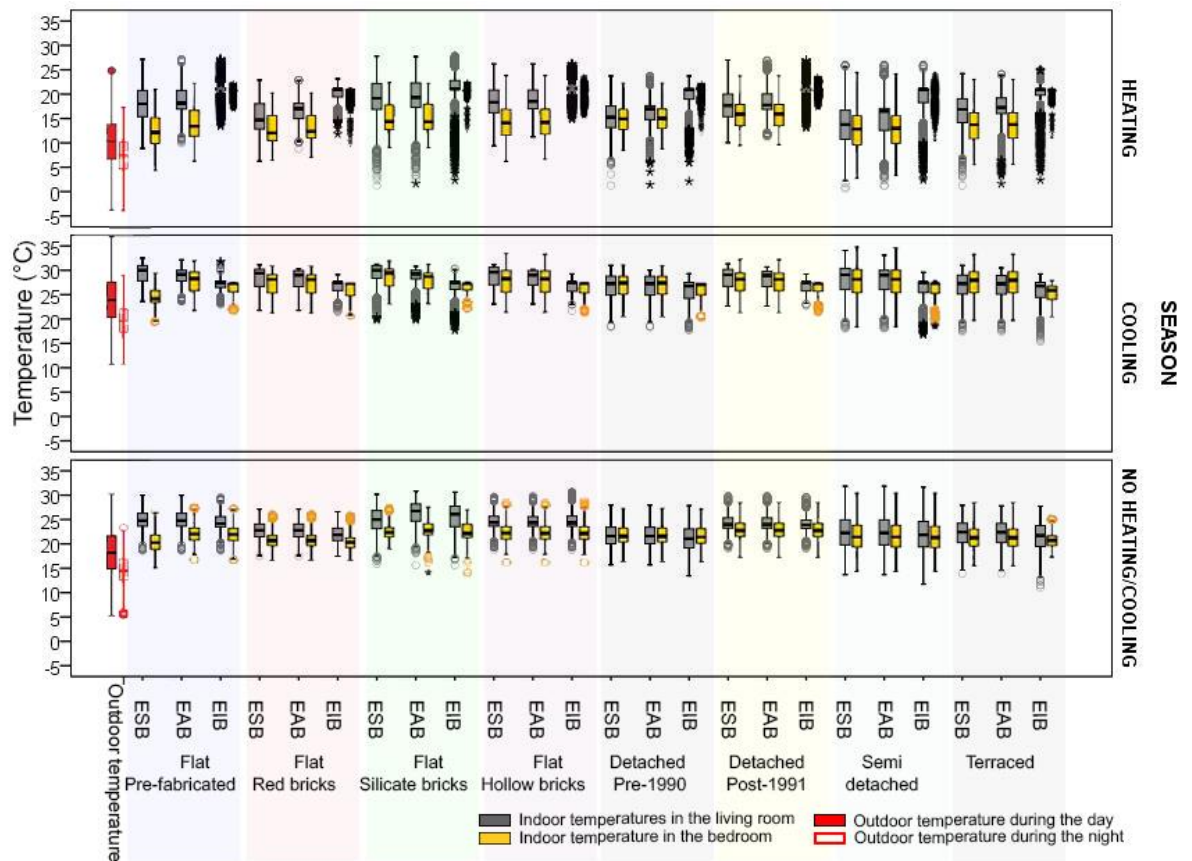


Figure 41: Boxplots of indoor temperatures of living rooms and bedrooms of each archetype from simulation baseline energy models using three energy behaviours profiles (ESB-Energy Saving Behaviour; EAB-Energy Average Behaviour; EIB-Energy Intensive Behaviour) during each season (heating, cooling and no heating/cooling), compared with outdoor temperature.

It can be noticed that during the no heating/cooling season, the indoor temperatures do not change greatly regardless of the profile that has been used for the simulation. However, lower temperature variation has been found in flats, mainly because of less cross ventilation compared to detached, semi-detached or terraced houses. On the other hand, looking at temperature variation during the winter, there is a noticeable increase in the indoor temperature during the winter using the Energy Intensive Behaviour profile compared to ESB or EAB profiles in both living rooms and bedrooms. The same is expected during the cooling season, where the indoor temperatures during the occupied hours have been lower in both living rooms and bedrooms. Tables 50 and 51 provide a descriptive analysis of indoor temperatures in living rooms and bedrooms respectively for each season.

Other studies, including a large-scale study examining summer temperatures in 207 dwellings across the UK performed by Beizaee et al. (2013), have also found that

detached homes were cooler than other built-form types, and that older dwellings and solid wall houses were cooler than new and cavity wall construction homes respectively.

Table 50: Descriptive analysis of indoor temperatures during the occupation hours in living rooms of each archetype using the three energy behaviours profiles for heating, cooling and no heating/cooling seasons

N=11315		SEASON											
		HEATING				COOLING				NO HEATING/COOLING			
		Mean	Max	Min	sd	Mean	Max	Min	sd	Mean	Max	Min	sd
Flat prefabricated	ESB	18.0	27.1	8.9	3.6	29.2	32.5	23.6	1.9	25.0	30.0	18.5	1.9
	EAB	18.5	27.1	10.0	3.1	28.7	32.2	23.6	1.6	25.0	30.0	18.5	1.9
	EIB	21.0	27.2	13.5	1.7	27.2	31.8	23.0	1.4	24.5	29.7	18.5	1.7
Flat red brick	ESB	15.3	22.9	6.2	3.3	28.6	31.1	21.8	2.1	22.7	27.1	17.5	1.9
	EAB	16.6	22.9	8.8	2.5	28.3	30.3	21.8	1.9	22.7	27.1	17.5	1.9
	EIB	20.2	23.1	11.8	1.5	26.9	29.1	21.4	1.5	22.0	26.6	17.5	2.0
Flat Silicate bricks	ESB	19.3	27.8	1.3	3.8	29.3	31.3	19.8	2.0	24.8	30.2	15.9	2.7
	EAB	19.7	27.7	1.6	3.5	28.7	30.8	19.8	1.7	26.3	30.8	15.6	2.5
	EIB	21.6	27.9	2.4	2.6	26.8	30.4	17.7	2.0	25.5	30.6	15.6	3.0
Flat hollow brick	ESB	18.4	26.2	9.4	3.3	28.8	31.2	23.1	2.1	24.7	29.7	18.8	1.8
	EAB	18.9	26.2	11.2	2.7	28.3	30.2	23.1	1.8	24.7	29.8	18.8	1.7
	EIB	21.2	26.2	14.8	1.3	26.7	29.3	21.7	1.5	24.9	30.6	18.8	2.1
Detached pre-90	ESB	15.4	23.7	1.3	3.1	26.8	31.0	18.4	2.5	21.7	28.0	15.7	2.5
	EAB	16.3	23.7	1.4	2.6	26.7	30.0	18.4	2.4	21.7	28.0	15.7	2.5
	EIB	19.8	23.7	2.1	2.2	25.8	29.3	17.7	2.3	21.1	27.9	13.4	2.7
Detached Post-91	ESB	17.8	27.0	10.1	3.2	28.4	31.3	22.7	2.2	24.2	29.8	19.0	1.9
	EAB	18.3	27.0	11.1	2.7	28.1	30.7	22.7	1.9	24.2	29.8	19.0	1.9
	EIB	20.8	26.9	13.1	1.6	26.8	29.2	22.7	1.5	24.0	29.6	19.0	1.8
Semi-detached	ESB	13.9	26.1	.5	4.3	28.1	34.1	18.0	2.9	22.4	31.9	13.7	3.5
	EAB	15.2	26.1	1.2	3.9	27.7	33.1	18.0	2.6	22.4	31.9	13.7	3.5
	EIB	19.5	26.1	2.4	2.9	26.4	29.6	16.8	2.2	22.0	31.7	11.7	3.6
Terraced	ESB	16.6	24.2	1.2	3.4	26.9	31.0	17.4	2.6	22.2	27.9	13.9	2.7
	EAB	17.3	24.2	1.6	3.0	26.7	30.5	17.3	2.5	22.2	27.8	13.9	2.7
	EIB	20.2	24.9	2.4	2.4	25.8	29.3	15.4	2.4	21.5	27.7	11.0	3.0

Table 51: Descriptive analysis of indoor temperatures during the occupation hours in bedrooms of each archetype using the three energy behaviours profiles for heating, cooling and no heating/cooling seasons

N=5474		SEASON											
		HEATING				COOLING				NO HEATING/COOLING			
		Mean	Max	Min	sd	Mean	Max	Min	sd	Mean	Max	Min	sd
Flat prefabricated	ESB	12.5	21.3	4.5	3.6	24.6	29.8	19.4	1.9	20.5	26.9	15.1	2.6
	EAB	14.1	22.5	6.5	3.6	27.9	32.1	21.9	2.5	22.2	27.7	16.7	2.4
	EIB	20.8	22.6	17.0	.8	26.4	27.6	21.7	1.5	22.1	27.5	16.7	2.3
Flat red brick	ESB	13.1	20.5	6.5	3.3	27.5	31.1	21.4	2.4	21.0	26.3	16.7	2.1
	EAB	13.3	20.5	7.2	3.1	27.4	31.0	21.4	2.4	21.0	26.3	16.7	2.1
	EIB	20.5	21.0	9.6	1.2	26.2	27.5	20.7	1.9	20.6	26.0	16.7	2.2
Flat Silicate bricks	ESB	15.4	22.6	9.2	3.2	28.8	32.0	23.2	2.2	22.7	27.6	19.0	2.0
	EAB	15.4	22.6	9.2	3.2	28.2	31.4	23.3	2.0	23.0	27.6	13.8	2.1
	EIB	20.9	22.8	12.5	.7	26.7	27.8	22.1	1.4	22.6	27.1	13.3	2.0
Flat hollow brick	ESB	14.4	24.1	6.4	3.6	28.0	33.6	21.6	2.7	22.3	28.8	16.2	2.3
	EAB	14.5	24.1	6.8	3.6	27.9	33.5	21.6	2.7	22.3	28.8	16.2	2.3
	EIB	20.8	24.1	15.6	.9	26.4	27.5	21.4	1.6	22.4	29.2	16.2	2.5
Detached pre-90	ESB	15.1	22.6	8.7	3.0	27.0	31.2	20.6	2.5	21.8	27.3	16.4	2.4
	EAB	15.3	22.6	9.0	2.9	27.0	31.1	20.6	2.5	21.8	27.3	16.4	2.4
	EIB	20.7	22.6	11.7	1.0	26.2	27.5	20.4	1.8	21.6	27.2	16.4	2.4
Detached Post-91	ESB	16.1	24.0	9.6	3.1	27.8	32.4	21.5	2.4	22.9	28.6	17.3	2.2
	EAB	16.2	24.0	9.8	3.1	27.8	32.3	21.5	2.4	22.9	28.6	17.3	2.2
	EIB	21.0	24.0	17.3	.6	26.6	27.5	21.4	1.4	22.9	28.5	17.3	2.2
Semi-detached	ESB	12.9	24.7	2.9	4.2	27.8	34.9	18.5	3.3	21.6	30.7	14.4	3.3
	EAB	13.1	24.7	3.5	4.0	27.8	34.8	18.5	3.2	21.6	30.7	14.4	3.3
	EIB	20.6	24.7	10.6	1.4	26.2	28.0	18.3	2.0	21.5	30.5	14.4	3.3
Terraced	ESB	13.8	23.3	5.6	3.6	27.6	33.5	19.9	3.0	21.5	28.9	15.6	2.8
	EAB	13.8	23.3	5.7	3.6	27.6	33.5	19.9	3.0	21.5	28.9	15.6	2.8
	EIB	20.7	21.3	11.2	1.0	25.4	28.0	20.6	1.9	20.9	25.4	17.4	1.9

6.4. Summary

This chapter set out with the aim of assessing the baseline energy performance of each archetype representing most of the Albanian housing stock through simulations of energy models of real case studies representing each archetype. It has been accepted that Albania lacks the statistical data regarding building information that is necessary to build archetypes. Furthermore, there are limited studies conducted on existing residential buildings in Albania regarding energy efficiency and retrofitting. Even in the other European countries where statistical databases exist, very few of them can cover enough of the information required to create an archetype, so combining and mixing different sources has been advised in these cases (Gulotta et al., 2021). The archetypes representing the Albanian housing stock in the energy point of view were mainly built based on the building characteristics and build period, as well as building materials. Eight archetypes have been produced by this analysis that could represent the existing residential building stock in Albania. However, various variations within the same archetype exist, especially in the residential buildings built after 1991. Furthermore, reference buildings have been defined for this study, to estimate energy consumption and environmental behaviour of the buildings in Albania as well as to estimate the potential energy savings of retrofitting measures, as previously applied by the TABULA project followed by the EPISCOPE project for the development of national typologies for European countries (Ballarini, Corgnati and Corrado, 2014; Coma et al., 2019). Using three different behavioural profiles developed in this study, a range of energy consumption were estimated for each archetype, as well as a variation in indoor temperatures. High variations in energy consumption found when using the Energy Intensive Behaviour profile (EIB) compared to the Energy Saving Behaviour (ESB) and Energy Average (typical) Behaviour (EAB) profiles were found to be due to different heating/cooling setpoints, different heating/cooling operation times and treated floor areas. The indoor thermal conditions also varied in response to different occupancy behaviours.

This investigation demonstrates the significance of occupants' behaviour on energy consumption used for heating and cooling the house. Although the results of this analysis are very important in the field of energy in residential buildings in Albania, the data derived from this study must be handled with caution when used at an urban or national level, mainly due to the estimations considered in this study, as well as archetype simplifications.

CHAPTER 7

Energy improvement models

7.1. Introduction

In this chapter, the improvement scenarios have been analysed using the baseline energy models developed in the previous chapter. In this study, both single energy retrofitting measures and combinations of measures have been applied for each archetype, and energy performance and indoor temperatures have been assessed at the dwelling scale. The improvements followed in exploring various retrofitting options is the fabric first approach. In total, eight options of energy retrofitting have been investigated. Notwithstanding the great attention net-zero energy buildings have gained, it is not explored in this study because Albania is in the first steps of retrofitting existing building stock and lacks the experience, information and expertise necessary to achieve this level of retrofitting. Furthermore, there is a lack of policies and incentives to support these kinds of investments. Nonetheless, NZEB can be the scope of future studies. Following energy simulation estimations, a Cost-Benefit Analysis based on three indicators (Net Present Value, the Internal Rate of Return and the Payback Period) has been calculated for each retrofitting measure and package to assess their cost-effectiveness. Thereafter, the results will be used in the next chapter to assess acceptability by homeowners as well as will serve as guidance for future energy retrofit policies.

7.2. An overview of applied energy retrofitting measures

From the analysis of the actual performance of the 49 case studies in this study, and baseline energy models in the previous chapter, it was found that almost all the dwellings were constantly overheated in summer and under-heated in winter, mainly due to the inability of the occupants to heat and cool the space during winter and summer respectively due to cost concerns and occupants' behaviours. Therefore, various energy retrofitting measures should be considered to improve energy consumption used for heating and cooling the space, as well as to improve the comfort of the occupants.

A building energy retrofit typically takes one of two forms: a shallow or deep energy retrofit.

Single measures, known also as shallow retrofits, consist of quick, straightforward energy savings where individual retrofit measures apply to different building

components, such as the envelope or heating systems, and controls, resulting in energy savings of up to 45% and involving little risk and limited costs (D'Agostino, Zangheri and Castellazzi, 2017). The single measures considered in this study are the most used recently in the Albanian context. The most innovative materials and technologies have been excluded because of the costs and the unconsolidated experience of the installers, which would result in failures of application and consequently their future performance.

Combinations of individual retrofitting measures into packages to involve whole building components, often known as deep retrofits, often results in energy savings of more than 45% (Dodoo, Gustavsson and Tettey, 2017; Jankovic, 2019) and up to 95% (National Energy Foundation, 2014) and it is a procedure that is recommended internationally (Dixon and Eames, 2013; Beagon, Boland and O'Donnell, 2018).

This study included the most typical elemental strategies, including insulation of various building components of the building envelope as well as heating system, followed by two packages for deep retrofit that could show the potential of energy retrofits in Albanian residential buildings to further reduce energy demand. With the right policy incentives, many homeowners can benefit from the full potential of deep energy retrofits.

An overview of retrofitting strategies considered in this study is detailed in Table 52.

Table 52: Description of retrofit measures and packages considered for energy modelling

Retrofit measure or package	Single measure/ combination	Retrofit measures type	Retrofit measures
M1	Single	Fabric	5cm external wall insulation
M2	Single	Fabric	10cm external wall insulation
M3	Single	Fabric	Replacement of single glazed windows with double glazing (argon 13mm infill) and blinds
M4	Single	Fabric	12cm roof insulation
M5	Single	Fabric	5cm floor insulation
M6	Single	Heating/cooling system	Higher efficiency of the split system
P1	Combination	Fabric	5cm external wall insulation and double glazing (M1 and M3)
P2	Combination	Heating/cooling system, fabric	10cm external wall insulation, double glazing, 12cm roof insulation, 5cm floor insulation and higher efficiency of the split system (M2, M3, M4, M5 and M6)

Notwithstanding the wide range of energy savings from elemental and deep retrofits from 45% (D'Agostino, Zangheri and Castellazzi, 2017) to 95% (National Energy Foundation, 2014) respectively, it is widely recognised that occupant behaviour can have a significant

impact on the successful results from energy retrofits. Therefore, behavioural change was considered in this study as part of the measures taken to energy saving. This method usually results in average savings of up to 25% (D'Agostino, Zangheri and Castellazzi, 2017) and even up to 50% (Zhao et al., 2017) and involves minimal risk and investment.

Renewables have not been considered in this study because the grid is already “low emission and renewable” since 90% of the country’s electricity production comes from hydropower and it already emits the lowest amount of CO₂ in the Western Balkans (International Energy Agency, 2008). However, it would be important to explore the profitability of renewables in terms of energy savings and that could be the scope of future studies.

7.3. Model inputs and assumptions

Energy baseline models for each archetype developed in the previous chapter are used for the assessment of different retrofitting measures considered in this study. One measure or package is applied at a time. Based on the findings of many other studies, including Sanders and Phillipson (2006), Druckman and Jackson (2008), Guerra-Santin and Itard (2010), Chitnis *et al.* (2013), Elsharkawy and Rutherford (2018) and Zahiri and Elsharkawy (2018), the heating and cooling loads are expected to increase as a result of ‘comfort take’, indicating that following the retrofit, heating and cooling is expected to be used for longer periods during the day and the night, as well as in more than one zone within the house. Therefore, the Energy Intensive Behaviour (EIB) profile has been used to inform the improvement energy model regarding the occupants’ behaviours. However, the estimated energy savings, as well as improvements in indoor temperatures after applying the retrofits, have been also compared against baseline results using Energy Saving Behaviours (ESB) and Energy Average (typical) Behaviours (EAB) profiles. Details regarding the model inputs are given in Table 53.

Table 53: Input data for building energy model

		Archetypes to model							
		Detache d pre-90	Detached post-91	Semi- detached	Terraced	Flats pre-90			Flats Post-91
						Full brick	Prefabricated	Silicate brick	
5 cm wall insulation	Floor area	75	92	61	106.5	45	47	57	77
	Treated area (m²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m²K)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	Wall U-value	0.54	0.53	0.53	0.54	0.54	0.52	0.54	0.53
	Ground floor U- value	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
10 cm wall insulation	Treated area (m²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m²K)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	Wall U-value	0.32	0.32	0.32	0.32	0.32	0.31	0.32	0.32
	Ground floor U- value	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
Double glazing + blinds	Treated area (m²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m²K)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Wall U-value	1.76	1.68	1.68	1.76	1.86	1.6	1.86	1.68
	Ground floor U- value								
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
12 cm roof insulation	Treated area (m²)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	Window U-value (W/m²K)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	Wall U-value	1.76	1.68	1.68	1.76	1.86	1.6	1.86	1.68
	Ground floor U- value	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	Roof U-value	0.31	0.13	0.31	0.31	0.13	0.13	0.13	0.13
5cm floor insul	Treated area (m²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m²K)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9

Higher efficiency of split system	Wall U-value	1.76	1.68	1.68	1.76	1.86	1.6	1.86	1.68
	Ground floor U-value	0.52	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
	Treated area (m ²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m ² K)	4.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
	Wall U-value	1.76	1.68	1.68	1.76	1.86	1.6	1.86	1.68
	Ground floor U-value	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
	Treated area (m ²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m ² K)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
5cm wall insulation and double glazing	Wall U-value	0.54	0.53	0.53	0.54	0.54	0.52	0.54	0.53
	Ground floor U-value	1.56	0.97	0.97	0.97	0.97	0.97	0.97	0.97
	Roof U-value	2.43	0.25	2.43	2.43	2.43	1.3	1.3	0.25
	Treated area (m ²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m ² K)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
all	Wall U-value	0.54	0.53	0.54	0.54	0.54	0.52	0.54	0.53
	Ground floor U-value	0.52	0.44	0.44	0.44	0.44	0.44	0.44	0.44
	Roof U-value	0.31	0.13	0.31	0.31	0.13	0.13	0.13	0.13
	Treated area (m ²)	29.3	45	28.8	41.7	24.5	28.7	26.9	41.4
	Window U-value (W/m ² K)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Table 54 presents the input data for space heating systems used for the improvement scenarios. An improvement of the heating system efficiency to COP 3 has been assumed. A duration of five months has been assumed, from November 1 to March 31, while the heating is assumed to be on during most of the day as well as night, with a heating setpoint of 20°C and 18°C for the living room and bedroom respectively.

Table 54: Input data for space heating systems

	Archetypes to model					
Space heating	Detached pre-90	Detached post-91	Semi-detached	Terraced	Flats pre-90	Flats post-91
Space heating system	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump	Air-to-air heat pump
The efficiency of the system: Coefficient of Performance (COP) ^a	3					
Heating duration in months	01 Nov - 31 March					
Heating duration during the day	07:00-10:00 + 12:00-14:00 + 15:00-21:00					
Heating at night	Yes					
Treated rooms	Living room + main bedroom					
Heating setpoint (bedroom)	20°C (18°C)					

Input data regarding the space cooling system and operation are given in Table 55. The same coefficient of performance as per heating of three is being used. Cooling has been assumed to be used for four months during the summer. Furthermore, cooling is estimated to be on after midday as well as during the night at a setpoint of 27.5°C.

Table 55: Input data for space cooling systems

	Archetypes to model					
Space cooling	Detached pre-90	Detached Post-91	Semi-detached	Terraced	Flats pre-90	Flats post-91
Space cooling system ^{a,b}	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)	Air-conditioning (split units)
The efficiency of the system: Coefficient of Performance (COP) ^a	3					

Cooling duration in months ^b	1 June – 31 September
The cooling duration during the day ^b	12:00-22:00 + 22:00-07:00
Cooling at night	Yes
Treated rooms	Living room + main bedroom
Cooling setpoint (setback) ^b	27.5°C

7.4. Results and analysis

7.4.1. Electricity consumption

Simulated monthly electricity consumption before and after improvements are plotted against mean indoor temperatures for each archetype in the graphs in Figure 42, including electricity consumption and mean indoor temperatures for three baseline models, using the three baseline behavioural profiles developed in the previous chapters. As was expected, the highest electricity reduction used for heating and cooling has been estimated for the older archetypes. Furthermore, the building material of the external walls has influenced the results considerably. Buildings with massive brick walls have seen a greater reduction in heating loads after wall insulation, whereas the newest constructions have seen greater reductions in cooling loads after external wall insulation. Looking at the detached houses-built pre-90 and post-91, there is a low cooling load during the summer compared with the heating load during the winter in houses pre-90. However, there is a balance of heating and cooling loads throughout the year in houses built post-91. This is affected by the thermal capacities of the external walls of both constructions.

In flats built pre-90, the estimated electricity consumption for heating and cooling after applying the packages P1 and P2 of the retrofitting measures are even lower than the electricity consumption using ESB and EAB profiles. That means that the indoor thermal conditions would greatly improve with the same or even less cost. However, in the other archetypes, although the cooling loads after applying the packages have been lower than the ones using ESB, the heating loads have been higher than the baseline heating loads using ESB. In all the cases, the heating and cooling loads have been reduced considerably after applying every single measure and package compared with the baseline using Energy Intensive Behaviour (EIB).

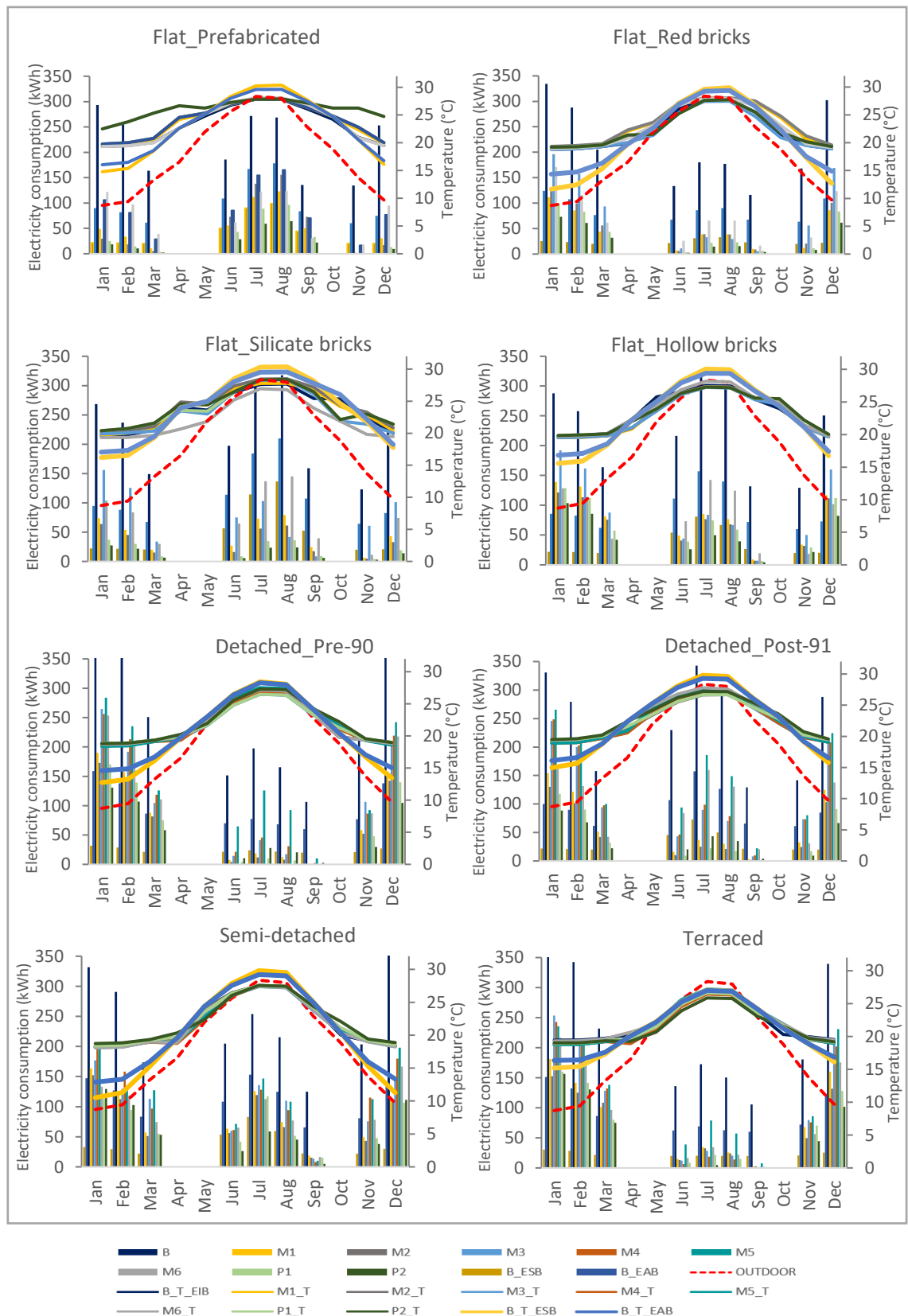


Figure 42: Monthly electricity consumption and indoor mean temperatures during occupation hours in living rooms for each archetype.

A summary of the results on energy reductions for each archetype using six single measures and two packages of measures is provided in Figure 43, followed by Table 56.

Using the simulation results, the effect of each measure is quantified as the percentage of reduction in the energy required to heat and cool the space, compared to the baseline model with the Energy Intensive Behaviour profile.

Among the energy retrofitting measures analysed, the measure that leads to the lowest energy requirements for heating and cooling the space is identified for each archetype. As expected, the potential effectiveness of the retrofitting measures to reduce energy consumption for heating and cooling the space depends on the age of the building. Typically, the highest energy reductions have been estimated for older buildings, as found previously in many studies (Krarti, Aldubyan and Williams, 2020). In all archetypes, the package with the combination of all single measures (deep retrofit) has been found to have the highest energy-saving potential for heating and cooling the space. However, package P1, which includes window replacement and 5cm external wall insulation, is estimated to deliver the second-high energy reduction after the full retrofit package P2.

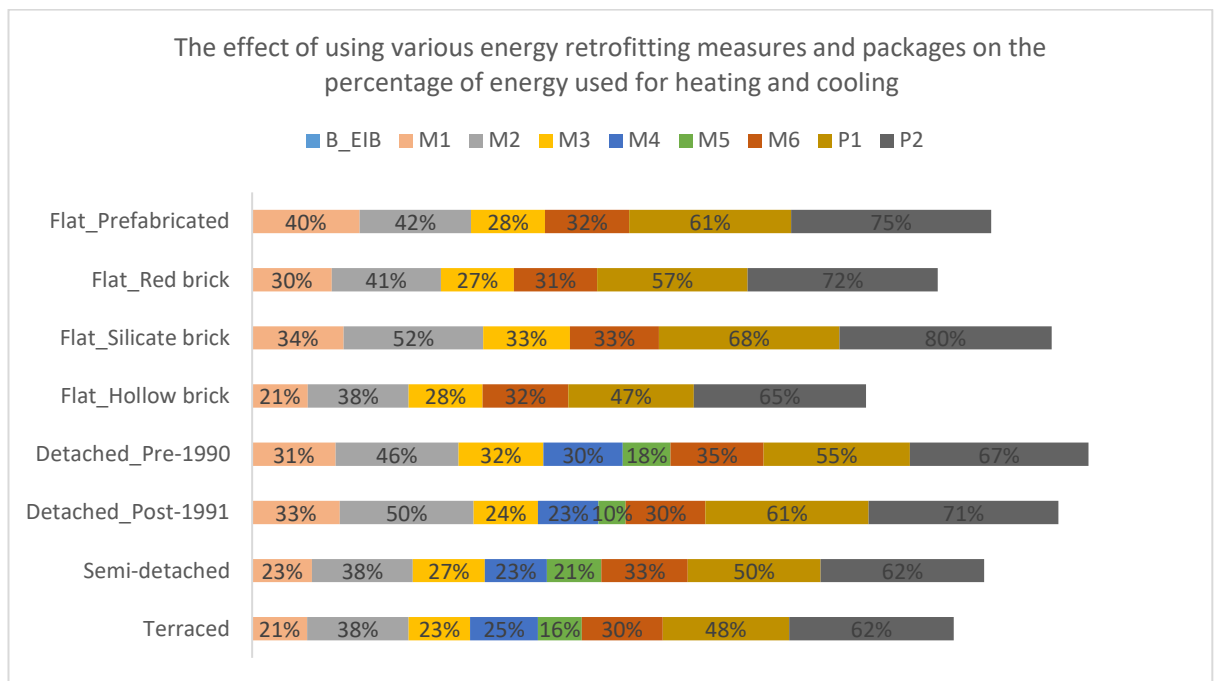


Figure 43: The effect of using various energy retrofitting measures and packages on the percentage of energy used for heating and cooling.

Table 56: The effect of using various energy retrofitting measures and packages on the percentage of energy used for heating and cooling

	Flat_Prefabricated	Flat_Red brick	Flat_Silicate brick	Flat_Hollow brick	Detached_Pre-1990	Detached_Post-1991	Semi-detached	Terraced
B	0%	0%	0%	0%	0%	0%	0%	0%
M1	40%	30%	34%	21%	31%	33%	23%	21%
M2	42%	41%	52%	38%	46%	50%	38%	38%
M3	28%	27%	33%	28%	32%	24%	27%	23%
M4					30%	23%	23%	25%
M5					18%	0%	21%	16%
M6	32%	31%	33%	32%	35%	30%	33%	30%
P1	61%	57%	68%	47%	55%	61%	50%	48%
P2	75%	72%	80%	65%	67%	71%	62%	62%

B-Baseline

M1-5cm external wall insulation

M2-10cm external wall insulation

M3-Double glazing

M4-12cm roof insulation

M5-5cm floor insulation

M6-upgrade of split system heat pump

P1-5cm external wall insulation + double glazing

P2-10cm wall insulation + 5cm floor insulation + 12cm roof insulation + upgrade of split system

External wall insulation of 5cm and 10cm are the most effective single measures regarding energy reduction, while floor insulation M5 has been found to be among the least effective, with electricity reduction estimated up to 21%. It has been found previously that thermal insulation of the opaque envelope elements is usually the most effective measure in terms of energy savings. Insulating 5cm thermal insulation on the external walls, estimates an energy reduction used for heating and cooling the space of 21-40% based on the archetype. The thermal insulation of the 5cm external insulation of the external walls has been considered an optimum thermal insulation level for zones A and B of the Albanian climate (Papadopoulos, 2003). In fact, in most of the archetypes, there is only a small increase in estimated energy savings when 10cm thermal insulation is used instead of 5cm, and hardly any change on flats pre-90. However, despite the high potential for energy savings through wall insulation, attention should be given during the construction stage as the expected performance may not be achieved in practice due to construction details and poor workmanship (Hansford, 2015).

Only double-glazing windows has been found to deliver potential energy savings of up to 33% for heating and cooling the space. In all the archetypes, potential energy savings have been found to be less than external insulation and more than other building envelopes thermal insulation as single measures. Oberegger, Perneti and Lollini (2020) found that window replacement was the most used in the South Tyrol region mainly because of its relatively low initial investment as well as the improved indoor environment and increased house value. Furthermore, they were easy to implement and manage in the context of apartment blocks and multi-family houses.

Roof insulation as a single measure has achieved potential energy saving only on single-family houses, which reaches up to 30% in the detached pre-1990 house. Change in energy consumption would also be noticeable in the top floor flats, however, because the reference dwellings have been chosen to be in between floors, no change has been shown after applying this measure. Similar to roof insulation, the energy-saving potential of floor thermal insulation has not been shown in flats, due to the middle floor location of the flats. However, a low energy saving potential of up to 21% has been shown in single-family houses (detached, semi-detached and terraced). Moreover, the floor insulation can be disruptive and is not likely to be undertaken as a single measure for energy savings, but as part of a whole retrofit (Shorrock, Henderson and Utley, 2005) or as part of changing the floor for decorative reasons.

The type of the heating system considered in this study is that of the split system with reverse action, which makes the system usable for cooling the space as well. The reason for choosing this type is due to its popularity in use as well as the lack of infrastructure for gas central heating in Albanian residential buildings. It is considered to have an energy efficiency with COP of three, as found a suitable one in the Albanian context by Novikova et al (2015). However, it is important to mention that using wood stoves in climatic zone C could be more effective than the split system. Upgrading the heating system is usually the cheapest measure in terms of investment costs and has the shortest payback period (Ballarini *et al.*, 2017). The energy savings potential for energy requirements for heating and cooling the space remains in the region of 30-35% for all the archetypes, regardless of the construction year of the built form. Compared to other single measures, the potential energy savings through upgrading the split system are greater than potential energy savings from replacements of windows, as well as thermal insulation of roof and floor in all the archetypes, while not always greater than the potential energy savings through thermal insulation of external walls.

It is noticed that in almost every case of retrofitting, the potential energy savings of the package of measures has been found to be lower than the sum of single measures taken alone. This has been also found previously by Ballarini *et al.* (2017). This highlights the advantage of analysing and simulating retrofit combinations to identify alternative retrofit combinations for different types of archetype dwellings. Potential energy savings of 47-68% have been found, with the highest energy saving potential for flats built pre-1990, confirming again the poor condition of the buildings' envelope. Creating a deep retrofit with the combination of all single measures (with 5cm external wall insulation) provides the highest potential for energy savings, reaching up to 80%. Again, the highest energy savings for heating and cooling have been found in apartment buildings built pre-1990. In all cases, the potential energy savings have been found to be lower than the sum of single measures taken alone. Therefore, a cost analysis is essential in the case of packages of measures to assess the energy saving – cost ratio.

The results obtained show the high potential in energy savings for heating and cooling the space in all archetypes in residential buildings in Albania, confirming once more the poor energy quality of the existing residential buildings in Albania.

7.4.2. Indoor temperatures in living rooms and bedrooms

Living room and bedroom indoor temperatures at half-hour intervals have been extracted from the computer simulation of each archetype after applying each of retrofitting measures. Thereafter, they are compared with the temperature occurrence of baseline models using three different behavioural profiles ESB, EAB and EIB as shown in Figures 44 and 46 for summer and winter respectively. When comparing baseline and improvement scenarios during the cooling season, there is an immense reduction in the occurrence of temperatures over 28°C after applying each of retrofitting measures, especially using the ESB and EAB. There is a higher chance of overheating in flats, which is expected with fewer possibilities for cross ventilation. It is noticed that the highest indoor temperatures are occurring in the prefabricated flat. Potential summer overheating issues after the application of retrofitting measures has also been found by (Qu *et al.*, 2021) who recommend more ventilation, either natural or mechanical, when adopting these measures.

The application of retrofitting measures has decreased the occurrence of temperatures above 28°C from over 70% of the occupied time using ESB and EAB to 21% of the occupied time after applying the packages of measures. It noticed a higher occurrence

of temperatures over 28°C after applying the single measures compared to the baseline temperatures using EIB. This indicates that the indoor thermal conditions may not get better than the baseline using the EIB, and higher electricity bills might occur for better indoor conditions related to lower setpoint temperatures than considered in this study (27.5°C).

As can be seen from Figure 44, significant improvements to indoor thermal conditions followed the application of fabric improvement. However, a slight improvement in indoor temperatures was noticed when using 10cm thermal insulation compared to 5cm. An increase in overheating because of thicker insulation, such as in the case of flats built with silicate walls and semi-detached houses, was also noticed. The application of the package of measures was followed by better indoor temperatures than the baselines, however, they were slightly increased on the silicate flat, which indicates the need for further ventilation of this archetype after full refurbishment to prevent overheating. Overall, there is noticed a shift in the percentage of temperature occurrence from over 28°C to 26-28°C when comparing the improvement scenarios with the baseline ones using ESB and EAB, affected by the setpoint temperature of 27.5°C used for the improvement scenarios compared with 30°C and 29°C for ESB and EAB profiles respectively.

On the other hand, there is noticed a lower percentage of occurrence of indoor temperatures higher than 28°C in bedrooms compared with the living rooms after each retrofitting strategy, similar to the baseline scenario using EIB.

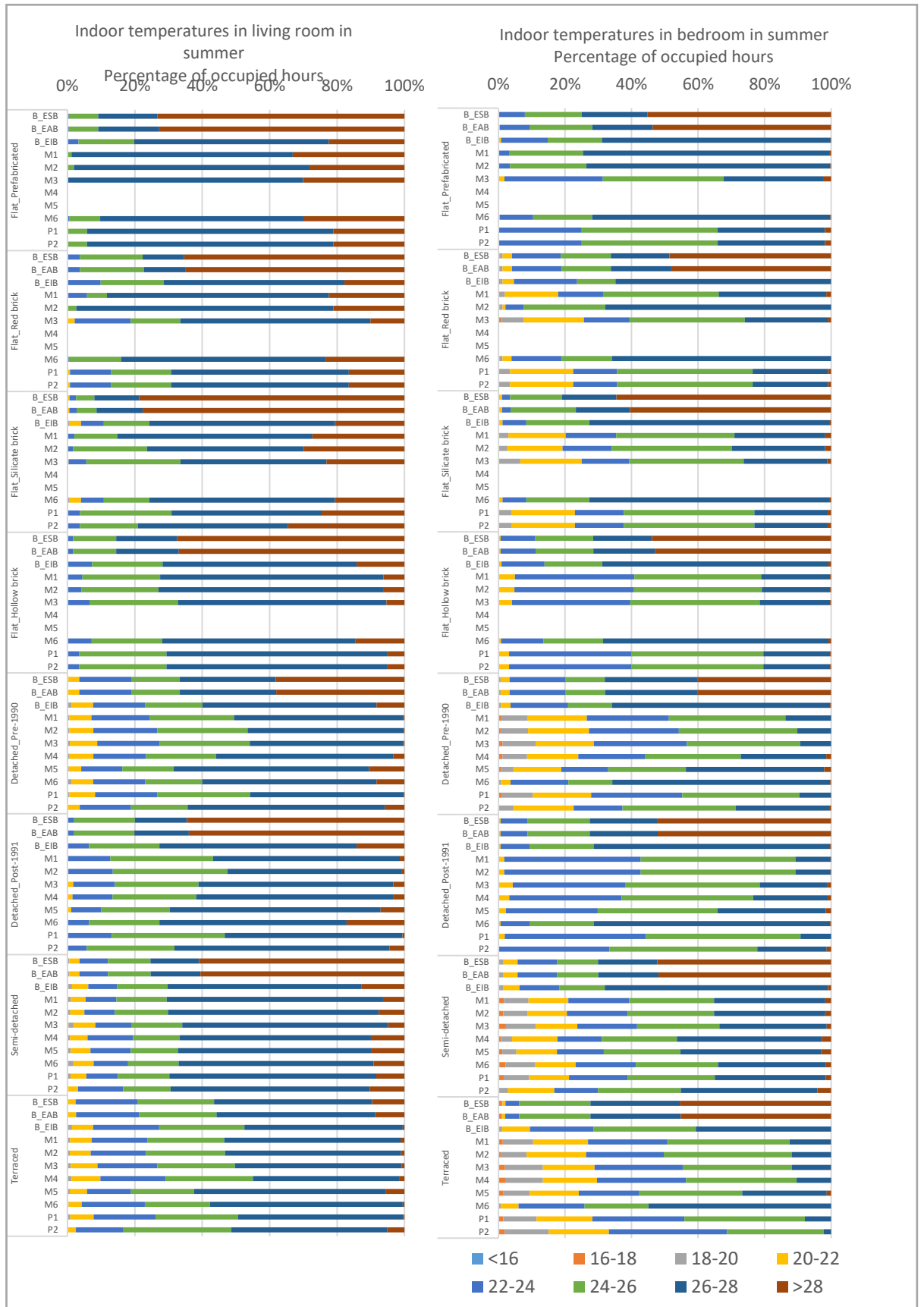


Figure 44: Indoor temperature duration during the occupation time in living rooms of each archetype modelled for each retrofitting measure during the cooling season.

In Figure 45, mean hourly temperatures are plotted for each archetype after applying each of the retrofitting strategies and comparing them with the mean hourly indoor temperatures of baseline energy models using all three behavioural profiles (ESB, EAB and EIB). It is noticed that mean indoor temperatures throughout the day are lower in houses/flats built with full bricks, due to the thermal mass that this construction is known to provide during the cooling season. Indeed, there is not a great difference between the mean hourly temperatures between the three baseline models, despite using three different behavioural profiles in terraced houses, detached pre-90 and flats with red bricks. The improvement can be noticed not only during the occupied hours but also during the night. It is interesting that there is no evident difference in indoor temperature throughout the day when improvement measures are applied to constructions with hollow bricks (hollow brick flats and semi-detached houses), while this difference is more prevalent in houses/flats built with red bricks. Mean indoor temperature is highest in the prefabricated flats even after applying the improvements. However, applying the packages P1 and P2 would provide the lowest indoor temperature in most of the archetypes. Insulating the roof proves to be one of the measures that improves the indoor thermal conditions of the houses, whilst choosing 10cm over 5cm external thermal insulation doesn't improve the indoor temperatures by more than 0.3°C. Upgrading the split system to a more efficient one improves indoor temperatures only during the operation hours, as can be seen in each graph.

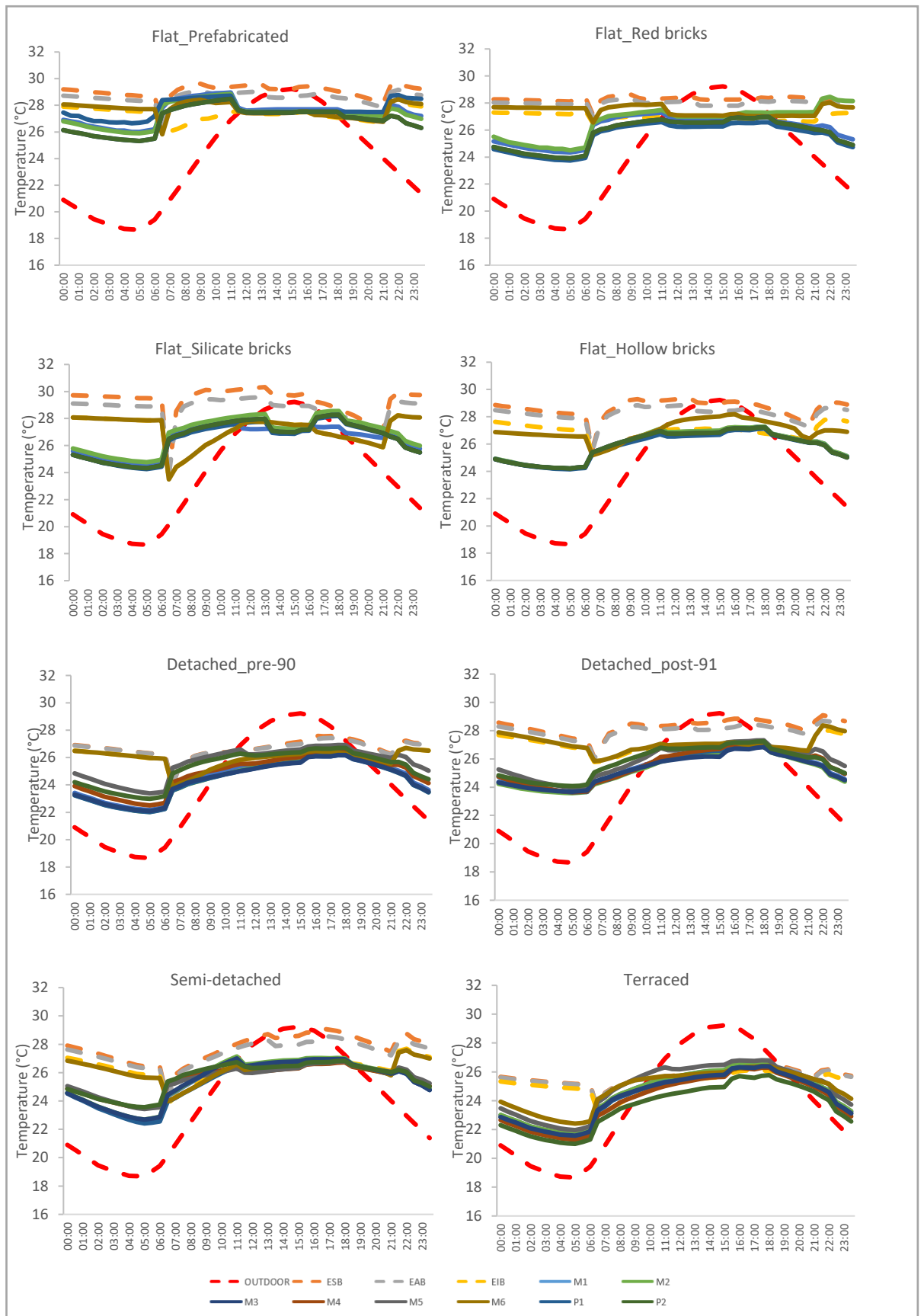


Figure 45: Mean hourly temperatures in living rooms during the summer.

The same analysis for the heating season (see Figures 46 and 47) shows an impressive improvement in indoor temperatures after applying each measure, when compared with the baseline indoor temperature using ESB and EAB, considering the reduction of the amount of time the temperatures below 20°C occurred. It can be noticed that the application of the packages of measures provided the highest improvement in indoor temperature. Indeed, the percentage of indoor temperatures below 20°C in the living rooms has decreased from 70% of the time in flats prefabricated before retrofitting, to 30% and 0.5% after applying 5cm thermal external insulation and a deep retrofit (P2) respectively. However, it is interesting that there is almost the same temperature occurrence after applying both packages of retrofitting (P1 and P2).

Furthermore, there is only a slight improvement after improving the efficiency of the split system. On the other hand, in bedrooms, the temperature above 18°C has increased from 83% to 99% of the time in flat_Red brick and Detached post-91 respectively. Compared to the baseline results using ESB and EAB that is a great improvement, considering that the indoor temperatures below 18°C have been up to 89% of the occupation time.

Looking deeply at indoor temperature distribution during the day during the heating season after improvements, as shown in Figure 47, it is interesting to notice that only in prefabricated dwellings, differ for each retrofitting measure applied, with the highest temperature provided by the application of a deep retrofit and 10cm external wall thermal insulation. However, these two scenarios have been the most effective ones for every other archetype in terms of thermal comfort. There is a lower temperature fluctuation during the day after retrofitting measures in the flats, compared to houses, mainly due to lower external surfaces.

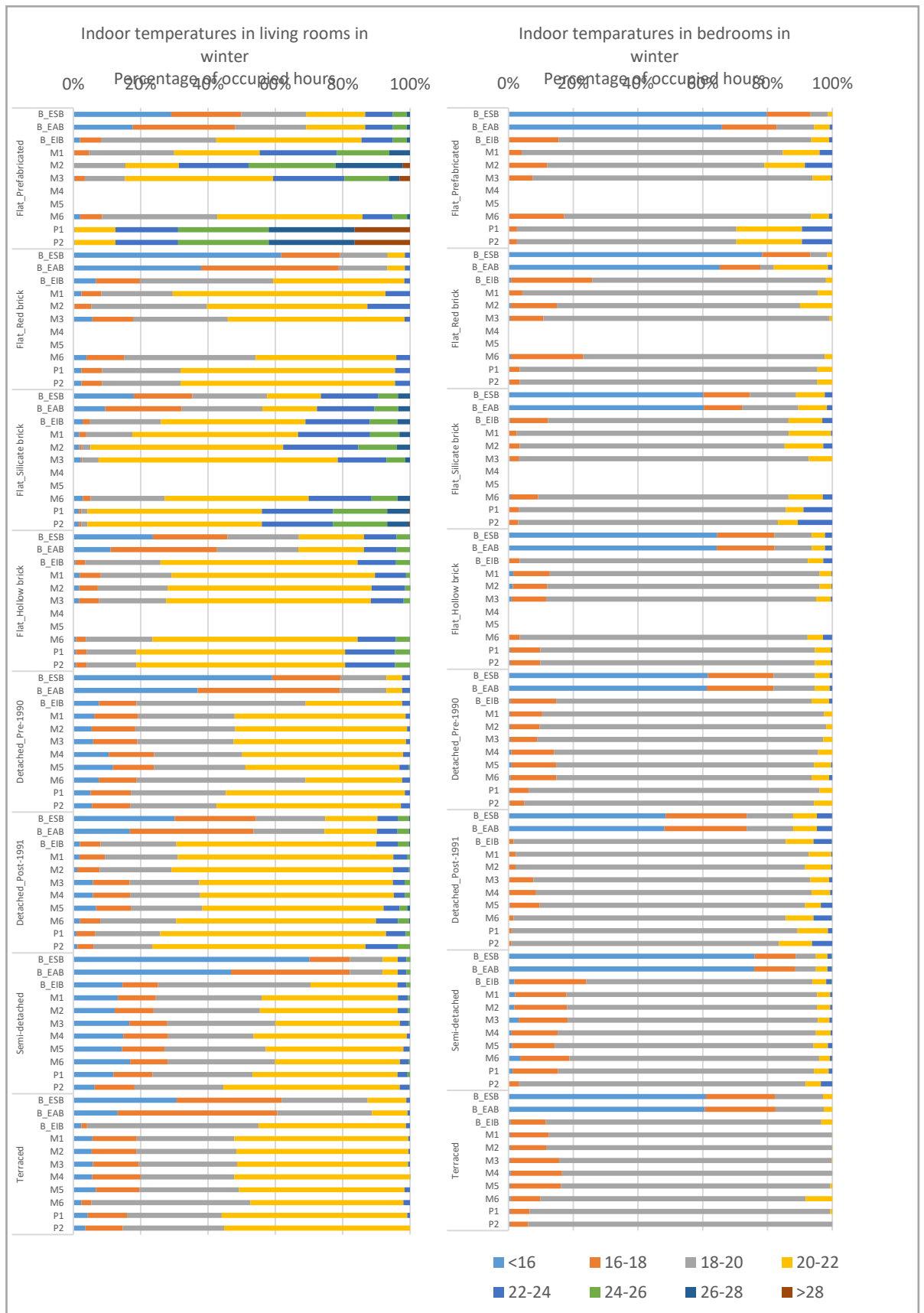


Figure 46: Indoor temperature duration during the occupation time in living rooms of each archetype modelled for each retrofitting measure during the heating season.

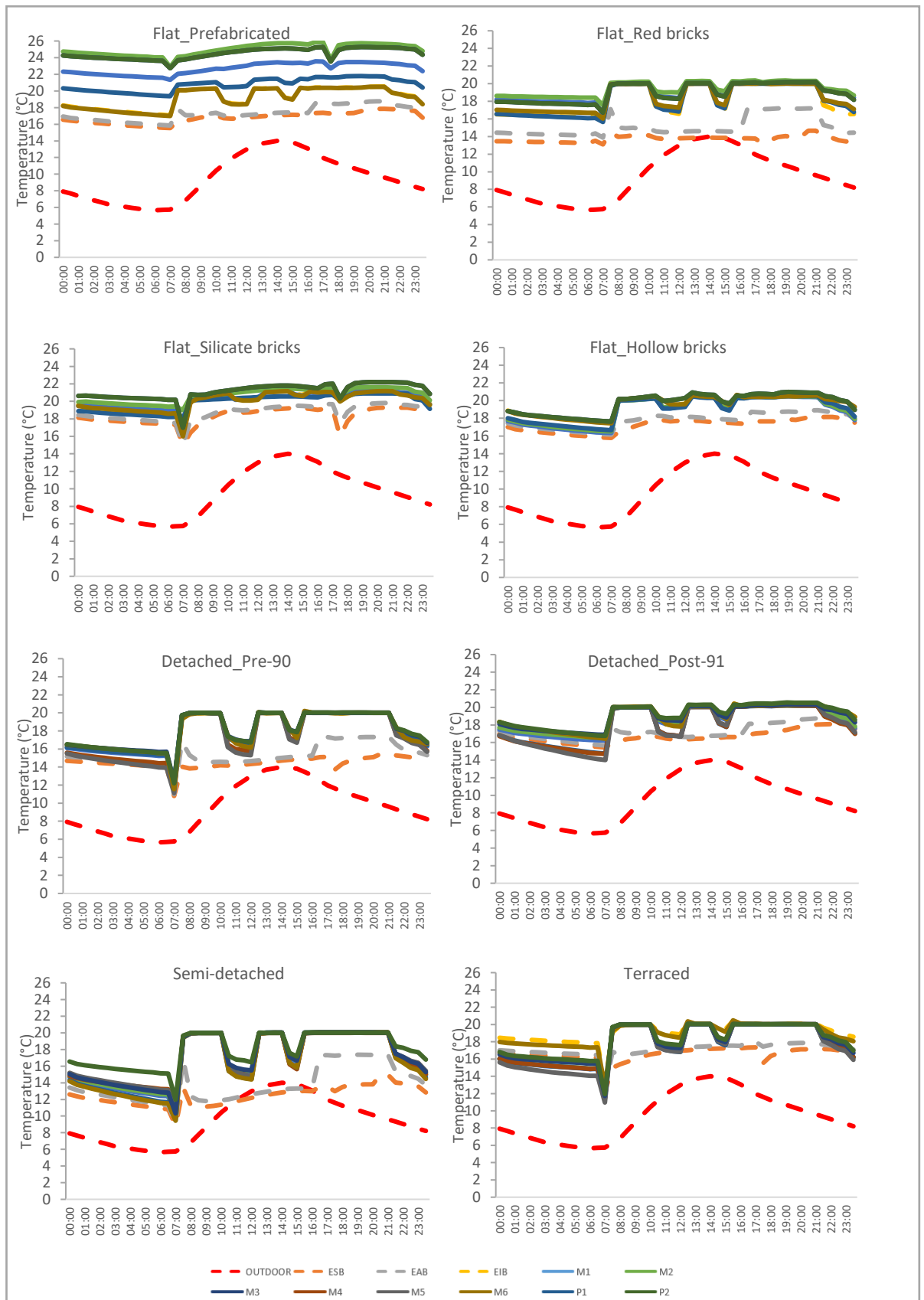


Figure 47: Mean hourly temperatures in living rooms during the winter.

7.5. The cost impact of the improvement measures

This section investigates the cost-effectiveness of the energy retrofitting strategies investigated in this study in Albanian residential buildings, in terms of their financial viability based on the identified building archetypes. Despite various research proving the large energy savings that are possible by applying various energy retrofitting measures, investments in energy efficiency in residential buildings remain low, and the cost of retrofitting strategies has been found to be one of the main barriers to action at dwelling scale (Bardhan *et al.*, 2014). On the other hand, the lack of accuracy of the projected savings has often led to questions about the benefits of investing in energy retrofitting of houses and has discouraged these kinds of investments (Fowlie, Greenstone and Wolfram, 2018). Therefore, undertaking a Cost-Benefit Analysis of the retrofitting measures would provide essential relevant information to decision-makers to design good efficient energy retrofit policies, as well as for households to choose the most appropriate intervention based on their needs and expectations.

Input data needed to conduct the Cost-Benefits Analysis have been aggregated from various data sources. Baseline energy consumption, as well as energy savings after applying each retrofitting measure or packages in each archetype, found previously in this study will be the basis of the cost calculations. Real investment costs for each measure have been taken from national price lists and costs from various companies operating in Albania.

Thereafter, the cost-effectiveness of each energy retrofit measure has been calculated, together with the distribution of Net Present Values. In these calculations, energy savings are considered as constant cash flows over time. Moreover, the electricity price is considered constant over the years due to the lack of provisions in Albanian literature, even though it is expected to increase, in line with other European countries.

Three indicators have been used to investigate the cost-effectiveness of the retrofitting measures proposed in this study:

The Net Present Value (NPV) – is a financial metric that seeks to capture the total value of a potential investment opportunity. It is used to measure the costs, benefits and the and profitability of an investment over time.

The Internal Rate of Return (IRR) – measures the attractiveness of the project and it is used to compare projects with different lifespans or amounts of required capital. It is the equivalent annual rate of return that reduces the NPV of an investment to zero.

The Payback Period (PP) – is a simpler alternative to NPV and it calculates how long it will it take for the initial investment to be repaid.

7.5.1. Results

As was found in previous research (Luddeni *et al.*, 2018; Belaïd, Ranjbar and Massié, 2021) the cost-effectiveness of some energy retrofitting measures can vary significantly with building characteristics. Studies (Luddeni *et al.*, 2018; Belaïd, Ranjbar and Massié, 2021) have demonstrated that the cost-effectiveness of energy retrofitting measures is extensively dependent on inputs parameters related to dwelling's initial characteristics, as well as the values of energy-saving amount, energy price and the discount rate. Similarly, Ortiz *et al.* (2016) have found that energy price, strategy cost, and interest rate have the greatest impact on the global cost of energy retrofitting strategies.

A classification of measures for each archetype is performed, aiming to assist private householders as well as policymakers in their decision-making process. It is demonstrated that energy retrofitting of the existing housing stock in Albania can lead to a great amount of energy reduction, however it requires substantial financial capacity.

The graph at Figure 48, followed by Table 57, shows each retrofitting strategy with its calculated average Net Present Value and Payback Period for a discount rate of 4% and a 30-year lifespan of measures. The best measures are those that have a low Payback Period and high NPV. It is noticed that single measures, including 5cm and 10cm thermal insulation of external walls and replacement of single glazed windows with double glazing are the most cost-effective measures with an NPV of €965.2, €750.5 and €754 respectively and a Payback Period of 8.6, 10.6 and 8.2 years respectively. Roof and floor insulation have a Payback Period of 17 and 12.9 years respectively, while the average NPV is €25 and €279.3 respectively. When it comes to the replacement of the split system, it has a positive NPV of €168, however, the payback period of this measure is 15 years, which might make it unattractive to many households. From the packages of retrofitting measures, it is noticeable that deep retrofitting (P2) is not cost-effective based on the high Payback Period (34.4 years) and the negative NPV (-€2,166.7), while the P1 package (5cm external wall insulation and window replacement) is found to be profitable with an NPV of 283.4 and a Payback Period of 14 years. This is due to the high investment costs of the P2 package of retrofitting measures, compared to the P1, as well as the difference in energy savings between the two packages of less than 20%. It is evident from this analysis that from the cost-benefit point of view, thermal insulation of

the external walls and replacement of the windows are the most cost-effective measures for residential buildings in Albania.

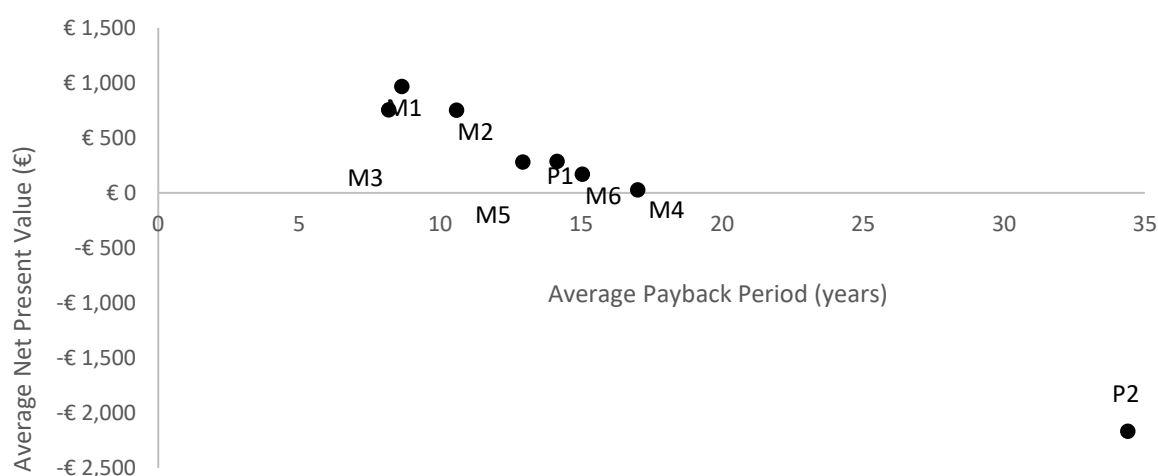


Figure 48: Distribution of retrofitting strategies according to their average NPV (€) and Payback Period (years) for a 4% discount rate and 30-year lifespan.

Table 57: Average Net Present Value (NPV) and Payback Period (PP) for each retrofitting measure considered in this study, for a 4% discount rate and 30-year lifespan.

	Retrofitting measure	Average PP	Average NPV
M1	external wall insulation 5cm	8.6	€ 965.29
M2	external wall insulation 10cm	10.6	€ 750.49
M3	double glazing	8.2	€ 754.02
M4	roof insulation 12cm	17.0	€ 24.91
M5	floor insulation 5cm	12.9	€ 279.26
M6	split system upgrade	15.0	€ 168.02
P1	external wall insulation 5cm and double glazing	14.1	€ 283.43
P2	external wall insulation 5cm, double glazing, roof insulation, floor insulation and split system replacement	34.4	-€ 2,166.74

However, despite the average NPV being positive for most of the retrofitting strategies, in looking deeper at the individual ones for each archetype (Figure 49), it can be noticed that some of the strategies have a negative NPV and are not profitable for some archetypes, such as 10cm thermal insulation of external walls and package P1 in detached houses built both before and after 1990, mainly due to high areas of external walls. Deep retrofitting (P2) has a negative NPV for all the archetypes, except the prefabricated flat, which has a positive NPV of €578.4. Overall, most of the individual

NPVs are positive and have a payback period of fewer than 15 years. As found by Belaïd, Ranjbar and Massié (2021), the variability of individual NPVs highlights the influence of highly variable costs and dwelling characteristics.

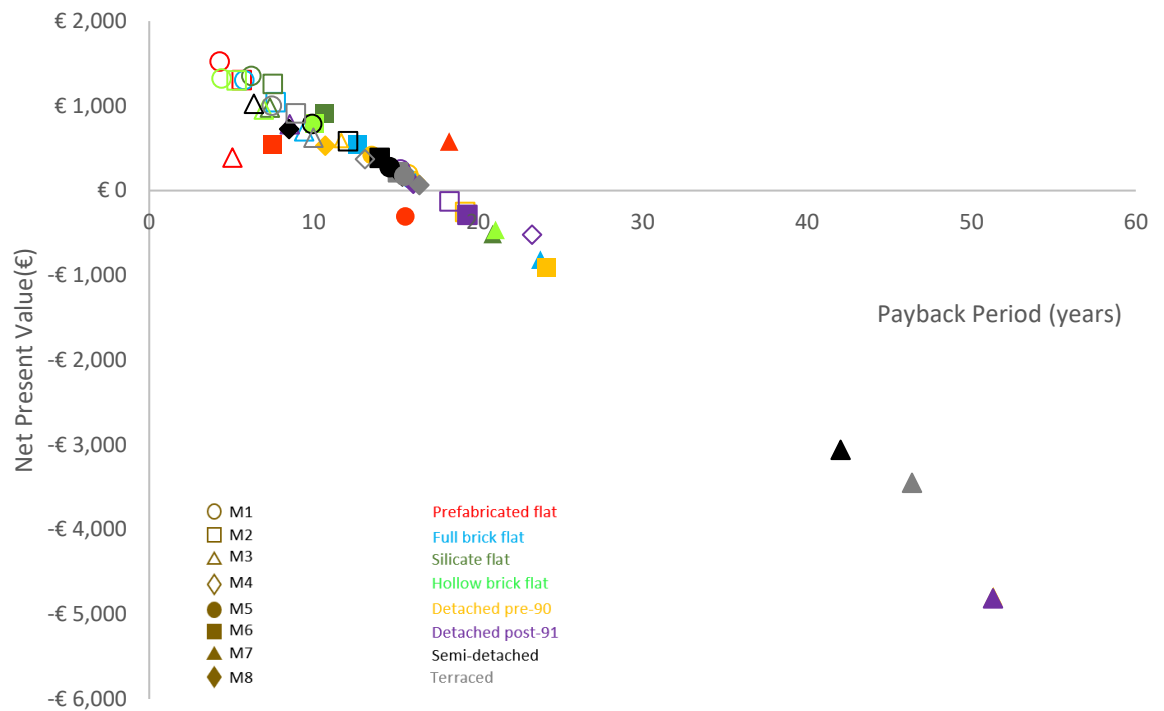


Figure 49: Distribution of retrofitting strategies according to their NPV (€) and Payback Period (years) for a 4% discount rate and 30-year lifespan.

The graph in Figure 50 shows the results of the three indicators used to investigate the cost-benefits of each retrofitting measure. While most of the retrofitting measures have a positive NPV, deep retrofitting (P2) estimates a net loss of up to -€4,813 in detached houses built post-91. Moreover, deep retrofitting is not attractive at the present with an average 0% Internal Rate of Return, which is less than the 4% discount rate. For an investment to be attractive, the Internal Rate of Return is expected to be higher than the discount rate (4% in this study). Furthermore, it represents the highest payback period with an average of 34.4 years and the highest payback period of 51 years in detached houses, regardless of the built period. On the other hand, 5cm thermal insulation of external walls is the most attractive investment with an internal rate of return of up to 25% in the prefabricated flats, followed by 10cm thermal insulation of external walls and window replacements, both with an average internal rate of return of 11% (max internal rate of return of 17% and 16% respectively). The upgrade of the split system is the measure with the lowest variability on all three indicators, regardless of the dwelling characteristics, due to the same investment cost for all the archetypes. It is important to notice the low payback period of window replacement for all the archetypes, making this

measure very attractive in Albanian residential buildings, regardless of the dwelling characteristics.

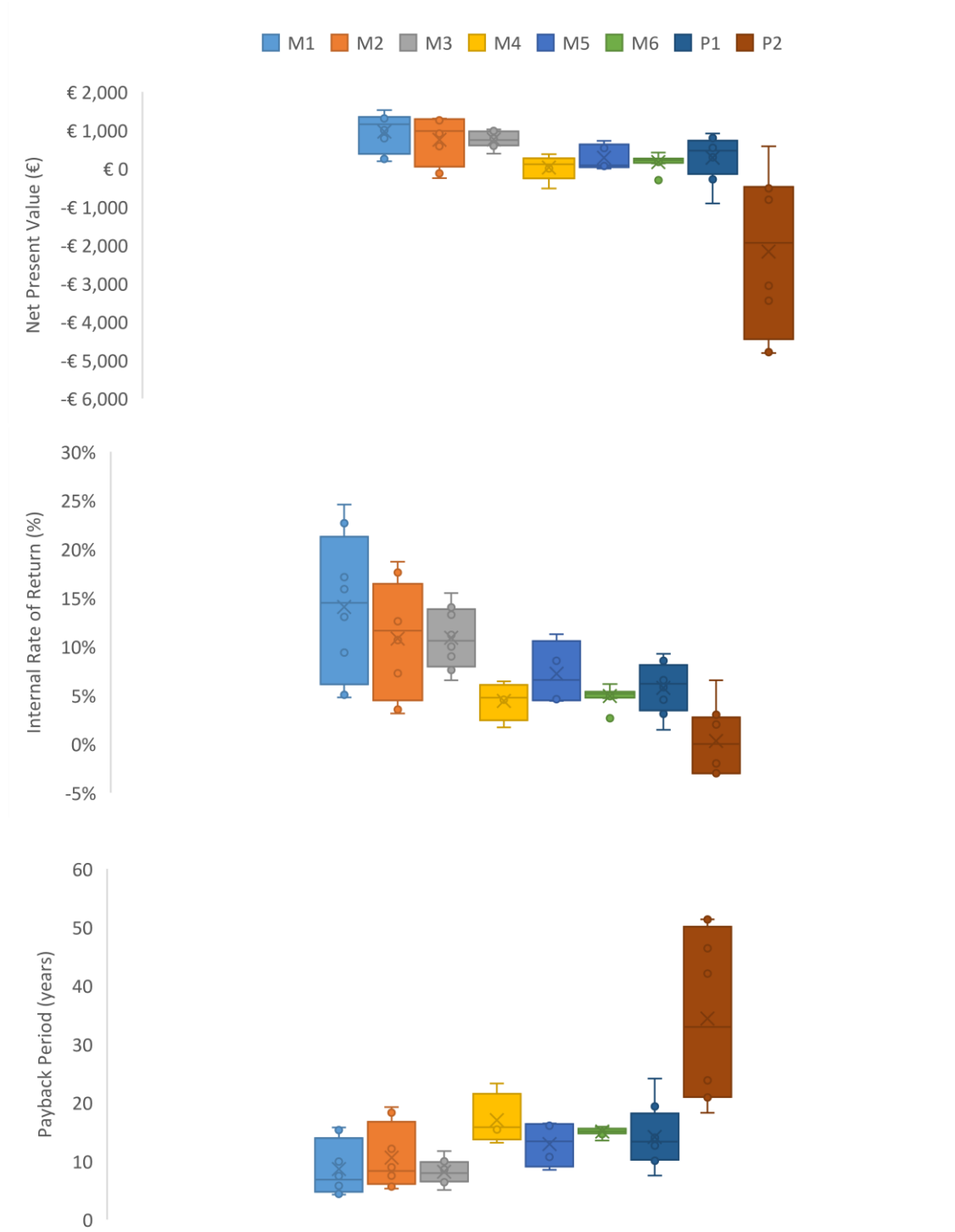


Figure 50: Distribution of Net Present Value (top) Internal Rate of Return (middle) and Payback Period (bottom) for each retrofitting strategy for a 4% discount rate and 30-year lifespan.

However, other studies have found that many factors influence the cost-effectiveness of the retrofitting strategies. The discount rate is one of the most influential factors in the profitability of the chosen retrofitting strategies (Luddeni *et al.*, 2018; Belaïd, Ranjbar and

Massié, 2021). Based on an uncertainty analysis using Monte-Carlo simulations, one study (Belaïd, Ranjbar and Massié, 2021) found that the largest driver of the uncertainty around NPVs is the energy gains, while the increase of the electricity price is found to massively improve the profitability of retrofitting strategies (Friedman, Becker and Erell, 2014; Guardigli *et al.*, 2018; Liu *et al.*, 2018), even for small increases of 1-2% (Friedman, Becker and Erell, 2014). However, the benefits would heavily outweigh the investment costs (Patiño-Cambeiro *et al.*, 2019). The benefits of energy retrofitting measures do not only extend to energy savings but include increased comfort, the extension of the lifespan of the building, increased property value, as well as increased rental fees for rented houses (Liu *et al.*, 2018), implying a good potential for job creation (Belaïd, Ranjbar and Massié, 2021).

7.6. Summary

The chapter set out the aim of assessing the potential of energy reduction used for heating and cooling the space in Albanian housing stock, assessed through archetypes using reference case studies. The effect on potential energy savings as well as indoor temperatures in both living rooms and main bedrooms of various single energy retrofitting measures as well as two packages of measures have been investigated through the analysis of computer simulation results.

It has been demonstrated that the packages of measures are the most effective interventions in all Albanian archetypes in terms of potential energy savings for heating and cooling the space. However, there are concerns that energy savings from the application of the measures, especially fabric insulation, may not be achieved in practice, mainly due to construction details and poor workmanship (Hansford, 2015). In addition, a cost analysis is essential to assess the cost-effectiveness of these packages and justify the choice of deeper retrofitting. The cost-benefit analysis undertaken for all the retrofitting measures proposed in this study found that the deep-retrofit is not cost-effective with an average negative NPV (-€2,167) and high average payback period (34.4 years). From the single measures, the thermal insulation of the external walls has been found to be the most effective in terms of potential energy savings (up to 52%). Other studies, including Ballarini *et al.* (2017) and Jones *et al.* (2017) have also found that fabric insulation is generally considered to be the most effective strategy. Pohoryles *et al.* (2020) found that retrofitting the external envelope of the building would achieve an estimated 70% reduction in heating and cooling loads. Moreover, it was found the most attractive investment in this study was thermal insulation of the external walls, with a positive NPV of 965 and 750 for 5cm and 10cm respectively, and a payback period of

8.6 and 10.6 years respectively. Previous studies have also found that the energy demand does not linearly decrease with the increase of thermal insulation and, for larger thicknesses, the reduction in energy demand is less pronounced. In line with the other studies, an increased thickness of the retrofit layer from 5cm to 10cm would not lead to significantly larger energy savings and would hence would not justify higher retrofit costs. Moreover, the indoor temperatures do not improve significantly when applying 10cm thermal insulation instead of 5cm. Even more, in the red brick constructions, there is a higher risk of overheating in summer and winter if 10cm external thermal insulation is applied to the external walls. On the other hand, floor insulation has been found to have the least effect on potential energy savings from all analysed measures. While roof insulation does not provide high energy savings (up to 30%), it does improve the indoor temperature. However, since energy savings of single measures are provided for each measure individually, these savings may change once measures are applied in combination, due to the contribution of other measures in decreasing energy demand.

In general, the highest energy saving potential through the application of energy retrofitting measures has been found in buildings built pre-1990, underlying once again their poor energy conditions. Energy retrofitting results at the building level of residential buildings in the EU studied by Gulotta *et al.* (2021) also showed that the oldest buildings benefit more than the newest for the same retrofit action, as also found by Rinaldi, Schweiker and Iannone (2018) and Uidhir *et al* (2020).

The findings suggest that the energy retrofitting measures investigated in this study have been successful in reducing energy use for heating and cooling the space, while generally improving the living conditions of households in Albania. Winter indoor conditions have been significantly improved while the energy use for heating has dropped as compared with the baseline energy use, especially when energy-intensive behaviours profiles have been used to calculate baseline energy use for heating the space in winter. Analysing the indoor condition data, accompanied by data on energy use for heating and cooling to create a full picture of to what extent the benefits of improved energy efficiency are taken as extra energy savings or as extra warmth, shows that 5cm external wall thermal insulation and package P1 are the most effective for Tirana's climate, followed by window replacement and roof insulation. Although deep retrofitting (P2) is estimated to deliver the highest energy savings, it has been found to not be cost-effective due to the high initial investment. Upgrading the split system with a more efficient one provides up to 35% energy savings for heating and cooling, however, there will be no improvement in indoor temperatures when it's not in operation. This is

the reason why this analysis discusses not only the benefits related to energy savings but also increased comfort.

However, despite the estimated savings on energy used for heating and cooling and improved thermal indoor conditions, it is essential to note that the occupants' behaviours and lack of advice and awareness can lead to the 'rebound effect' phenomenon, as has been previously found by other studies focusing on residential buildings and occupant behaviours (Druckman and Jackson, 2008; Guerra-Santin and Itard, 2010; Chitnis *et al.*, 2013; Thomsen *et al.*, 2016; Elsharkawy and Rutherford, 2018). Elsharkawy and Rutherford (2018) found in their study that there was a tendency among many households to achieve a unified state of thermal comfort throughout the dwelling, and the heating patterns changed significantly after the renovation for a significant number of dwellings, where all rooms were heated for longer periods, from 20% of the time before the retrofit to 63.5% of the time after the retrofit. It is found by Zhao *et al.* (2017) that occupants' behaviours could contribute to more than 50% of the energy efficiency potential of a building, compared to only 42% of energy efficiency savings made by improvement of building systems, and 73% of the households agreed to have had warmer homes and improved internal home conditions. Pisello and Asdrubali (2014) demonstrated through an integrated numerical and experimental study about occupant practices of energy saving that occupant actions could replace energy retrofit interventions, in terms of energy and costs. Ascione *et al.* (2020) demonstrate that a convenient investment in energy and economic terms can turn into a less convenient investment due to unconscious and incorrect occupant behaviours. Therefore, occupant behaviour and expectation need to be addressed through deeper occupant engagement before, during and after retrofitting, as found to be essential by Gupta and Gregg (2016).

CHAPTER 8

Acceptability through occupants' narrative experience

8.1. Introduction

Energy retrofits are typically an integrated part of living in and continuously renovating the house (Fawcett, 2014; Gram-Hanssen, 2014a), and they should not be seen as distinct from amenity (non-energy purposes) renovations, but should take place alongside them (Gram-Hanssen, 2014a; Wilson, Crane and Chryssochoidis, 2015). Pan and Pan (2021) have found that economic factors were the most significant in both drivers and barriers to zero carbon buildings (ZCBs) in high-density cities. Although economic and rational decision-making is critical in deciding what and how to renovate, according to Gram-Hanssen (2014a), this is not necessarily the case. Because the financial benefit of retrofitting is one of the greatest drivers to retrofit, it has been regularly argued that policies that frame opportunities as overly financial do not treat the social context within which decisions are made as of relative insignificance (Wilson, Crane and Chryssochoidis, 2015). The barriers, as well as benefits, might be perceived differently by different groups of homeowners (Azizi, Nair and Olofsson, 2019). Current policy initiatives in Europe do not consider the large social differences among the homeowners as well as the differences in the characteristics of their houses (Azizi, Nair and Olofsson, 2019). Ambrose, Goodchild and O'Flaherty (2017) suggest that generalisations made across diverse residential communities in energy efficiency programmes, in terms of age, class, ethnic group, biography and so forth, makes their impact and social acceptability more problematic. Cherry *et al.* (2017) found that personal, family and financial circumstances were very important given the unpredictable nature of modern life. Moreover, they consider the issue of payback times to be the key concern, rather than just an unwillingness or inability to pay.

On the other hand, it is widely acknowledged now that occupant behaviour could have a considerable impact on building energy demand and on indoor thermal conditions (Jia, Srinivasan and Raheem, 2017; Ascione *et al.*, 2020; Ben and Steemers, 2020), and this depends on the heterogeneous ways of using the building and on the occupants' capability to adapt to the indoor environment (Ascione *et al.*, 2020). However, in reality, the role of the occupants is not sufficiently involved (Jia, Srinivasan and Raheem, 2017). According to Schaffrin and Reibling (2015), all forms of consumption energy practices

demonstrate lifestyle choices and can be a form of self-expression. Occupant behaviours are interplays of personal, environmental and social factors and their actions are influenced by the way the occupant understands energy, control, or comfort (Ortiz, Itard and Bluysen, 2020). Therefore, to understand human perception from a behavioural point of view, it is important to understand their knowledge of the context surrounding them (D'Oca et al., 2017). According to Boerenfijn *et al.* (2018) the active participation of the residents and their willingness to change their behaviour and lifestyle are at the centre of the energy efficiency of buildings and can result in substantial energy savings in existing buildings without the need to retrofit. Considering the high impact that the occupants have on the energy performance of their house, are they willing to change their behaviours to maximise the benefits of energy retrofitting, or adapt to new behaviours of energy use? On the other hand, what are the factors that influence householders to accept energy retrofitting strategies in their homes? And, what and why are they willing to accept to implement from the list of energy retrofitting strategies proposed in this study?

These are three main questions that the analysis presented in this chapter aims to answer. This analysis intends to understand the willingness to retrofit among homeowners considering their actions, behaviours, valuations, perceptions, and experiences.

This analysis does not intend to statistically evaluate the results of the interviews, but solely to investigate the factors behind the homeowner's willingness to implement energy retrofitting.

8.2. Results and analysis

A total of 88 themes of factors affecting the acceptability of energy retrofitting have been identified and then combined into two main categories, namely: 1) Accept and 2) Do not accept. For each of the main categories, four sub-categories have been created depending on the nature of the theme: 1) Financial; 2) Occupant; 3) Building; and 4) Institutional and Administrative. Each sub-category is then organised into further groups of themes to facilitate the analysis further. It is important to note that an interaction does exist between the factor themes and the sub-categories because that some of the factors have on various phases of the retrofitting project. Alam *et al.* (2019) has also found an interaction between the barrier themes and the categories. Each category and the identified factor themes are shown in Figure 51.

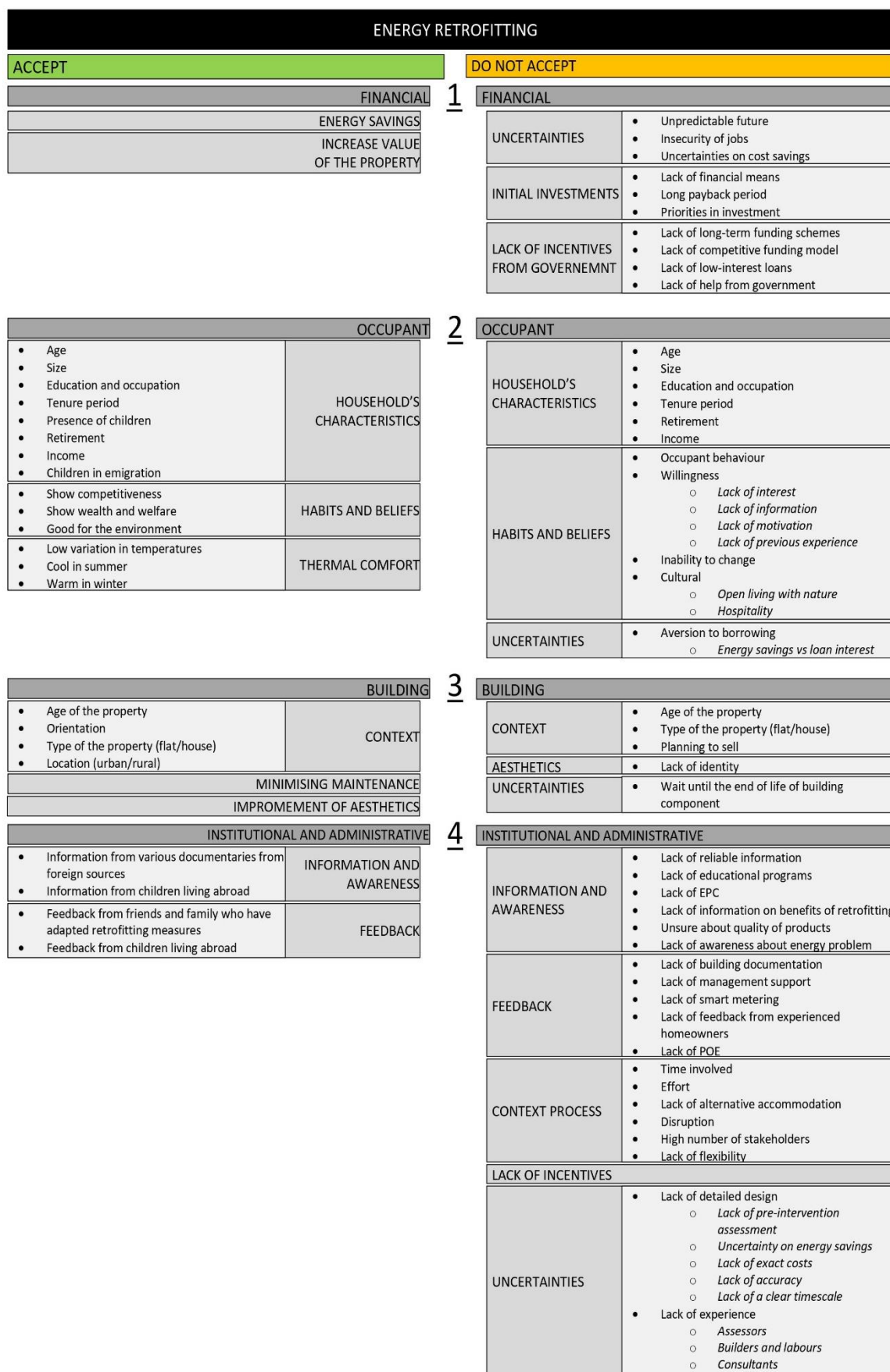


Figure 51: Themes of factors affecting acceptability of energy retrofitting

8.2.1. What affects householders to accept energy retrofitting strategies in their homes?

Financial themes

Financial themes lead the long list of factors found to affect the implementation of energy retrofitting in Albania. The top factors identified by the participants preventing them from applying various energy retrofitting strategies were highly related to uncertainties, high initial investment, and lack of incentives from the government. After a long time under the communist political system and nearly three decades of an unconsolidated democratic system, people in Albania suffer from economic insecurity, including insecurity of jobs. Some of the participants wanted to keep some of their savings for any unfortunate health or family event in the future and thought that expenses for improving the energy performance of their house were “not essential”. Previous life experiences related to expenses and investment had made them more conscious about investing in new things. Furthermore, macro-economic events such as economic crises could also impact consumer willingness to borrow money for non-essential home products (Zhao et al., 2012). In previous studies (Jaffe and Stavins, 1994; Lai et al., 2021) uncertainty and risks to the profitability of investments were found to be an important barrier. Moreover, the lack of affordable financing or low-interest bank loans is found to be another important financial-related factor in this study, as well as previously acknowledged by Tuominen et al. (2012). Huang, Ma and Song (2021) also investigated homeowners’ willingness and influencing factors to make investments in energy efficiency retrofits in residential buildings in China and found that barriers related to insufficient investment funds were the top barrier. Zhao et al. (2012) studied consumer responses towards home energy financial incentives and found that the willingness of participants to adopt energy efficiency measures was low, especially because of high capital costs.

Although many of the respondents wanted to improve energy efficiency in their homes, they did not want to take out loans. The interest rate was high for the loan. One of the respondents said:

“It is not something essential, that we cannot do without it. I have done a mistake previously, taking a loan to cover our wedding venue’s expenses... and I have paid back three times more... I have sworn to myself that if it is not something essential, my foot will never step in the bank for another loan...”

Achtnicht and Madlener (2014) observed previously that most homeowners would wait until building components were approaching the end of their usual life before considering options for replacement or renovation. Some of the homeowners interviewed in Albania

would not be willing to invest in any renovation until it was necessary. Nevertheless applying energy retrofitting measures as part of an intervention already needed to improve the functionality of a building component is one of the main drivers of energy retrofitting (Caputo and Pasetti, 2017), it was found that this was not always feasible simply due to an inability to pay additional investment costs associated with the measure. This is clearly stated in the comment below from a retired participant:

“The roof is leaking, and we are planning to undertake some works to fix it, however, I don’t think we will be able to thermal insulate it due to additional costs...although that would be better if we could. With one stone we would kill two birds...”

Another one said:

“...our windows are very old, and when they will not be functional anymore, I am not sure if we’ll be able to replace them with double-glazed ones as they are very expensive for us...but we will see until then...”

Many of the homeowners thought that the packages were costly and the time of repayment is long. Cherry *et al.* (2017) also found that payback times above 10 years have been seen as particularly unreasonable. In addition to that, there does exist great uncertainty among participants on the achievement of real energy savings, as one questions:

“How do we know that these measures will be effective, and we will achieve energy savings? What if they won’t work and all our savings go in the bin?”

However, some homeowners believed in real energy savings from successful retrofitting projects and that these interventions would increase the value of the property when marketing it. Although the increase in the market value of the retrofitted house is reported to be an important driver to undertake energy retrofitting (Zundel and Stieß, 2011), this was not reported as essential during the interviews in Albania, for two reasons: 1) almost all of the participants did not have plans to sell their house, and 2) the country lacks to provide energy performance certificates (EPC), which are a policy instrument that promotes energy retrofitting as an investment by enabling the comparison of buildings and influencing the market value based on their energy performance. Huang, Ma and Song (2021) also found that homeowners do not believe that their investment in energy efficiency retrofits would increase the selling price of the property. Although in Azizi, Nair and Olofsson (2019) it was found that those that intended to sell their house within the next three years were less motivated to implement retrofitting. They also found the increase in the market value of the property was not a determinative benefit for their

decision to retrofit as they did not perceive a renovation would significantly increase the property value.

Occupant themes

Three groups of factors related to occupant themes have been found. Although this study does not aim to analyse the results statistically, a household's characteristics do affect the acceptability of energy retrofitting in homes in Albania. Most of the participants who had difficulties accepting retrofitting were older and retired.

Mills and Schleich (2012) discussed that the elderly are unlikely to make long-term investments in energy retrofits, not only because they often have a more limited time horizon over which they make decisions, but also because of constraints in terms of behaviour, knowledge and attitudes. Huang, Ma and Song (2021) also found that investing in a retrofit was seen as not worthwhile among older homeowners because of the uncertainty about their lifespan. Moreover, there was a high confusion found among the homeowners, especially the older ones. One of them struggled to understand why he should save energy when savings would go to pay the loan interest. Fylan *et al.* (2016) also found that the residents "can receive a conflict of interest between trying to save money by installing insulation and being charged interest on a loan, albeit at low-interest rates".

Furthermore, it was noticed that households with lower income and that were living in the same property for less than 10 years were less likely to retrofit. Mills and Schleich (2012) found that, similar to elderly households, less-educated households are mainly motivated by financial savings to save energy. Highly educated occupants, on the other hand, were more likely to be aware and knowledgeable about energy retrofitting and its benefits. Azizi, Nair and Olofsson (2019) also found highly educated occupants were more likely to implement energy renovations. One interesting fact of retrofitting not being accepted was the inability and lack of willingness to change, due to many factors including lack of interest, information, motivation as well as lack of previous experience in adapting to these kinds of renovations. On the other hand, the fact that people were used to living with doors and windows open almost all the time would make the retrofits ineffective. A follow-up interview with a homeowner who participated in the previous field study and did not want to close the front door because that would show lack of hospitality to the guests, found she had the same opinion two years later:

"...I thought about our discussion last time, but I still cannot close the front door...I don't know, I don't feel like I can do it...Also, it looks like I do not have enough fresh air inside if I close the door or even the windows..."

This feeling of the necessity of close contact with the outdoor space and air was found important in interviews with other homeowners, especially older ones.

On the other hand, related to the cultural beliefs of the occupants, according to one participant, a good quality house would show wealth and welfare, and he had recently invested in energy retrofitting to have the most energy efficient house in the neighbourhood. Haque, Lemanski and de Groot (2021) also investigated the role of socio-cultural attitudes and practices in the acceptance of energy technologies by low-income households in Mumbai and Cape Town and found them highly influential in motivating, or not, their adaptation.

Another interesting finding is the fact that households that had a child who had emigrated were more likely to have implemented one or more energy retrofitting strategies or having intentions to do so shortly. One participant explained:

“...my son lives in the UK and every time he comes back home, he does some improvement to the house. It is not only the fact that he pays for the expenses of the works, but he knows better than us...he’s got more experience...”

He continued:

“We know that for a fact that thermal insulation of the house and good double-glazing windows improves the thermal comfort inside the house as well as decreases the energy bills.”

However, as Gram-Hanssen (2014a) and Azizi, Nair and Olofsson (2019) concluded, it is unlikely that homeowners base their decision to implement energy retrofitting measures solely on reducing energy costs, and often it is considered an added value of retrofitting. Bartiaux *et al.* (2014) also found that using financial savings and climate protection alone as motivators for energy-efficient renovations would not be effective. The main factor affecting homeowners’ acceptance of energy retrofitting was found to be the possible improvement of the indoor environment to promote health and comfort. This was also found to be a significant driver for the homeowner to energy retrofit in recent studies (Organ, Proverbs and Squires, 2013; Gram-Hanssen, 2014a; Azizi, Nair and Olofsson, 2019; Ebrahimigharehbaghi *et al.*, 2021). Ebrahimigharehbaghi *et al.* (2021) found that ‘improving comfort’ could perform as a better promotional message to the homeowners compared to other energy efficiency messages. One of the respondents stated:

“I am a new mum and I spend most of the day at home. So now I know best how important it is to have a comfortable home. I do my best to provide my baby with the best indoor conditions. This means I have higher bills to pay. However, I would say that for me the most important thing

is to achieve a good indoor environment rather than to save more on the bills. If that comes with the retrofitting anyway, I am more than happy to apply some of the most effective measures.”

Azizi, Nair and Olofsson (2019) also found that 41% of the households that had children intended to undertake energy renovations. Mills and Schleich (2012) also found that families with young children were more likely to adopt energy-efficient technologies and use energy conservation practices in their homes. Ebrahimigharehbaghi *et al.* (2021) investigated contextual factors, such as household and building characteristics, and found that families with children were more likely to undertake energy retrofitting measures. The fact that a retrofitted house would provide low variations of indoor temperature, as well as make the house cool in summer and warm in winter, made most of the participants even more interested in knowing more about energy retrofitting.

Building themes

Themes related to the building itself were found to affect the acceptability of the energy retrofitting strategies in this study. Although factors regarding the context or aesthetics of the building were mentioned during the interviews, they were not the determining factors for accepting or not the retrofits. These factors were found to be a bonus. Homeowners living in houses older than 10 years accepted to implement energy retrofitting measures as part of the inevitable refurbishment of their homes. Nonetheless, they needed detailed information and expertise. Azizi, Nair and Olofsson (2019) found a significant influence on the intention to renovate homeowners whose house is older than 25 years. Ebrahimigharehbaghi *et al.* (2021) also found that the construction year, building type and age of occupants are among the significant contextual factors in deciding on energy retrofitting renovations. Dolšak, Hrovatin and Zorić (2020) found that households living in an older building and those in multi-dwelling buildings were more inclined towards investing in energy efficiency in comparison to those living in newer buildings and single-dwelling buildings respectively. Some of the homeowners who had moved in recently, within five years, had done some of the works prior to moving in. Living in a flat or a single house made a big difference in the acceptability of certain retrofitting strategies, such as thermal insulation of the external walls. Participants living in a single house, were more likely to accept full retrofitting, however, those living in apartment buildings found it difficult, not to say impossible, to motivate all homeowners in the building to implement thermal insulation of the external walls externally. Instead, four of them had insulated the external walls internally. Lai *et al.* (2021) also found that the housing type affected the intentions of homeowners to adopt some energy retrofits,

such as roof insulation and installation of a solar water heating system, mainly because of a few disputes over the roof property rights.

One motive in thermal insulating the external walls and changing the windows were mentioned to be the improvement of the appearance of the building, although this alone would not be a determining reason to undertake the measure. As one of the five participants explained:

“Although I would love to improve the quality of the exterior of the building...turn it into a better-looking and new-looking building, I would not do any intervention if it was not structurally important...I just cannot afford it. And I do not want the hassle just to look better...”

However, other studies including Mortensen, Heiselberg and Knudstrup (2014) have found the improvement in building appearance to be an important motive in a major renovation. Azizi, Nair and Olofsson (2019) also found that aesthetic improvement and extending living space are determinative drivers to undertake to retrofit, even though the improvement may not lead to energy efficiency if it is considered to be the sole motivation for retrofitting.

Bjørneboe, Svendsen and Heller (2018) stated that homeowners often renovate to improve their lifestyle or as a DIY project. Only two homeowners stated that they did not need to implement any retrofitting strategies as they liked their house as it was.

Institutional and administrative themes

The highest number, but not necessarily the most determining number of the factors grouped in this sub-category contribute to not accepting to implement the energy retrofitting strategies, including lack of information and awareness, lack of feedback, complex incentives, lack of incentives and uncertainties due to lack of detailed design and lack of experience.

As Ortiz, Itard and Bluysen (2020) have acknowledged the fragmented nature of information about energy renovations, with different information presented to the residents from different sources, based on their benefits and interests. The government has never been present and transparent with the residents regarding existing energy retrofitting projects. Only one resident claimed to have heard something on a TV programme regarding some sort of project where the expenses could be partly covered by the government, but it was incomplete information.

“I think I have heard on TV regarding a project that the government would help with the costs of the renovation if the building qualified...but I did not hear what the criteria of classifications were...”

Lack of awareness regarding energy retrofitting and its benefits other than energy savings was identified as a significant barrier. Caputo and Pasetti (2017) discuss the need for educational programs in schools and media to increase awareness of the energy-environmental issue. The following quotes from the participants in this study also highlight this necessity:

"I think the school has a major impact on teaching the new behaviours. I think that the new generation should be taught how to save energy, to make it part of their culture. It is very difficult for us to change behaviour now at this age..."

"Media also has a great impact. More TV programs should be produced to promote energy efficiency and the right behaviours in homes."

"My daughter was telling me about this the other day. She had learnt it at school... She was coming after me every time I left a light open when I left the room [laughs]"

However, the new information technologies and the high rate of internet use among the younger group of homeowners makes the information more accessible within this target group than the older homeowners Azizi, Nair and Olofsson (2019). According to Santangelo *et al.* (2018) education has to be more comprehensive and go beyond the household to make people take responsibility for their role in the built environment, as well as to come from credible, trustworthy sources. However, it is noticed that information regarding technology and energy efficiency labels were more present among the participants. Checking energy efficiency labels was one of the behaviours that most of the participants agreed to undertake before purchasing a new electrical appliance.

There was found to be a high level of uncertainty regarding the real benefits of the energy retrofitting, the time and cost involved, and whether the estimated energy savings were achievable. However, information from various documentaries and children living abroad had a great impact on accepting and trusting the effectiveness of energy retrofitting. On the other hand, there was little trust in the currently operating companies in Albania, with claims they were inexperienced and there was a lack of expertise. One of the participants complained:

"...as you can see, I have thermally insulated the whole external walls...and I did that five years ago. Have a look around, look how everything is falling apart... Maybe it was my mistake that did not research the market, but went with the first company that approached me..."

On the other hand, it has been acknowledged that feedback plays a significant role in raising energy awareness and changing consumer attitudes towards energy consumption. Santangelo *et al.* (2018) found that the more frequent the feedback is

given, the more effective it was (Abrahamse et al., 2005). Tuominen *et al.* (2012) have previously proposed creating one place, for example, a website with information on the different products available in the marketplace, giving consumers the chance to evaluate and compare them. Due to the complexity of the process, as well as the high number of stakeholders involved, Caputo and Pasetti (2017) have recommended the creation of a hub that could bring together skilled professionals and provide the necessary information to facilitate the process of retrofitting. Campaigns to raise awareness regarding energy efficiency and available energy retrofits to improve the energy performance of the building, as well as other benefits, would be essential in the case of Albania, where the level of information and awareness is very low. The information should be trustworthy, easy to access, tailored and comprehensive for the homeowners (Tuominen *et al.*, 2012; Santangelo *et al.*, 2018). However, Azizi, Nair and Olofsson (2019) have acknowledged that strategies based on information campaigns alone to increase awareness and knowledge have been shown to be ineffective over time. Therefore, more incentives from the government should be considered and implemented to increase the level of acceptability of the energy retrofits among homeowners.

Energy retrofitting of houses can indeed be time-consuming, and some homeowners just do not have the time to deal with it (Zundel and Stieß, 2011; Azizi, Nair and Olofsson, 2019). However, various strategies can be adopted over time. As one participant explained:

"I can proudly say that I have built a comfortable house for myself and by myself. It took me some years to finish it as I could not do it all at once. But it has been a learning process as well, all these years. I have thermally insulated the whole fabric of the house. I sleep with a blanket in the summer.... [laughs] But I have big heavy curtains that stay closed all day long until in the evening and remain open together with windows and internal doors throughout the night for cross ventilation."

Although Gram-Hanssen (2014a) found that often homeowners renovate their homes because they like the projects as well as the process of renovating and personalising their home, this was not found to be a determining motivator among the homeowners, although they liked the idea of renovating as that would bring a new feeling to the house.

8.2.2. What are householders willing to accept to implement the energy retrofitting measures proposed in this study in their homes?

The same methodology has been followed to identify the factor themes affecting the acceptability of the energy retrofitting measures proposed in this study. Participants have been shown the results of the technical and financial side of the analysis undertaken as part of this study, including energy savings; average indoor temperatures in summer and winter; initial investment costs, annual electricity savings as well as payback period for each of the strategies proposed in this study. However, the participants have not been limited to these criteria for evaluating their acceptability. Eight sub-categories have been created for each retrofitting strategy, and themes have been categorised into two broader categories, namely: Accept and Do not accept, as illustrated in Figure 52.

ENERGY RETROFITTING STRATEGIES		
ACCEPT		DO NOT ACCEPT
• Good energy savings • Low initial investment (flat) • Warm in winter • Cool in summer • Good annual electricity savings • Low payback period (flat) • Improves the aesthetics of the building	5CM THERMAL INSULATION OF THE EXTERNAL WALLS	• High initial investment (single house) • High payback period (single house) • Lack of identity of the building • Uniform appearance • Like the appearance of the existing building • Time-consuming • Lack of collaboration between other homeowners • Already have applied internal insulation
• Good energy savings • Low initial investment (flat) • Warm in winter • Cool in summer • Good annual electricity savings • Low payback period (flat) • Improves the aesthetics of the building	10CM THERMAL INSULATION OF THE EXTERNAL WALLS	• High initial investment (single house) • High payback period (single house) • Lack of identity of the building • Uniform appearance • Like the appearance of the existing building • Time-consuming • Lack of collaboration between other homeowners • Would prefer 5cm instead of 10cm based on initial investment costs • Already have applied internal thermal insulation
• Good energy savings • Reasonable initial investment • Reasonable warm in winter • Cool in summer • Good annual electricity savings • Low payback period • Improves the aesthetics of the building	DOUBLE GLAZING	• High initial investment
• Reasonable energy savings • Reasonable initial investment • Reasonable warm in winter • Cool in summer • Reasonable annual electricity savings	ROOF INSULATION	• High initial investment • High payback period • Low average indoor temperatures in winter • Does not benefit the flat directly • Removes the water tanks (apartment buildings)
• Cool in summer • Reasonable warm in winter • Improves the interior of the house • Like the feeling of warm floor in winter	FLOOR INSULATION	• High initial investment • High payback period • Low energy savings • Low average indoor temperatures in winter • Does not benefit the flat directly • Disruption of normal use • Effort
• Good energy savings • Cool in summer • Reasonable warm in winter • Good annual savings • Quick respond after switching on	UPGRADE OF SPLIT SYSTEM	• High initial investment • High payback period • Already have one in good condition
• Good energy savings • Cool in summer • Reasonable warm in winter • Good annual savings • Improves the aesthetics of the building	WALL INSULATION + DOUBLE GLAZING	• High initial investment • High payback period • Lack of identity of the building • Uniform appearance • Like the appearance of the existing building • Time consuming • Lack of collaboration between other homeowners (flat) • Already have applied internal insulation
• High energy savings • Cool in summer • Warm in winter • High annual savings • Improves the aesthetics of the building • New feeling • Shows wealth and welfare	WALL INSULATION + DOUBLE GLAZING + ROOF INSULATION + FLOOR INSULATION + UPGRADE OF SPLIT SYSTEM	• High initial investment • High payback period • Lack of identity of the building • Uniform appearance • Like the appearance of the existing building • Time consuming • Lack of collaboration between other homeowners (flat) • Already have applied some of the measures • Disruption of normal use • Effort • The building is not in need of full renovation • Not enough experience and knowledge for such investment • Do not have an alternative accommodation • Unable to change behaviour to benefit most from the retrofit

Figure 52: Themes of factors affecting acceptability of energy retrofitting strategies proposed

As highlighted throughout the interviews, financial themes have been found to highly affect the energy retrofitting implementation. High initial investment costs have been found to be the top theme, stopping people from accepting the implementation of a certain strategy. However, the improvement of thermal comfort has been found to be the top factor making people not only accept the strategy but also think about compromising in relation to other aspects, such as aesthetics of the building as well as time spent, effort and disruption of the normal use of the building to name a few, caused by each strategy.

Double glazing, followed by the upgrade of the split system has been found to be the most accepted strategy due to financial and thermal benefits associated with it, but also due to the quick implementation and small effort required for installation. However, the high initial investment costs were found to hold people back.

Thermal insulation of the external walls is highly accepted, mainly due to the improvement of the indoor temperatures in summer and winter, but also for its financial and aesthetic benefits. However, high initial investment costs are a constraint in their implementation in houses compared to flats. On the other hand, participants living in a flat claimed to have collaboration issues with the other homeowners. Two homeowners claimed that they had implemented internal thermal insulation of the external walls, due to the lack of collaboration with other homeowners, and were not interested in contributing to the costs for full external insulation of the apartment building. Due to the lower initial investment cost and similar financial and thermal benefits, 5cm external insulation is more acceptable than 10cms.

Roof and floor insulation were not particularly accepted as single measures due to not only the high initial investment costs but also the disruption to the use of the building, as well as practical issues such as the possibility of not being able to use the roof space to place the water tanks anymore. Furthermore, homeowners that did not directly benefit from the floor and roof insulation in the case of apartment buildings were not willing to accept the implementation of the strategy.

Testing the two packages of measures, it was found that wall insulation and double glazing were highly accepted, despite the high initial investment cost and high payback period. Homeowners were willing to accept this package due to the good energy savings and improved indoor temperatures in summer and winter. While the deep retrofit through the second package was harder to be accepted despite the high energy savings and the improved indoor environment. High initial investment costs and high payback period, together with the disruption, time and effort were the top themes for not accepting its implementation. However, insecurity about high investment without having the right

information and experience was often mentioned as an additional barrier. Some of the respondents, especially retired ones, found it very difficult to accept changing their behaviour to most benefit from the package implementation. On the other hand, providing a new feeling in the house, as well as showing wealth and welfare were mentioned as added benefits of a deep retrofit.

8.2.3. Are householders willing to accept changing their behaviours to maximise the benefits of energy retrofitting?

It is acknowledged that occupant behavioural change often has higher energy-saving potential compared to other technical measures. Furthermore, it is no/low-cost intervention and is easily applicable to both new and existing buildings, requiring no high-technology knowledge (Ascione et al., 2020). Notwithstanding the energy retrofitting measures profitable, the wrong actions of the occupants could affect their profitability and often happen because of lack of awareness of how much their behaviour can affect the building's energy demand (Ascione et al., 2020).

Ascione *et al.* (2020) modelled various wrong behaviours undertaken in a refurbished building and found that the incorrect use of windows alone led to a 31% increase in overall primary energy use by the refurbished building compared to the base building. They concluded that, depending on the occupant's behaviour, the dynamic building energy demand of a refurbished building could vary from 94kWh/m² to 202kWh/m². Ashouri *et al.* (2019) found potential savings of up to 21% of total energy consumption through better use of lighting and appliances. Ascione *et al.* (2020) also concluded that the wrong habits of the occupants can negatively undermine the effectiveness of energy efficiency measures as well as the foreseen payback period. It was found during the field studies that occupants were opening windows and doors when heating or cooling was on, making them increase the temperature settings in winter and lower it considerably in summer, increasing energy consumption. Wang *et al.* (2021) has found that a setting a higher AC temperature can improve energy efficiency.

According to Santarius and Soland (2018), attitudes need more than one technique to change, and an average person will not change their behaviours because of information given to them. Abrahamse *et al.* (2005) have also found that higher levels of information and knowledge do not necessarily result in behavioural change or energy savings and that rewards have been effective but with short-lived effects on energy conservation. Therefore, campaigns to raise awareness among occupants are essential to try to

persuade them to change their habits, behaviours and attitudes to become more energy-efficient (Ortiz, Itard and Bluysen, 2020), however, they need to be carefully tailored. For example, financial incentives would be effective when people consider prices when making choices (Abrahamse et al., 2005). It is essential that the design and implementation of each chosen retrofitting strategy addresses and changes possible barriers to behavioural change, by examining which behavioural determinants should be targeted by the intervention (Abrahamse et al., 2005). Kastner and Stern (2015) explain that identifying the consequences associated with the selected behaviour would be an important early stage on influencing potential adapters to design a strategy to change a behaviour, where the consequences include the benefits (motivation and reasons) that motivate people to act and barriers deterring them to adopt the behaviour. Li, Menassa and Karatas (2017) define motivation as, “an occupant’s readiness, willingness, interest and desire to process energy-saving information provided through any of the intervention strategies, and subsequently adopt the stipulated energy-saving behaviours”. However, based on their MOA-theory on behaviour, people must have not only motivation but also opportunity and ability if they are to carry out energy renovations. While motivation is necessary to initiate action and is rooted in beliefs, attitudes and social norms, opportunity creates the setting for action and refers to outside factors, such as a high energy bill or a need for maintenance etc. (Bjørneboe, Svendsen and Heller, 2018). It is also important that people can take action in terms of money, time and mental capacity (Bjørneboe, Svendsen and Heller, 2018). Azizi, Nair and Olofsson (2019) conclude that policy instruments need to take into account the specific needs and interests of homeowners to increase their interest and motivation. They continue that the implementation of energy retrofitting measures can be motivated or impeded by a combination of benefits and barriers. Monetary rewards may serve as an extrinsic motivator to save energy (Abrahamse et al., 2005). However, when analysing the willingness of people to change their behaviour related to energy use, household characteristics, such as age and education, have been found to have a strong positive impact on household energy-efficiency technology adoption and on household use of energy conservation practices (Mills and Schleich, 2012).

Most of the previous research has been focused on technologies, even though it has been found that application of advances technologies does not overcome the benefits of building energy efficiency achieved by educating occupants to change their behaviour (Jia, Srinivasan and Raheem, 2017). Although it is expected to be difficult, it is nevertheless a very important part of the strategy to increase the number of private energy retrofits (Mortensen, Heiselberg and Knudstrup, 2014). Following the conception

that “people don’t understand technologies”, a housing and construction expert interviewed by Cherry *et al.* (2017) stated that: “complex interactions between the house and occupants, the influence of unruly occupant behaviour on energy use, and beliefs regarding the need for the correct use of technology, led many to advocate that the best way to drive down the carbon use in properties is actually to take people out of the equation”. However various studies have shown that involving the occupants throughout the whole process of energy retrofitting, and in interacting with the new technologies in the right way afterward, were key to successful outcomes. Therefore, the approach expected to generate the most future success is a combination of information of energy consumption, raising education and motivation, and a sensible investment size supplemented with a financial grant (Mortensen, Heiselberg and Knudstrup, 2014).

To target occupants’ purchasing behaviours of energy-efficient equipment, it is important to target specific products and users, as well as provide simple implementation processes (Lynne *et al.*, 1995).

8.3. Summary

The analysis undertaken in this chapter tried to contextualize the implementation of energy retrofitting measures investigated in this study in Albania to investigate the willingness of homeowners to undertake retrofits based on their perceptions and needs. Although the investigation presented in this chapter has not been based on quantitative data, the aim was to contribute to the state of knowledge by unveiling various barriers through people’s perceptions and perspectives about retrofitting their home and further suggesting the involvement of occupants throughout all the stages of the retrofitting process to achieve successful outcomes.

Various factors were found that affect homeowners’ willingness to accept energy retrofitting in their homes, and they could be differently classified as financial, occupant, building and institutional and administrative-related factors. It was found that economic factors associated with the high investment costs, long payback period, as well as lack of incentives from the government, are the main barrier to implementing energy retrofitting strategies in Albania. While the main driver to accept implementing them is the improvement of the indoor environment and comfort, as well as energy savings. Mortensen, Heiselberg and Knudstrup (2014) also found that improved comfort, indoor environment and functionality of the house would be better motivation factors to accept energy retrofits since they were important to the homeowners. Ebrahimigharehbaghi *et al* (2021) found that not only improving comfort but also maintaining good physical and

structural conditions of the house are the main motivations for all types of energy efficiency renovations, except for PV panels. Although various institutional and administrative themed factors were found to be affecting the acceptability of energy retrofits among Albanian homeowners, lack of information and awareness was found to top the list. However, they were considered secondary factors, meaning that even if homeowners have the right information, that was not enough to motivate them to implement energy retrofits. Santangelo *et al.* (2018) also found that information alone is unlikely to motivate changes in the long term.

Following the analysis of factors affecting householders to accept energy retrofitting strategies in their homes, what they were willing to implement was investigated. Energy retrofitting strategies and scenarios that required high upfront capital costs were found to be less attractive and less accepted due to high initial investment costs and high payback periods. Double glazing, although perceived as an expensive energy retrofitting measure, was found to be the most accepted measure due to financial benefits, thermal benefits, quick implementation, and the small effort required for installation. Similar findings were unveiled regarding the upgrade of the split system. Thermal insulation of external walls has also been found to be highly accepted by homeowners as a single measure, while roof and floor were among the least accepted measures. mainly due to the disruption of the use of the building. On the other side, wall insulation and double glazing were highly accepted as a package due to energy savings and improved indoor temperatures in both summer and winter. On contrary, notwithstanding the high energy savings estimated by the deep retrofit scenario, it was not accepted due to a combination of factors including high upfront investment cost, disruption, and the time and effort associated with its implementation.

Future programs aiming to motivate homeowners in Albania to retrofit would be successful if they focus primarily on the motivation factors that have been found to be important in studies like this one, starting with information and education programs that target behavioural change to reduce energy consumption. A hub that could bring together skilled professionals and provides information and guidance regarding energy retrofitting would be essential as a proven strategy to successfully overcome some of the main barriers related to information and awareness (Caputo and Pasetti, 2017). Also, an energy advisory agency on the local authority would be effective in equipping the building owners and companies with the information that is essential to choose and undertake the right measures for their homes or buildings. More involvement of the local and national authorities is required not only in the form of more detailed and tailored information but also through financial programs to financially facilitate and motivate

private retrofitting projects. Economic reasons are on top of the reasons to retrofit as well as a perceived barrier preventing retrofitting.

To summarise, from this analysis it is found that there is a strong willingness among the homeowners to retrofit their homes if there is more than one benefit from it. They do not accept implementing retrofitting for aesthetic reasons alone but in combination with other benefits from which the most motivational would be energy savings and improvement of thermal comfort. Energy retrofits that provided the lowest initial investment and highest energy savings, as well as a host of co-benefits such as improved thermal comfort, were found to be the most attractive strategies for homeowners in Albania.

CHAPTER 9

Discussions

9.1. Introduction

The overall aim of this study was to investigate the most effective energy retrofitting strategies for improving comfort and energy use in Albanian homes and to inform homeowners and policymakers on strategies that are not only technically feasible and cost-effective but also accepted by homeowners. Objectives to achieve the overall aim have been outlined in Section 1.6 and are further discussed in Chapter 4. In this chapter, the implications of this thesis are discussed. This discussion starts with summarising the findings of the literature review in Section 9.2, as well as a summary of the findings of the empirical part of the research. In Sections 9.3 and 9.4, specific recommendations to policymakers, homeowners, and house providers/developers are made to assist them with the energy retrofit policy development and decision-making process respectively. Reflections are provided on each branch of the methodological framework proposed in this study, in line with its objectives.

9.2. Summary of findings through reflections

9.2.1. Reflections on the literature review

The literature review has been the first step in a broader investigation and identification of research gaps in the existing body of knowledge on energy retrofitting of the existing building stock. According to Sibilla and Kurul (2020) it is exactly the literature review that seeks to build an innovative cognitive learning platform to enable transdisciplinary collaboration in energy retrofits. Figure 53, illustrates the considerations taken into account in the framework development of this study, based on the existing literature.

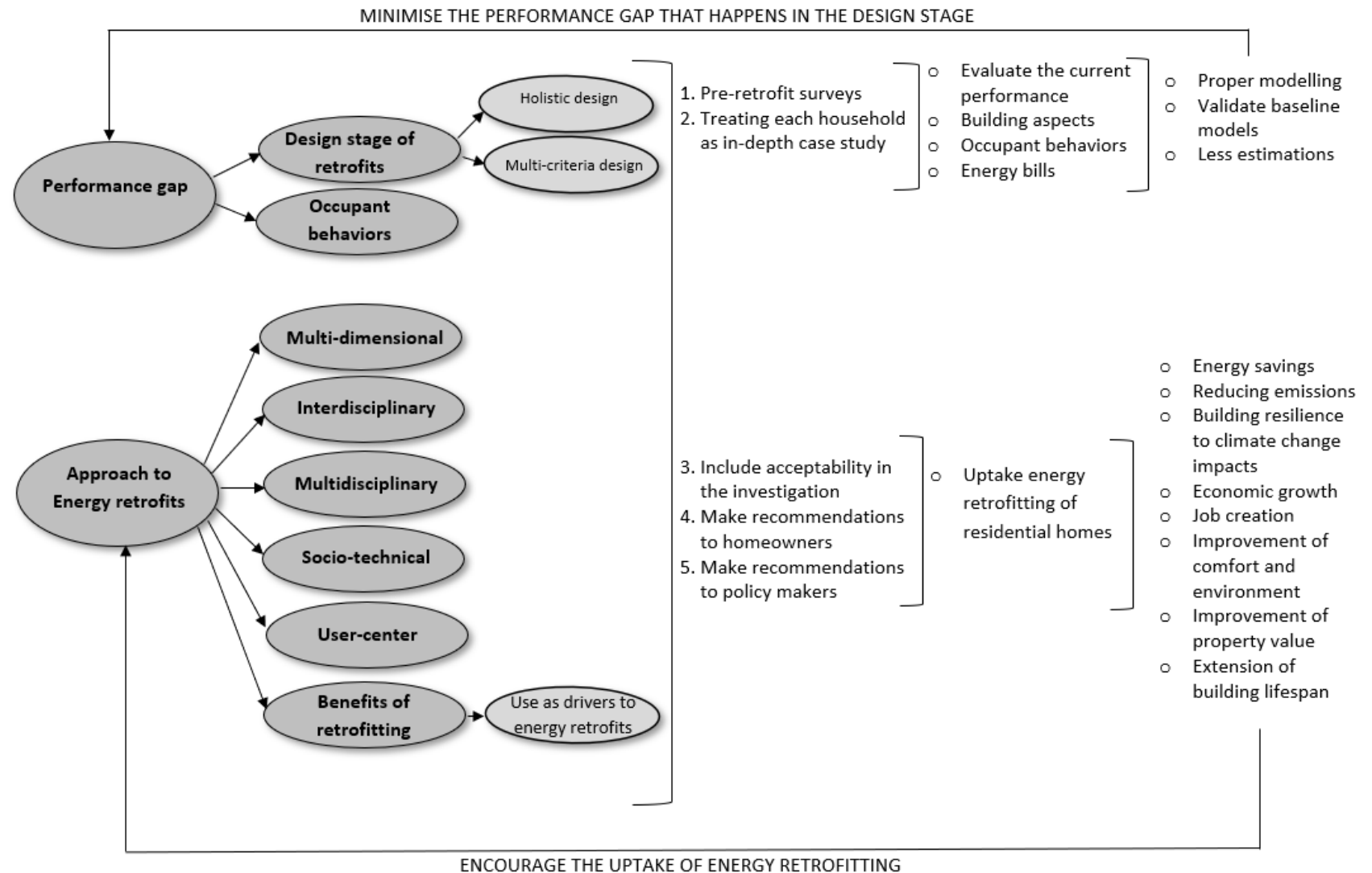


Figure 53: Map showing the way literature background affected the study framework.

The literature review found that energy retrofitting of existing residential buildings has been framed as having numerous benefits apart from reducing emissions and building resilience to climate change impacts (European Commission, 2016), including and not limited to energy savings, economic growth, job creation, improvement of comfort and environment, improvement of property value, and the extension of building lifespan (Technology Strategy Board, 2014; Zeng *et al.*, 2018; Prabatha *et al.*, 2020; Belaïd, Ranjbar and Massié, 2021; Ebrahimigharehbaghi *et al.*, 2021). Notwithstanding that the building sector, and especially residential buildings, have a great potential for energy saving (Wei *et al.*, 2018; Hu *et al.*, 2020), around 80% of the energy savings potential of energy efficiency in buildings has been untapped in the last decade (Belaïd, Ranjbar and Massié, 2021). Although energy retrofitting policies have existed for several years in many countries around the world, they have not always achieved most of the benefits at a macro level and also on the dwelling level.

This could happen because of many factors explored in Chapter 2.

Indeed, Chapter 2 sets out to assess the 'wicked' problem of energy reduction because of the complexity and fragmented nature of retrofits (Stafford, Gorse and Shao, 2011; Gupta and Gregg, 2012a; Karvonen, 2013; Judson and Maller, 2014), and aims to unveil strategies to overcome the barriers related to incomplete or contradictory knowledge, the number of people and action involved, the large economic burden and the nature of interconnectivity to reduce energy use in buildings through energy retrofits.

There are two broad issues derived from the literature review affecting the uptake of energy retrofits in residential buildings, and the methodology and analysis developed in this study intends to tackle them:

1. *The performance gap*

It is widely found that actual energy consumption is less than official estimations (Demanuele, Tweddell and Davies, 2010; Carbon Trust, 2011; Glad, 2012; Gupta and Gregg, 2012a; Ma *et al.*, 2012; Sunikka-Blank and Galvin, 2012; Galvin and Sunikka-Blank, 2013; Tweed, 2013; Galvin, 2014b; Gram-Hanssen, 2014b; Gupta, Barnfield and Hipwood, 2014; Technology Strategy Board, 2014; Zero Carbon Hub, 2014; Gupta and Gregg, 2016; Zou *et al.*, 2018; Palma, Gouveia and Simoes, 2019). This performance gap appears to be a recurring challenge in both new buildings and renovated ones (Canale *et al.*, 2021) that happens at various stages of the retrofitting process, from the design stage to construction, operation and feedback stages. The literature review revealed that most of the factors affecting the performance gap happened during the

design stage, which reinforces the need to take action to minimise this performance gap from the start. This finding has been advocated by many researchers including Niu, Pan and Zhao (2016), Shin *et al.* (2017), Zou *et al.* (2018) and Lassen *et al.* (2021). Holistic and multi-criteria designs are required to be adopted in the practice of energy retrofits, allowing for a combination of different performance requirements as well as finding balanced solutions for computing parameters, including environmental, comfort, life-cycle, energy requirements, etc. (Lassen *et al.*, 2021).

On the other hand, the significant impact that occupant behaviour has on building energy demand and on indoor thermal comfort conditions has been widely recognised by a recent body of research (Steemers and Geun Young, 2009; Sunikka-Blank and Galvin, 2012; Gram-Hanssen and Georg, 2018; Ascione *et al.*, 2020; Ben and Steemers, 2020). However, occupant behaviour is usually oversimplified and predefined through static schedules in building performance simulations, ignoring its stochastic nature, dynamics and diversity (Menezes *et al.*, 2012; Gaetani, Hoes and Hensen, 2016; Hong *et al.*, 2017; Ascione *et al.*, 2020; Ben and Steemers, 2020; Laaroussi *et al.*, 2020). Accurate prediction is not easy for designers due to limited data, knowledge and experience (Zero Carbon Hub, 2014; Zou *et al.*, 2018), as well as oversimplifying the complex reality (Gorse *et al.*, 2016). Integrating the occupant behaviour in building energy simulations has been found to be challenging even though there has been significant research on occupant behaviours in buildings in recent years (Jia, Srinivasan and Raheem, 2017). For these reasons, pre-occupancy data collection is proposed in recent studies as a new data collection method that aims to help designers evaluate and optimize a design before construction (Shin *et al.*, 2017; Zou *et al.*, 2018).

Intending to respond to this gap, energy modelling undertaken in this study was informed by reality, and a pre-design survey of houses has been the starting point of the investigation of the effectiveness of the retrofitting strategies investigated in this thesis, to reveal how the house is used and what are the expectations of the residents, what they like and dislike, as well as how flexible they are to accept the strategies, in terms of their cost, appearance, social and cultural implications and so on. Furthermore, each household has been treated as an in-depth case study, as previously recommended by Gupta and Barnfield (2013), Tweed (2013) and Ingle *et al.* (2014) to understand the people who live in the properties and propose solutions specifically for them. Going further, model validation with real data on energy and environmental performance, rather than estimations, were performed in this study, minimising the performance gap between the expectations and outcomes and improving the reliability of model estimation. This step has been considered to be highly significant in other studies (Korjenic and Bednar,

2012; Guerra-Santin *et al.*, 2016; Gupta and Gregg, 2016; Ben and Steemers, 2020) for minimising the performance gap.

2. Approaches to energy retrofits

Notwithstanding the large impact that the design of energy retrofitting measures has on the energy retrofits, it is interconnected with other stages of the whole process, especially with the policy design. Although the other stages of the retrofitting process, including construction, operation and feedback stages, are not within the scope of this study, special attention is also required during these stages. Multi-disciplinary and interdisciplinary practice should be considered when planning new policies, where various stakeholders are encouraged to contribute in areas beyond their professions (Sibilla and Kurul, 2020). Involving them and tying together the policy, implementation and learning stages of any retrofit must be the focus of a whole-systems approach for retrofit research, to meet the carbon-reduction targets (Bell *et al.*, 2010; Gupta and Gregg, 2012a). All stakeholders, including clients, design and building teams, users, homeowners, managers, policymakers and industry will need to engage much more closely with achieved performance, delivering better transparency between intention and outcomes (Bordass, Cohen and Field, 2004; Butera, 2013; Fedoruk *et al.*, 2015; Jia *et al.*, 2021). Furthermore, energy policy development should capture all the diverse interests among the different stakeholders to be successful (Prabatha *et al.*, 2020). Stakeholder requirements and decision priorities should be considered together in determining regional policies, as the often-adopted 'one-size-fits-all' view in retrofit planning and policymaking is not the right approach (Prabatha *et al.*, 2020). Comfort, environmental issues and aesthetics have often been not carefully considered in the design of energy-efficient buildings (Lassen *et al.*, 2021). This is the reason the study did not only consider the technical and economic feasibility of retrofits, but also investigated the degree of their acceptability by homeowners. The background literature demonstrated that a multi-dimensional interdisciplinary, socio-technical and user-centre approach, incorporating sociology, psychology, economics, engineering and design factors (Mills and Schleich, 2012; Delzendeh *et al.*, 2017; D'Oca *et al.*, 2017), as well as unifying language, unfold methods, metrics, benchmark, and platforms to compare results (Hong *et al.*, 2017) should be followed when approaching energy retrofitting to achieve successful outcomes.

Occupant behaviours are associated with relatively high levels of uncertainty of their acceptance of energy retrofitting strategies or their successful outcome (Butera, 2013) because of different perspectives on the goals and the way to achieve them from different

stakeholders due to different backgrounds, knowledge, position, objectives and interests (Roberts, 2001; Van Bueren, 2009). This is the aim of the RetrofiTEA framework proposed in this study, which considers that the design stage is fundamental in proposing energy retrofitting strategies that are technically and economic feasible, as well as accepted by homeowners, while using the benefits that come from retrofitting as drivers to encourage uptake of energy retrofitting of residential buildings.

9.2.2. Reflection thoughts regarding technical feasibility

Based on the first stage of the RetrofiTEA framework proposed in this study, the implications regarding the technical feasibility of energy retrofitting strategies have been explored in terms of what is the estimated energy saving of each strategy proposed and to what extent the indoor environment has been improved by applying each of the strategies.

Due to the lack of energy retrofitting research in Albania, an large amount of work has been done to provide the information needed to develop the baseline energy models that were used to perform the investigation, aiming to tackle the performance gap by minimising the assumptions made related to building operation, which is widely recognised as one of the key factors of the performance gap, making it a key challenge for recent research (Kavgic et al., 2010; Aragon et al., 2017; Guerra-Santin and Silvester, 2017; Abuimara et al., 2019). Data collected through the first two field studies in 49 dwellings in Albania were used as the main analysis of technical feasibility. Many studies including Gupta and Barnfield (2013), Tweed (2013) and Ingle *et al.* (2014) have acknowledged the need to treat each household as an in-depth case study to be able to collect and generate a rich database that was used to determine the implications for modelling the energy baseline models, including occupancy, heating and cooling profiles, as well as to also validate the baseline energy models.

The actions taken regarding technical feasibility include:

1. Investigation of energy and thermal performance of existing homes in Albania (Objective 1)

From the analysis of data collected, it was found that most of the dwellings were performing poorly in both winter and summer and both in terms of energy and thermal performance. However, most of the homeowners found heating their home was more essential than cooling it, even though there were more adaptive options during the winter compared to summer including, and not limited to, the use of several layers of clothing, blankets, localised heating, hot water bottles etc. Furthermore, considering the Mediterranean climate and culture, one reason that cooling their home in summer is less

critical than heating it during the winter could be impacted by the long time spent outdoors in summer in Albania.

Electricity was found to be the main type of energy used for heating and cooling the home. The sample's average electricity consumption was 6,426kWh/year, which is nearly double the ERE's calculated average energy consumption, which does not include heating or cooling the space. This means that on average, over half of the energy consumption is for heating and cooling the space. Nonetheless, there were households in the sample that had monthly electricity consumption as low as the calculated ERA's baseline electricity consumption, meaning that they did not heat or cool the space at all. The occupants' survey revealed unaffordable energy prices was mainly to blame. Spearman correlation analysis showed a statistically significant correlation of 0.037 between electricity consumption and the period of construction of the building, revealing their poor energy performance, especially in older buildings. However, poor energy performance was not only related to the buildings themselves, but also to unhelpful behaviours by the occupants, with the most common being leaving windows and doors open while the heating and cooling was on. Interestingly, the presence of a child in the household would often dictate the amount of time heating or cooling was used. However, the presence of a retired person in the household did not have the same impact, which was found to be mainly due to energy costs. Retired people used other adaptive approaches, such as blankets or hot water bottles, to cope with colder weather.

Indoor temperature monitoring showed recordings as high as 41°C in summer and as low as -6°C in winter and with an average of 28.6°C and 15.6°C in summer and winter respectively, being far from the recommended guideline of indoor temperatures in living rooms of (23°C to 25°C) and (22°C to 23°C) for summer and winter respectively (CIBSE, 2006). More than 75% of the living rooms in the sample experienced high indoor temperatures of over 28°C for more than 50% of the day during the summer. On the other hand, indoor temperatures below 23°C were recorded for the whole day in 60% of the dwellings, in winter. A seven-point ASHREA scale for thermal sensation and a five-point scale for thermal preference was used for a subjective evaluation of the thermal comfort in both winter and summer. The results showed that 86% and 75% of the households were feeling hotter than neutral and colder than neutral in summer and winter respectively. In total, 60% of them wanted to feel much cooler in summer and 49% of them wanted to feel much warmer in winter. Building-related variables, such as archetype and construction materials and elements were found to be the most influential factors affecting the variation in thermal sensation votes. However, other contextual factors related to cultural norms and personal preferences could affect occupants' thermal sensations during both summer and winter. For example, keeping the main door

open to show hospitality impacts the indoor temperature, and it may indirectly affect how people feel indoors.

This is the first study in the Albanian context that holistically investigated the existing energy and thermal performance of existing homes. The very poor performance by the homes show there is an unquestionable need to improve their energy and thermal performance.

2. Baseline energy models of Albanian main residential archetypes

The second objective of the thesis was to develop baseline energy models for the main Albanian residential archetypes.

Dynamic energy simulation using EnergyPlus V8.5 with DesignBuilder V5 as a user-friendly interface was used to construct the energy models and to extract estimated data on energy use and indoor temperatures for each of the main archetypes considered in this study.

Whilst there are some statistical data from INSTAT regarding buildings typologies and period of construction, they have not been collected for the purpose of evaluating energy performance of buildings and are not comprehensive enough for this purpose. Therefore, this study has developed eight main residential archetypes from the existing data as well as data collected from the surveys undertaken in this study. To assist the energy evaluation, 'reference buildings' have been used for each of the archetypes. Each reference building is represented by a real case study within the sample of 49 dwellings, however, variations within the same archetype exist, especially in residential buildings built after 1991. Before undertaking any investigation, the energy model of each case study was validated using the real data collected during the field studies.

Due to the high variability of recorded indoor temperatures, it was necessary to determine the most typical indoor temperature profiles from which to extract essential information that was closer to reality, including setpoint temperatures for winter and summer as well as heating and cooling duration. Hierarchical cluster analysis was used to develop these clusters using an agglomeration schedule and Wards' method to maximise the significance of the differences between clusters. Three statistically different clusters were created for each winter and summer and were thereafter described by testing the differences in several buildings, socio-demographics and occupant behaviours factors. This information was later used to inform the baseline energy models through three user profiles, Energy Saving Behaviour (ESB), Energy Average Behaviour (EAB), and Energy Intensive Behaviour (EIB), which estimated the energy consumption used for heating and cooling the space with a variation of up to 41.2kWh/m²/year

(detached pre-1990) only by using the same dwelling differently through three user profiles. Higher variations in energy consumption has been found when using the Energy Intensive Behaviour profile (EIB), 26.6-57.9kWh/m²/year for heating and 13.5-36.4kWh/m²/year for cooling, compared to Energy Saving Behaviour (ESB) 4.2-7.8kWh/m²/year for heating and 2.6-25.2 kWh/m²/year for cooling, and Energy Average Behaviour (EAB) profiles, 14.2-35.2 kWh/m²/year for heating and 8.4-32.8 kWh/m²/year for cooling. This result was found to be due to different heating/cooling setpoints, different heating/cooling operation times and treated floor areas.

Building material, building type, floor area and period of construction all contributed to the energy consumption that was used for heating and cooling the space. When investigating baseline energy consumption for each archetype using the three user profiles, a variation of up to 67kWh/m²/year was found in detached buildings built pre-1990, only by using the same dwelling differently. Janda (2011) also found that different occupants living in the same type of house can have energy consumption that changes by a factor of three or more, mainly because occupants behave in more complex ways than designers account for. Energy consumption that varies dramatically for neighbouring houses with nearly identical construction has also been found by other studies including Andersen *et al.* (2009), Gram-Hanssen (2013), Ingle *et al.* (2014) and Ascione *et al.* (2020), because people behave in different ways and there is no 'standard' household (Shove, Pantzar and Watson, 2012).

On the other hand, indoor temperature was investigated in each archetype using the validated energy models for each of the baseline user profiles. As expected, indoor temperature was found to be higher in winter using EIB than the other two user profiles due to the higher heating setpoint used for simulations. Similarly, lower indoor temperatures were found during the summer when EIB user profiles were used for simulations because of the lower cooling setpoint compared to EAB and ESB.

Energy modelling of baseline scenarios would be routine unless there was something novel regarding data input or findings. The use of three user profiles developed from the real data, including measured indoor temperatures as well as responses captured during the occupant's surveys, determined a range of estimated energy consumption for each archetype as baseline energy consumption rather than a single value. Considering various energy behaviours through the user profiles, provides closer estimation of energy consumption depending on the specific behaviour of each household.

3. Improvement energy models

The selected energy retrofitting measures were applied in the validated baseline energy models for each archetype. From the investigation of data output from simulations, it was

found that the packages of measures P1 and P2 are the most effective interventions in all Albanian archetypes in terms of potential energy savings for heating and cooling the space. However, the achievement of these results is significantly dependent on the application in practice of the measures and attention to detail. Albania lacks experienced builders and specialists in the field of energy efficiency, and this is a considerable limitation affecting the success of the energy retrofits. Hansford (2015) has also highlighted concerns related to the application in practice of the measures that estimated energy savings will not be achieved, especially fabric insulation may not be achieved, mainly due to construction details and poor workmanship. Pohoryles *et al.* (2020) have also found there is great potential to reduce heating and cooling loads by an estimated 70% by retrofitting the external envelope of the building.

From the single measures, external wall insulation of 5cm and 10cm were the most effective, with an estimated energy saving of 21% to 40% and 38% to 52% respectively, depending on the archetype. The thermal insulation of the 5cm external insulation of the external walls has been considered an optimum thermal insulation level for zones A and B of the Albanian climate by Papadopoulos (2003). However, thicker insulation might be more efficient in colder climates including the inland zone C in Albania. Therefore, further investigation on the effectiveness of the retrofitting strategies proposed in this study needs to be undertaken for this zone of the Albanian climate. Indeed, the increase of insulation thickness from 5cm to 10cm in almost all archetypes did not lead to significantly larger energy savings, or better indoor temperatures. Previous studies have also found that the energy demand does not linearly decrease with the increase of thermal insulation and for larger thicknesses the reduction in energy demand is less pronounced. Therefore, a balance between the savings and investment costs is essential in this case. Other studies, including Ballarini *et al.* (2017) and Jones *et al.* (2017) have also found that fabric insulation is generally considered to be the most effective strategy, especially thermal insulation of the opaque envelope elements. Significant improvement in energy savings and the indoor environment was also achieved by window replacement and roof insulation while upgrading the split system with a higher efficient one, provides up to 35% energy savings for heating and cooling, however, there will be no improvement in indoor temperatures once it's not in operation. On the other hand, floor insulation M5 was found to be among the least effective, with an estimated electricity reduction of up to 21%.

As expected, higher energy savings were estimated to be possible by energy retrofitting older buildings built pre-1990 than those built post-1991, underlying their poor energy conditions and highlighting the high energy saving potential from retrofitting them. The same finding has been discovered by Gulotta *et al.* (2021) from energy retrofitting results

at the building level of residential buildings in the EU. Rinaldi, Schweiker and Iannone (2018) and Uidhir *et al* (2020) also showed that the oldest buildings benefit more than the newest from the same retrofit action.

However, despite the high energy saving potential that each of the energy retrofitting strategies offers, the improvement of the indoor environment of the retrofitted homes should be highlighted. From the comparative analysis of the indoor temperature data of the baseline and improvement scenarios, a significant improvement in indoor temperatures in both winter and summer was found. However, some of the measures have been found to be more efficient than others. Improvement of the building fabric has been shown as the most effective strategy for improving indoor temperature. In the same line of energy savings, the increase of thickness of the external wall insulation from 5cm to 10cm, does not bring a significant improvement in the indoor temperatures within homes. On the contrary, in some of the archetypes, including flats built pre-1990 with silicate bricks and semi-detached houses, there is an increased risk of overheating in summer.

Although most of the homeowners in Albania claimed to have more difficulties heating their homes in winter, it was also found that space cooling during the summer is a concern. An increase in energy use is expected not only due to the progressive overheating of cities but also as a result of the high demand for, and decreasing prices of, space cooling equipment (European Environment Agency, 2019; Ascione *et al.*, 2020). It is expected that the air conditioning market will boost even more with the increasing affordability of cooling devices as well as economic growth as has happened in other countries, including America during the 1980s (Biddle, 2008). However, the main driver defining the future needs of air conditioning is higher ambient temperatures induced by global and local climate change (Santamouris, 2016). Just to give an economic reference, the additional electricity cost for cooling due to global and local warming in Europe is predicted to be between 22 and 89 billion euros per year by 2050 (Mima, Criqui and Watkiss, 2011). From the field studies undertaken in this study, it was found that many residents do not have enough information about how to properly use heating and cooling appliances to maximise their heating and cooling efficiency. Leaving windows and doors open while heating and cooling were on, was the main wrong behaviour that could cause heating and cooling load to increase. This behaviour was not always due to lack of awareness, but rather cultural factors. It has also been previously suggested that a higher temperature setting for air conditioners can improve cooling efficiency of the equipment (Wang *et al.*, 2021). Ascione *et al.*, (2020) found that the wrong occupant behaviour has a more significant impact on the cooling demand rather than the heating demand.

The findings suggest that the energy retrofitting measures investigated in this study were successful in reducing energy use for heating and cooling the space, as well as improving living conditions of households in Albania in both winter and summer. However, the investigation, which used three user profiles, demonstrated that occupant behaviour can affect significantly the results and success of the retrofits proposed in this study. Moreover, lack of advice and awareness can lead to the 'rebound effect' phenomenon as has been found in other studies (Druckman and Jackson, 2008; Guerra-Santin and Itard, 2010; Chitnis et al., 2013; Thomsen et al., 2016; Elsharkawy and Rutherford, 2018), and is explained as being a tendency among households to achieve a unified state of thermal comfort throughout the dwelling, heating all rooms for longer periods. Elsharkawy and Rutherford (2018) found an increase in heating periods of 43.5% after retrofit compared to pre-retrofit. Zhao et al. (2017) found that 73% of the households had warmer homes and improved internal home conditions after the retrofit. The results demonstrate that the effectiveness of energy retrofits is highly dependent on occupant behaviour and raising awareness and information regarding energy use and occupant behaviour plays a central role in the success of energy retrofits of residential buildings.

9.2.3. Reflections regarding the economic feasibility

Mortensen, Heiselberg and Knudstrup (2014) discuss that the economy of the project is the "deal breaker". There is a growing body of research on the Cost-benefit analysis of energy retrofitting strategies. The fourth objective of the thesis was to assess the most cost-effective energy retrofitting strategies in the Albanian context by using a cost-benefit analysis with three indicators: The Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback Period (PP). The average lifespan of retrofitting measures is taken to be 30 years, with a discount rate of 4%, in compliance with the European Commission recommendations.

The Cost-Benefit Analysis found most energy retrofitting strategies are economically viable. More precisely, it was found that thermal insulation of walls and replacement of single glazing with double glazing were the most cost-effective energy retrofitting strategies in the Albanian context with an average NPV of €965.2 and €754 respectively and an average Payback Period of 8.6, and 8.2 years respectively. Roof and floor insulation have a Payback Period of 17 and 12.9 years respectively, while the average NPV is €25 and €279.3 respectively. Upgrading a split system has a positive NPV of €168, with a payback period of 15 years. The combination of these two measures as a package (P1) was found to be more cost-effective, with a NPV of €283.4 and a Payback

Period of 14 years, compared to the deep retrofit (P2) which had a high Payback Period (34.4 years) and negative NPV (-€2,166.7). Applying energy retrofitting measures to homes built pre-1990 was found to provide the greatest energy savings, due to the poor original construction and design of these buildings. Wang *et al.* (2018) have also found that retrofit measures at the building envelope have a shorter payback period in older buildings compared to newer ones. Luddeni *et al.* (2018) and Belaïd, Ranjbar and Massié (2021) have also found that the cost-effectiveness of some energy retrofitting measures can vary significantly with building characteristics and initial conditions.

It is important to note the short payback period for window replacements for all the archetypes (5 to 11.7 years), making this measure very attractive for all residential buildings in Albania, regardless of their characteristics.

However, the occupant behaviour should not be taken off the equation and should be considered as important as technical aspects. Ascione *et al.* (2020) demonstrated that a successful investment in energy and economic terms can turn into a less successful one due to unconscious and incorrect occupant behaviours. The payback period for the retrofitting strategies may be reduced if the uncertainties related to the impact of the human factors are addressed, making retrofit investments more attractive (Santangelo *et al.*, 2018). Notwithstanding the result of the cost-benefit analysis that demonstrated the cost-effectiveness of most of the proposed energy retrofitting strategies in each archetype of the Albanian homes, their application requires substantial financial capacity, which should be carefully considered in energy policies.

9.2.4. Reflections regarding acceptability

The fifth objective of the thesis was to evaluate the most accepted energy retrofitting strategies in terms of costs, culture, and appearance, using semi-structured interviews with the Albanian homeowners.

Although economic factors are critical in deciding what and how to renovate, it was discussed that policies should inevitably treat the social context within which decisions are made (Wilson, Crane and Chryssochoidis, 2015), because generalisations made across diverse residential communities in energy efficiency programmes, in terms of age, class, ethnic group, biography and so forth, make their impact and social acceptability more problematic (Ambrose, Goodchild and O'Flaherty, 2017). As one size often does not fit all, the policy schemes should be designed to be consistent with the interests and needs of the specific groups of homeowners that they aim to deal with (Azizi, Nair and Olofsson, 2019). The analysis and findings from this research reinforce the need to understand the high impact that occupants, with their behaviour, preference, capability

of adapting to the indoor environment, and knowledge of the context surrounding them, have on the energy performance of their house. Understanding these factors would address their willingness to accept energy retrofitting and change their behaviour to maximise the benefits of their application.

From the interviews undertaken with 31 homeowners in Albania, 88 themes of factors of financial, occupant, building and institutional and administrative nature, were identified that affect the acceptability of energy retrofitting. Due to the interconnected nature of retrofitting, an interaction between various factors was found. As previously found in other studies (Jaffe and Stavins, 1994; Tuominen *et al.*, 2012; Zhao *et al.*, 2012; Huang, Ma and Song, 2021; Lai *et al.*, 2021), financial factors in general and the high capital costs required were the top factors affecting the applicability of energy retrofits. Worrying about the high cost was found to be the primary reason why residents were unwilling to undertake green retrofits in China (Lai *et al.*, 2021). In this study, it was found that deep retrofitting was not accepted as easily as single measures, mainly due to the high initial investment costs and long payback period. Furthermore, this study found that uncertainties related to different aspects of retrofitting happening at different stages of the retrofit process were prevailing, especially as the right information and experience were missing. Homeowners in Albania were uncertain of their future economic situation, making them reluctant to invest in 'non-essential' home improvements, especially if the building was functional. This finding is supported by Achtnicht and Madlener (2014) who also found that most homeowners wait until building components were approaching the end of their usual life before considering options for replacement or renovation. However, it is important to provide information and raise awareness of these groups of homeowners of the need to include energy retrofitting strategies as part of the renovation of their homes when the right time comes for them, as this does not always happen in practice. Caputo and Pasetti (2017) found that even when renovation has been undertaken to improve the functionality of a building component, adding energy retrofitting strategies has not always been feasible due to the inability to pay additional investment costs associated with the strategy.

Regarding the scenarios proposed in this study, double glazing, although perceived as an expensive energy retrofitting measure, was found to be the most accepted due to its financial benefits, thermal benefits, quick implementation, and ease of installation. Similar findings were unveiled regarding the upgrade of split systems. Thermal insulation of external walls has also been found to be highly accepted by homeowners as a single measure, while roof and floor measures were among the least accepted, mainly due to the disruption involved during the installation process. Regarding the packages of measures, P1 was highly accepted due to the potential energy savings and improved

indoor temperatures in both summer and winter. Despite high estimated energy savings, P2 was not widely accepted due to this high upfront investment cost, disruption, and time and effort associated with its implementation.

From a further investigation of the acceptability of each energy retrofitting strategy proposed in this study, building age and type has a significant impact on the choice. Building type was found to affect the willingness to accept some of the strategies over the others. For example, households living in multiple-dwelling buildings were more motivated to invest in building fabric improvement, mainly due to investment costs per household in a multi-dwelling building being significantly lower than for single-dwelling buildings, as previously found by Dolšak, Hrovatin and Zorić (2020). The age of the building was also found to affect willingness to retrofit. The building characteristics, including the year of construction and floor area, were identified as important factors affecting willingness to pay for residential retrofits (Huang, Ma and Song, 2021; Lai et al., 2021). On the other hand, although the aesthetic side of the energy retrofitting measures has not been found to be one of the determining factors affecting their acceptance, more attention should be given to aesthetic aspects of these measures by the product and service providers to make them appealing to motivate the homeowners to adopt them (Azizi, Nair and Olofsson, 2019).

It is important to highlight that a household's characteristics, especially age, might have a significant effect on willingness to accept energy retrofitting. Older and retired homeowners found it difficult to understand and accept retrofitting strategies because of many reasons, including uncertainty about their lifespan, limited knowledge, inability to change attitudes and behaviours related to cultural aspects, as well as financial circumstances. These findings are supported by other studies including Huang, Ma and Song (2021) and Fylan *et al.* (2016). Lower-income as well as lower-educated groups of households were also found to be less enthusiastic about energy retrofits, although they were highly motivated by financial savings through decreased energy use, as was previously found by Mills and Schleich (2012), Azizi, Nair and Olofsson (2019), Huang, Ma and Song (2021) and Lai *et al.* (2021). From the analysis of the sample of dwellings selected in this research, low-income households had dwellings with worse building conditions, with no renovation undertaken whatsoever for many years, and that were less comfortable. Therefore, special attention should be given when addressing policy to lower-income households, as most often a reduction in energy consumption means a reduction in general comfort, with occupants becoming increasingly at risk of energy poverty, social deprivation, isolation and ill health (Schaffrin and Reibling, 2015). Increasing awareness and information regarding energy use in buildings and energy retrofits among Albanian homeowners was also found to be essential, especially in the

lower-income and lower-educated group of households. Raising awareness has also been found to be a fundamental policy action in many other studies including Tuominen *et al* (2012), Caputo and Pasetti (2017), Santangelo *et al.* (2018), Azizi, Nair and Olofsson (2019), Ortiz, Itard and Bluysen (2020) and Jia *et al.*(2021).

Gram-Hanssen (2014a) argues that energy policies and recommendations should also include an understanding of lifestyles and home renovations, considering not only economic rational approaches but also appreciating lifestyle arguments for completing energy renovations. Schwarz, Nakhle and Knoeri (2020) recommend that policymakers include a technical and economical feasibility test for homeowners to successfully implement cost-effectiveness as a guiding principle. However, the analysis undertaken in this study underlines the essential role of factors that affect the acceptability of the energy retrofitting measures, which are not always of an economic nature. Therefore, future retrofit policies should also consider socio-cultural aspects and other factors that affect the willingness to accept various energy retrofitting strategies.

9.2.5. Holistic retrofit framework

The final objective of the thesis was to develop a retrofit framework that holistically assesses the performance of energy retrofitting strategies in residential buildings. The novelty of this framework is that it evaluates the effectiveness of the strategies not only technically and economically, but also by evaluating their acceptance by the homeowners. The RetrofiTEA framework devised in this study is a socio-technical approach that considers the implications and limitations of residential energy retrofits during the design stage. The framework aims to achieve a holistic and multi-criteria design that takes into account different performance requirements, including environmental, comfort, energy, cost-effectiveness, appearance, cultural and social implications, as well as other factors impacting acceptability to homeowners. The framework could also aid in the development of a knowledge base of information regarding retrofit recommendations, associated implementation costs, as well as factors and supportive behaviours to consider when choosing each retrofit, for each archetype. However, the purpose of this study, based on the empirical results, is not to provide a definitive recommendation on how to retrofit specific archetypes, but to identify key strategies for a group of similar buildings and investigate technical, environmental, and economic measures to save energy and improve the indoor environment that are also accepted and implemented by homeowners.

The baseline energy models developed for three user profiles clearly showed that occupants' behaviour, including their preferences and capability and willingness to adapt to the indoor environment, has a big impact on the energy performance of their home. However, the impact of occupants' behavioural change on the proposed energy retrofitting strategies has not been analysed because there is too much uncertainty and variability within Albanian households. Nevertheless, homeowners are willing to change behaviours for many reasons, including energy savings and achieving a better indoor environment, but they face challenges related to costs and, more importantly, a lack of knowledge and awareness.

9.3. Recommendations for energy retrofit policy development considering technical, economic, and socio-cultural aspects of energy retrofits

Based on the analysis undertaken in this study, as well as reflections drawn above, a list of recommendations has been enumerated regarding retrofit policy development considering technical, economic, and socio-cultural aspects, which of course are interconnected and have strong interrelationships between them. The analysis undertaken in this study does not aim to be exhaustive in policy implication terms, but rather to provide useful and reliable information on the most effective energy retrofitting strategies that create great potential in energy savings and improvement of the indoor environment, as well as being cost-effective and accepted by the homeowners, bearing in mind the factors affecting their implementation explored in each stage of the analysis. Figure 54 illustrates as a cognitive map the main considerations to be taken into account when developing energy retrofit policies.

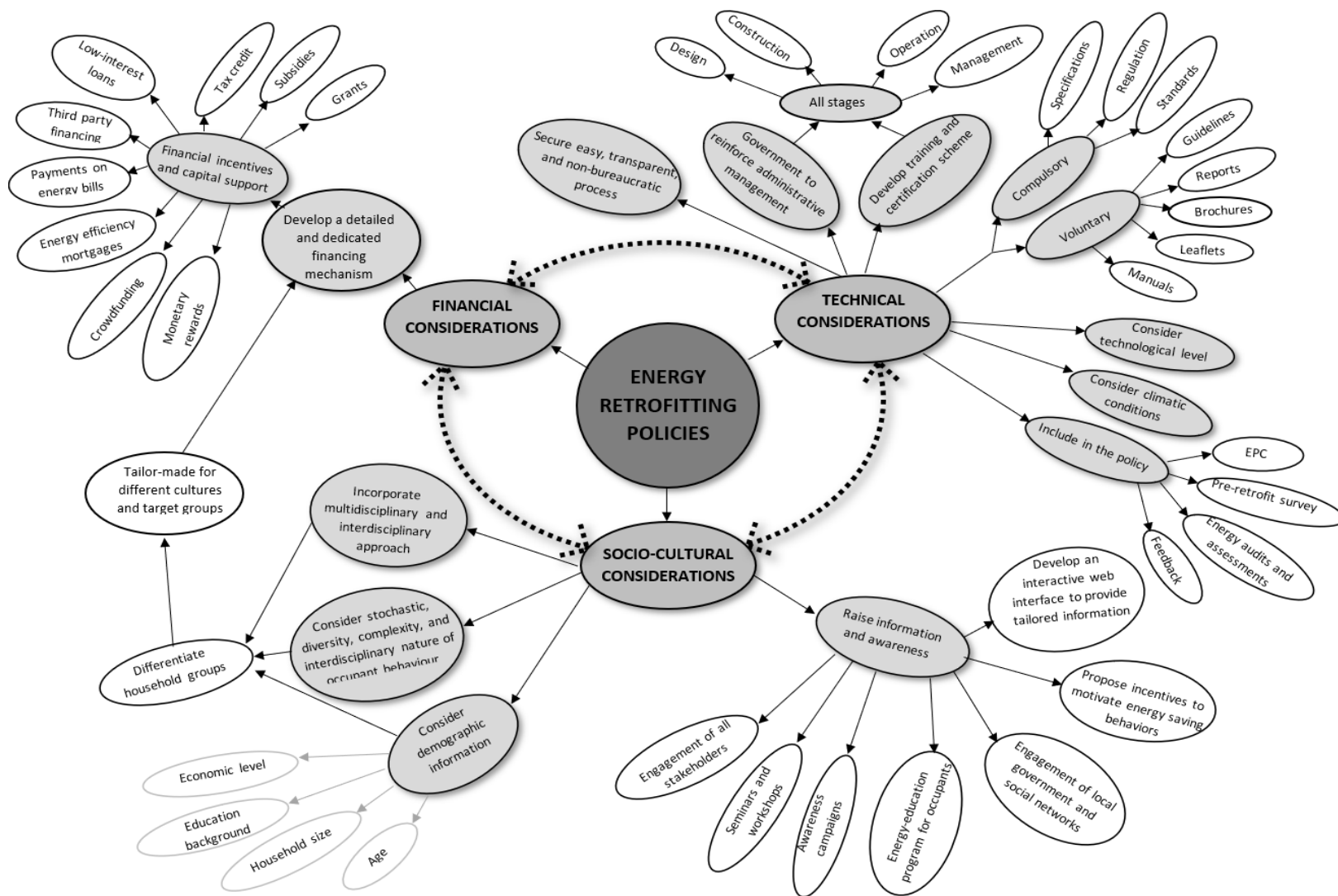


Figure 54: Considerations to be taken into account for energy retrofit policies as a cognitive map

9.3.1. Socio-cultural considerations

Recent research has reinforced the need to move toward a multidisciplinary approach in energy retrofits (Sibilla and Kurul, 2020). Laaroussi *et al.* (2020) recommends an interdisciplinary approach between drivers, needs and actions. A broader rational approach that is not linear and sufficient political will should be encouraged. Previous studies (Belaïd, Ranjbar and Massié, 2021) have recommended policy shift away from technically-oriented energy efficiency programs towards a mixture of renovation and behavioural change. This study highlights the significance of occupants' behaviour in energy consumption and possible energy savings for heating and cooling the houses, presses an urgent need for an energy-education program for building users and proposes incentives to motivate energy-saving behaviours. The energy policies should not assume occupant behaviour, but consider its stochastic, diversity, complexity and inter-disciplinary nature to provide the successful policies' development, implementation, monitoring and evaluation (Hu *et al.*, 2020). Ascione *et al.* (2020) has also determined this should be a starting point for better predicting energy demand before and after retrofitting.

A one-size-fits-all view on the effectiveness of energy efficiency measures irrespective of occupant behaviour is an unsuccessful approach to energy retrofits (Ben and Steemers, 2020). Energy retrofits should not only be conceptualised as a technological or environmental intervention, but also as a socio-cultural intervention, especially in the context of low-income urban developments, understanding the broader social norms and capital of the target group, and the socio-political environment (Haque, Lemanski and de Groot, 2021). Therefore, energy retrofits should be tailor-made for different cultures and target groups of households (Ben and Steemers, 2020; Dolšak, Hrovatin and Zorić, 2020; Ebrahimigharehbaghi *et al.*, 2021; Huang, Ma and Song, 2021; Lai *et al.*, 2021). To formulate a targeted energy-saving policy for a specific household lifestyle, it is essential to understand user profiles (Santangelo *et al.*, 2018; Ebrahimigharehbaghi *et al.*, 2021). Ben and Steemers (2020) also demonstrate that strategies tailored to household archetypes result in improvements in energy savings while maintaining occupant comfort, as well as responding to their needs and preferences (Haque, Lemanski and de Groot, 2021). Usually, policy schemes consider the homeowners as a homogenous group and assume they benefit equally from implementing energy retrofitting measures (Azizi, Nair and Olofsson, 2019), therefore there is a need to categorise them to create targeted strategies and policies to motivate diverse homeowners with different characteristics to implement energy retrofitting strategies. For example, Dodoo, Gustavsson and Tettey (2017), Wei *et al.* (2017) and Ben and Steemers (2020) have

found that larger energy savings can be achieved if the policies target higher energy-consuming households. Government should develop policies, incentives and plans for energy retrofits considering attitudes, preferences and willingness to pay among different stakeholders based on demographic information including, and not limited to, economic level, education level, household size and age.

Many studies have shown that raising awareness of energy efficiency can effectively promote energy-saving behaviours. Information-based policies have an important role in enhancing occupants' retrofit awareness (Huang, Mauerhofer and Geng, 2016; Jagarajan et al., 2017). Ben and Steemers (2020) have proposed an interactive web interface that can provide homeowners with tailored information concerning the most effective energy retrofit strategies for their home as well as behavioural and comfort choices that will significantly improve the accuracy of retrofit recommendations. Local government and social networks could also play an important role in building trust in the local community regarding energy retrofits, using local knowledge as well as engagement with consumers (Bergman and Foxon, 2020), through seminars and workshops presenting previous cases of retrofits, benefits and relevant policies (Zhang and He, 2021). However, awareness should be raised not only among homeowners but also among other stakeholders regarding the impact of occupant behaviour on improving energy performance (Ascione et al., 2020). Although changing consumption habits is difficult, making policies based on raised information and awareness has only a modest impact on energy use (Schaffrin and Reibling, 2015). Therefore, future policies should also take financial and technical considerations into account to increase the uptake of energy retrofits.

9.3.2. Financial considerations

Decreasing building final energy intensity is becoming the policy target for both developed and developing countries due to energy security and climate change issues (Hu et al., 2020). Various policies for encouraging and supporting energy retrofits have already become widespread throughout countries in the EU and in other markets worldwide, supported by various tools including financial incentives and capital support including grants, subsidies, tax credits, low-interest loans and third-party financing (Baek and Park, 2012; Wilson, Crane and Chryssochoidis, 2015; Delmastro, Mutani and Corgnati, 2016; Bjørneboe, Svendsen and Heller, 2018; Pombo, Rivela and Neila, 2019; Bergman and Foxon, 2020; Hu et al., 2020) as well as payment on energy bills, energy efficiency mortgages and crowdfunding (Bergman and Foxon, 2020). Monetary rewards for households with the lowest incomes could be motivating (Belaïd, Ranjbar and Massié,

2021), and including the household's financial status among eligibility criteria for financial support could help properly allocate public funds (Dolšak, Hrovatin and Zorić, 2020). The implementation and success of these policies have been dependent on each country's socio-economic situation. For example, Mikulić, Bakarić and Slijepčević (2016) found that energy retrofits in Croatia were not financially viable from the homeowner's perspective if not subsidised. The Green Deal in the UK, which was financed by a third party and paying back on energy bills, was not successful in upscaling energy efficiency retrofits, mainly because the process was complex and bureaucratic, the interest rates were above mortgage rates, there was no guarantee of energy savings as well as the objective being only financial savings, rather than households' comfort and wellbeing (Bergman and Foxon, 2020). Being financially viable does not mean that there will be a loss of comfort or wellbeing. On the contrary, with the right amount of guidance and training they could be successful (Boerenfijn et al., 2018). Bertone *et al.* (2018) have demonstrated that appropriate financing and procurement options would boost the government building energy retrofitting rate. Financial support in the form of subsidies in several instalments, and loans with affordable repayment terms, accompanied with information that promotes retrofits, could be one way of policy intervention (Hou et al., 2016; Ben and Steemers, 2018; Azizi, Nair and Olofsson, 2019; Huang, Ma and Song, 2021). Notwithstanding that drivers play a significant role in pushing all stakeholders to recognize, accept and implement energy retrofits, there is a danger that if they are too weak they automatically become barriers to implementing them (Zhang and He, 2021). Nevertheless, as shown in other studies (Dolšak, Hrovatin and Zorić, 2020), there might be a higher impact on future energy retrofits if the implementation of financial incentives is made in combination with informing and educating the public. Furthermore, different approaches to energy efficiency policy are needed for different types of households through a comprehensive and well-targeted mix of policy instruments that are based on a range of economic perspectives and analysis of what works in practice.

9.3.3. Technical considerations

The retrofit policy integrates two main strategies that affect the employment of energy retrofits: policy objectives (the quantifiable ambition level of the government) and policy instruments (the means, methods and measures adopted by the government to achieve the objectives) (Rogge and Reichardt, 2016; Arababadi et al., 2017; Liu, Tan and Li, 2020). Zhang and He (2021) have recommended that stakeholders' behaviour can be regulated by relevant governmental policies in compulsory (through specifications, regulation and standards) and voluntary (guidelines, reports, brochures, leaflets and manuals to enhance people's knowledge and improve their awareness) ways. Huang,

Mauerhofer and Geng (2016) also discusses that mandatory regulation is a powerful tool to promote energy retrofits. However, reaching policy solutions to energy retrofitting is not sufficient to lead to their application. The whole process of application for the financing of retrofit projects should be simple and transparent. Albania is a developing country that faces challenges in developing standards and certification processes. Therefore, the policies designed to encourage energy retrofits should also include not only financial incentives and capital support but also energy audits and assessments, energy performance certificates, certification and training of contractors, community renovation schemes, as well as awareness campaigns (Brown, Swan and Chahal, 2014; Baldwin *et al.*, 2018; Tan *et al.*, 2018; Pombo, Rivela and Neila, 2019; Liu, Tan and Li, 2020). Because lack of trust in professionals undertaking assessments and work has been found one of the awareness barriers, developing a scheme to train and certify qualified professionals has been proposed (Alam *et al.*, 2019). Technical training of designers, engineers, constructors, builders and building operators should be proposed in the policies for them to have the best understanding of the requirements and techniques for implementation, operation and maintenance of various energy retrofitting strategies. This would be extremely essential in the case of Albania, where there is a lack of extensively experienced specialists carrying out energy retrofitting activities from energy auditing, designing and estimating the energy performance of various retrofitting measures, applying the measures, and verification and commissioning. Retrofit policies should include training programs specialists at every stage of the retrofitting process, including design, construction, operation and management. Moreover, there is an urgent need to develop a new generation of practitioners who are able to manage the complexity of technical and social issues related to sustainability (Udhir *et al.*, 2020), especially in Albania. Likewise, to achieve a successful implementation of the retrofit programs, the government should reinforce administrative management into all stages of implementation of these projects.

This study determined the importance of a pre-retrofit survey on not only minimising the performance gap but also understanding occupants' needs and willingness to accept various energy retrofitting strategies. Therefore, policies could be developed based on findings of temporal monitoring as well as building and occupants' characteristics to target different households and focus on both energy performance as well as comfort. Using these surveys to differentiate household groups will allow a better energy saving prediction, as well as help choose the most effective retrofit strategies to achieve an optimum energy demand reduction (Ben and Steemers, 2020). Furthermore, Zhang and He (2021) recommend the development of an informative technique checklist with

feasible conditions, construction methods, limitations, as well as potential performance and cost-effectiveness for each energy retrofit strategy.

Setting minimum requirements for buildings' energy use through building energy codes has proven to be effective and efficient for building decarbonization (Schwarz, Nakhle and Knoeri, 2020). Energy Performance Certificates (EPC) can also serve as a tool to help occupants decide which household type they belong to (Ben and Steemers, 2020) and enable them to either choose the retrofit strategies based on their household type or change their behaviour to benefit the most from the chosen retrofit options. Retrofit programs should not only consider and support the technology with the highest energy saving but greater freedom should be allowed to determine the most effective strategy or strategies for individual homes within the programme. Giving feedback on electricity consumption has been shown to tend to reduce this consumption (Kendel, Lazaric and Maréchal, 2017). Government should develop policies, incentives and plans for energy retrofits considering the technological level and climatic conditions (Zhang and He, 2021).

9.4. Recommendations to house providers/developers and homeowners for choosing energy retrofit strategies

The analysis undertaken in this study provides valuable findings that can facilitate homeowners in their decision-making process. Furthermore, the recommendations could benefit the house providers/developers. First, it is important to underline that any energy retrofitting strategies adapted to existing residential buildings would benefit the occupants in one way or another. However, deciding the most effective energy retrofitting strategies depends on many factors, including technical and economic as well as social and cultural factors, as analysed in this study. The most important considerations to be taken by the homeowners when choosing the right energy retrofitting strategies for their homes are given as a cognitive map in Figure 55.

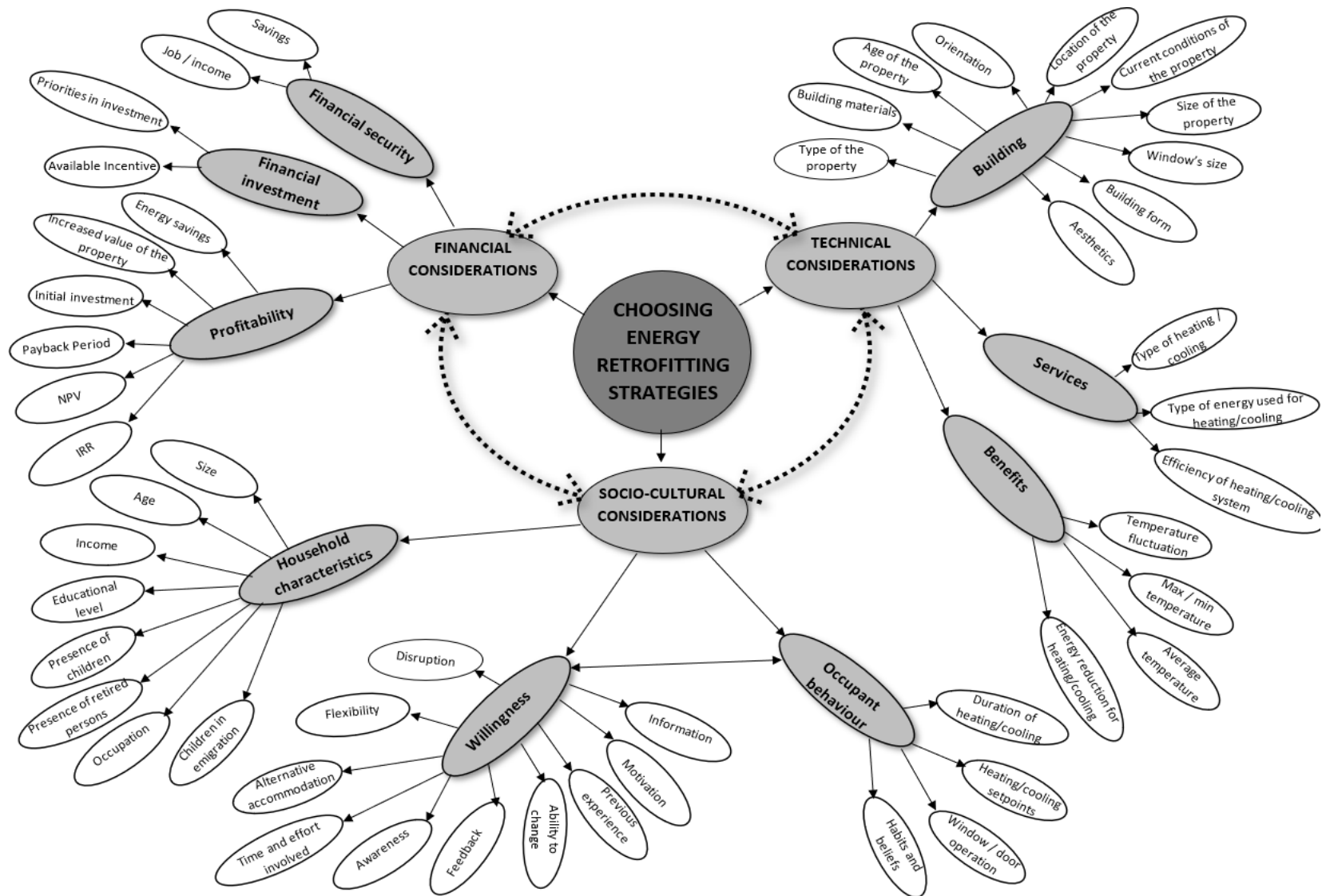


Figure 55: Cognitive map of the considerations to be taken in the decision-making process by homeowners

9.4.1. Technical considerations

After investigating the technical feasibility of the proposed energy retrofitting strategies in this study, it was found that each of the strategies contributed to energy reductions for heating and cooling and improvement of the indoor environment in homes. However, the effectiveness of the retrofits and the success of achieving the estimated energy savings and improvement of the indoor environment is highly dependent on building characteristics, including the type and age of the building, construction materials, location and orientation, as well as building form. The impact that building-related factors have on energy consumption, as well as the indoor environment, has also been explored by other studies including Oreszczyn *et al.* (2006), Guerra Santin, Itard and Visscher (2009), Steemers and Geun Young (2009), Shipworth *et al.* (2010), Kelly *et al.* (2013), Huebner *et al.* (2015) and Hamilton *et al.* (2017). It was found that buildings with solid brick walls have a greater potential for reductions in energy used for heating, whereas greater reductions in cooling loads were found in buildings constructed with hollow bricks. The analysis also revealed that archetypes with higher chances for cross ventilation during the summer, including detached, semi-detached and terraced houses, may have a higher range of indoor temperatures. While in winter, it is the flats that have the highest indoor temperatures due to fewer external walls, and more attention should be given to occupant behaviour in detached and semi-detached houses as the archetypes with more external walls.

Furthermore, the current condition of the buildings has been shown to have a significant effect on the potential energy savings. This study, which is supported by previous studies including (Luddeni *et al.*, 2018; Rinaldi, Schweiker and Iannone, 2018; Uidhir *et al.*, 2020; Belaïd, Ranjbar and Massié, 2021; Gulotta *et al.*, 2021), found the fact older buildings offer more potential for energy savings than the new buildings is associated not only with building materials with better properties being used in new buildings but also with the fact that old buildings are more possible to be degraded. Other building characteristics, such as the size and window area, directly affect the energy used for heating and cooling. On the other side, the type of energy used for heating and cooling as well as the type of heating and cooling systems together with their efficiency, affect the energy savings estimated from each energy retrofitting strategy chosen.

9.4.2. Financial Considerations

Although the results of the study showed that most of the energy retrofitting strategies proposed were cost-effective, each homeowner might be in various circumstances as

well as have different priorities in investment. Notwithstanding the positive attitude to retrofits, in this study, it was found that financial insecurity was hindering whether to invest in retrofits or not, depending on the job and income continuity as well as available savings. While most effective energy retrofitting strategies in terms of energy savings and improvement of the indoor environment would be preferable for each homeowner, their financial figures must be considered, including the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback Period (PP). Strategies with a shorter payback period and higher NPV were among the favourite strategies among the homeowners in Albania. Higher energy savings, as well as the increase in the value of the property, were also listed as benefits of retrofitting. Notwithstanding the high initial investment cost of some of the strategies including the packages of measures, homeowners were driven and motivated to explore options to support their investment because of the benefits offered by retrofitting, especially the improvement of the indoor environment. The initial investment was found to be the top barrier to retrofits among homeowners in Albania, as it has been found previously in studies undertaken by (Jaffe and Stavins, 1994; Tuominen *et al.*, 2012; Zhao *et al.*, 2012; Huang, Ma and Song, 2021; Lai *et al.*, 2021). Exploring the available government incentives would be crucial to increase the opportunities for applying the most affordable strategy. Even though cost-effectiveness was found to be essential in the decision-making process when choosing the energy retrofitting strategies, it is important to underline that their profitability is dependent on technical considerations regarding the building itself and the operating systems available in the property. Although the most effective energy retrofitting strategies in terms of energy savings and improvement of the indoor environment are those that offer the highest energy savings and lower temperature fluctuations within the comfortable temperature range, these results are dependent on each building's characteristics. Homeowners should take into consideration specialist advice as the type and age of the property, building materials used, orientation, location, size as well as building form have a significant effect on the estimated energy savings for each building. Furthermore, the current condition of the property, as well as the glazing area, influences the final results of each energy retrofitting strategy. Some of the strategies, including thermal insulation of external walls as well as two packages of measures, can alter the aesthetics of the building, therefore, this aspect must be considered when choosing the right measures.

Notwithstanding the improvement of the building's envelope thermal performance, the operating systems used for heating and cooling the space in the house as well as their efficiency have a significant effect on the energy savings. The improvement of the energy efficiency rate of the split system alone from 2.2 and 2 for heating and cooling

respectively to 3 for both, would increase the energy savings up to 35% in dwellings in Albania.

9.4.3. Socio-cultural considerations

Notwithstanding the nature of the factors determining retrofitting choices, the success of the implementation of retrofits is highly dependent on the occupants' behaviour (Andersen et al., 2009; Gram-Hanssen, 2013; Ingle et al., 2014; Ascione et al., 2020) and their willingness to change and adjust their behaviour to ensure the effectiveness and success of the applied retrofitting.

From the field studies undertaken in this study, it was found that many residents do not have enough information about how to properly use heating and cooling appliances to maximise their heating and cooling efficiency. It has been previously suggested that a higher setting temperature of the air conditioners can improve cooling efficiency (Wang *et al.*, 2021). Leaving windows and doors open while heating and cooling were on, was the main wrong behaviour that could cause heating and cooling load to increase, while this behaviour was not always due to lack of awareness, but rather to cultural factors. The right occupant behaviour related to window and door operation during the day and making use of passive cooling at night would lower the overheating risk in these archetypes in summer.

Accepting energy retrofitting in Albanian homes was found to have a significant effect on household characteristics, including size, age, income educational level and occupation. Other studies (Mills and Schleich, 2012; Gucyeter, 2018; Azizi, Nair and Olofsson, 2019; Huang, Ma and Song, 2021; Lai *et al.*, 2021) support this finding. Furthermore, the presence of children was one of the main factors that imposed a better indoor environment in homes as found previously by Zahiri and Elsharkawy (2018), making retrofitting an acceptable option. However, the presence of a retired person did not significantly affect the willingness to implement any retrofitting strategies even though previous studies have shown significant improvements in the health of this age group of households after retrofits. Apart from economic reasons and uncertainty of their lifespan, retired homeowners did not accept retrofitting also due to their unwillingness to change behaviour to maximise the success of retrofits. Similar findings were highlighted in Huang, Ma and Song (2021) and Fylan *et al.* (2016). For example, it was found that it was difficult for them to close windows in summer and sometimes in winter due to the strong connection they have with the outdoors. However, homeowners in Albania trying to choose the right energy retrofitting strategies for their homes should not consider only

the technical and economic aspects of them. Different strategies require different flexibility as well as time and effort. They also differ by the degree of disruption to their lives as well, as it might require alternative accommodation. Having had previous experience in retrofitting their home, as well as being motivated, would increase their willingness to accept further retrofits and changes in their behaviour. Therefore, the main recommendation to the homeowners is to ensure they are provided with the right information, which is complete and is coming from reliable sources.

CHAPTER 10

Conclusion

10.1. Introduction

In the context of the growing climate emergency, research into ways to reduce energy use by buildings, which are recognised as contributing up to 40% of total direct and indirect CO₂ emissions (IEA, 2020a), is vital. Whilst much research has been done in this area, this thesis is unique in its focus on the impact of the behaviour and attitudes of occupants of residential buildings on their energy use and on their willingness to undertake retrofitting – and to what degree.

The impact that energy retrofits of Albanian housing stock can have on saving energy as well as improving the indoor environment for occupants, should not be underestimated. This is especially the case when the buildings are old and have high energy-demands as a result of a low-quality building envelope and inefficient heating and cooling systems. The list of additional benefits retrofitting can provide is long and includes reducing emissions and building resilience to climate change impacts (European Commission, 2016), economic growth, job creation and reducing the risk of fuel poverty on a local, national and global scale (Technology Strategy Board, 2014; Global Buildings Performance Network, 2015) as well as increasing property values or rental fees and extending the lifespan of buildings (Zeng *et al.*, 2018; Belaïd, Ranjbar and Massié, 2021). Although cost-effectiveness, potential energy savings, and improvement of thermal comfort are the top drivers for people to undertake a retrofit, these estimated results are not always achieved. It has been acknowledged, especially during the last decade of research, that unhelpful habits and behaviours by occupants are a significantly contributor to this performance gap (Steemers and Geun Young, 2009; Sunikka-Blank and Galvin, 2012; Yoshino, Hong and Nord, 2017; Gram-Hanssen and Georg, 2018; Ben and Steemers, 2020). In line with the recent research, a multi-dimensional interdisciplinary, socio-technical and user-centre approach, incorporating sociology, psychology, economics, engineering and design factors (Mills and Schleich, 2012; Delzendeh *et al.*, 2017; D'Oca *et al.*, 2017) should be followed when approaching energy retrofitting to achieve successful outcomes. It is worthwhile to mention that the majority of energy modelling gaps occur due to data being limited or almost non-existent (Ali *et al.*, 2020).

This chapter sets out conclusions from this study, including its contribution and limitations, and recommendations for future research.

10.2. Contribution to knowledge

This study contributes original knowledge in the following areas:

1. *Using empirical data that leads to the creation of indoor temperature clusters that can be used for energy modelling of Albanian housing.*

The proposed methodology offers a way to bridge the performance gap between estimated and achieved energy savings through various ways:

The development of indoor temperature profiles demonstrated the importance of considering various energy behaviours when estimating energy use to improve the overall model performance. The findings suggest that using the standardised assumptions about heating preferences, including heating/cooling setpoints and heating/cooling duration, will most likely produce unreliable predictions of space heating and cooling energy demand given the large variability observed in heating/cooling setpoints and periods, as a result of variations in occupants' behaviour.

Furthermore, using empirical data to evaluate the actual building conditions and performance, as well as occupants' behaviour and perspectives regarding energy use in their homes, and further validation of energy simulations, would lead to more reliable estimations.

2. *Modelling work itself is quite routine unless some of the findings are novel.*

There is nothing new in the recent research about modelling work itself. However, making it part of a broader picture — as in this case when the strategies have not been seen only as technical estimations of the energy savings but were further evaluated for cost-effectiveness and acceptability — brings a new perspective to the way future retrofitting projects could be approached to ensure their applicability and effectiveness.

3. *A deeper understanding of the extent and reasons for the lack of acceptability of energy retrofits.*

This study provides a fresh perspective by including the acceptability of energy retrofitting strategies to homeowners as well as investigating their potential to

save energy, improve the indoor environment and their cost-effectiveness. Factors affecting homeowners' willingness to accept, or not, each energy retrofitting strategy proposed in this study have been examined, and the framework suggests a way to include occupants and their behaviour in the equation of energy retrofits.

4. *The analysis undertaken in this study poses a challenge to expand the analysis of interdisciplinary research.*

The study offers a challenge to policymakers to engage in in-depth discussions about psychological, physiological, social and cultural factors affecting the uptake of energy retrofits in residential buildings as well as those of a technical and economic nature. This is not the first study that acknowledges the existence of factors of various natures that could serve as barriers or drivers to energy retrofits. However, this study considers them and analyses their impact on homeowners' willingness to accept the implementation of various energy retrofits. This study demonstrates the urgent need for an interdisciplinary approach to energy retrofits that considers the occupants.

5. *This study owes its originality to providing technical information about the main residential building archetypes in Albania, then providing recommendations for each archetype for the most effective strategies to save energy and improve the indoor environment, based on their cost-effectiveness and acceptability to homeowners.*

It develops a framework that intends to assist homeowners in their decision making regarding energy retrofits in their homes. Although the study is based on the Albanian context, the results regarding the importance of including homeowners and occupants in the decision-making process, rather than proposing a one-fits-all strategy, could be generalised. Basing policy development on energy savings alone has not proven to be successful in increasing retrofits. Instead, policies should be multidimensional and supplemented by other incentives that also consider cultural and social factors. The empirical evidence in this study suggests that there is a huge potential for space heating and cooling energy savings at the household level. Therefore, developing the right policies and proposing the right incentives would be an efficient strategy for reducing energy use by the residential sector at a national level. Implementing these energy retrofitting strategies at a country scale has great potential in terms of energy savings, however, input factors in assessing

the cost-effectiveness of each strategy should be carefully considered for each retrofitting project. The application of the framework proposed in this study and consideration of the results of the analysis would be fundamental to supporting energy policies and strategies at a national level. From a policy perspective, the findings of this study have several potential implications that could encourage the speeding up of energy retrofitting of residential buildings in Albania. The findings provide evidence to policymakers that various energy retrofitting strategies offer great potential in terms of energy saving and offer key information for policymakers to identify and prioritise the least energy efficient dwellings, as well as the most effective retrofitting strategies for each archetype. Furthermore, the exploratory analysis of the factors affecting the acceptability of each energy retrofitting measure aid policymakers in addressing and overcoming the barriers to large-scale implementation of energy retrofits in Albanian housing stock.

Carefully designed retrofit policies can unlock huge potential for improving building energy efficiency in developing countries (Liu, Tan and Li, 2020), especially where the built area and energy consumption are expected to increase as a result of the ongoing development of these countries. The results achieved through this analysis are perceived to be strong and deep enough to build foundations for retrofitting programs that will increase private energy retrofits.

10.3. Critical comments on the research

I acknowledge the limitation of this research.

10.3.1. Limitation of time

Although this thesis took over six years to complete, the first stage of data collection, including the first and second field studies, was undertaken in the first year. Additionally, data recordings of indoor temperature were only undertaken for six weeks in summer and six weeks in winter. Although monitoring for an entire year would have provided more detailed information on the indoor environment during the no heating/cooling seasons, that was not feasible due to time limitations, disruption to participants, and additional travel costs.

Furthermore, whilst changes in policy discourse and legislation were observed during this period, only a part of the updated legislation on energy efficiency in Albania was included in this study, as detailed information and implications are not yet available.

Future research could investigate the long-term effects of this new legislation, regarding the policies proposed for energy efficiency projects in Albania, the economic effects, the tightening of building regulations in 2010, as well as policies regarding their implementation. This would make for interesting research as these policies play an important role in promoting energy retrofits in residential buildings in Albania.

10.3.2. Limitation of funds

This study had a limited fund, and some important issues could not be followed up in this research. As previously mentioned, one of the reasons for the limited monitoring time was the funds that would be required for additional travel. Cost also limited the choice of monitoring device. Being able to measure other indoor environment parameters, including the air temperature, radiant temperature, air movement and humidity, would have provided a more accurate picture of thermal comfort within the sample of dwellings selected for this study. This could be the scope for future research.

Limitations on time and resources were also the main reason dwellings chosen for this study were located only in Tirana and not in other parts of Albania.

10.3.3. Limitation of scope

Lack of data and information regarding residential buildings, their energy and thermal performance, economic figures, policies and so on, was found to be the most critical issue in building the foundations of this research. Therefore, preliminary work has been done to address this lack of information and the limitations related to it.

- No database includes all the necessary information in one place. Therefore, several data sources have been aggregated and adapted to create the archetypes as thermo-physics models representing the baseline scenario.

The archetypes were developed based on building type, construction period and material. Although residential buildings in Albania are classified into five different construction periods in the available statistical data (Instat, 2012), there is no classification available in terms of energy performance. Therefore, the archetypes are built based only on two construction periods: pre-1990 and post-1991, not taking into consideration buildings built pre-1960. However, classifying them by their construction materials (red bricks, silicate bricks and prefabricated) for the buildings built pre-1990 and hollow bricks for those built post-1991 accounts for the other construction periods.

The study does not take into consideration residential buildings that have already undergone retrofits, as these buildings might not be the focus of further retrofitting by their homeowners. However, a more detailed classification can be adapted in further research.

- Albania has three climatic zones; however, the case studies were selected only in Tirana so the results of each retrofitting measure may vary for the other climatic zones. Further research would be necessary to investigate the effectiveness of the proposed energy retrofitting strategies in this study for other climate conditions in the country.
- Only electricity consumption for heating and cooling has been considered in this study. The electricity consumption related to DHW, lighting and appliances is assumed to be constant. This study is focusing mainly on strategies that improve the envelope of the building and the heating and cooling system, and therefore does not change DHW and equipment or lighting.
- The study does not include energy regeneration strategies including PV and solar thermal because, although they might be efficient for the Albanian climate, which is characterised by a high number of sunshine hours of up to 2,500 hours per year (Ministria e Infrastruktures dhe Energjise, n.d.), the grid is already “low emission and renewable”. In Albania, 90% of electricity production comes from hydropower, and it already emits the lowest amount of CO₂ in the Western Balkans (International Energy Agency, 2008). Moreover, the strategies have been chosen mainly because they have a direct effect on heating and cooling energy consumption.

The Cost-Benefit Analysis of the energy retrofitting strategies considered in this study provide a guide rather than an exact calculation of the final investment's profitability, taking into account the lifespan of the energy retrofitting strategies. Therefore, the robustness of cost-effectiveness indicators through a sensitivity analysis has not been performed, even though the researchers acknowledge the previous finding that energy retrofitting strategies' cost could vary according to the local conditions of the energy retrofits market and the existence of rebound effect or climate (Belaïd, Ranjbar and Massié, 2021). Furthermore, Sensitivity analysis of the financial results in relation to the future energy prices has not been performed as part of this study, rather than the focus has been on the methodological approach. Therefore, these results might change depending on the scenarios and assumption used for future analysis.

- I understand that the research has been focused only on the homeowners and no other professionals and authorities have been interviewed. However, the

focus has been on the homeowners' perspectives and experiences and that is the angle that usually is not fully explored and understood. Moreover, (Fawcett, 2014) has recognised the household as an important route of enquiry for examining environmental behaviour. As (Haque, Lemanski and de Groot, 2021) point out, this is an area that has received limited attention. The findings, whilst informative, are based on the experiences of participants in the interviews. Therefore, there might be other perspectives, barriers and drivers to overcome for each of them.

Even though the field study is based only on occupants' perspectives, it exposed some great and useful insights into their preferences, needs and expectations. Future studies should be undertaken to include other stakeholders involved in the retrofitting process. From the field studies, it is noted that households are very diverse and other unobserved heterogeneity may exist that is not accounted for in this study. And the information can be subjective for each respondent.

- This study performs a cross-sectional evaluation of variations in occupant behaviours, as reported by the participants, and not a longitudinal one. Therefore, the possibility of these behaviours changing over time have not been considered, which might result in different energy savings from those estimated. Savings made possible through behavioural change have not been evaluated in this research due to high uncertainties related to them. (Ben and Steemers, 2020) have proposed an estimation of a behavioural pattern change as a possible route to tackle this problem.
- Only the indoor temperature has been monitored during the field studies to provide an indication of the range of temperature present within homes. The focus of this thesis was not to conduct a thermal comfort field study, but to have an insight into how people evaluate how their home was performing. A national scale thermal comfort field study considering all the environmental parameters, including the air temperature, radiant temperature, air movement and humidity, as well as personal factors of metabolic heat production and clothing, would be essential to investigate the breadth of thermal comfort conditions in homes and identify the indoor conditions that are sufficiently acceptable for occupants.
- To have a long-term prediction of buildings' performance in terms of energy savings and thermal comfort, an investigation of climate change scenarios would be useful. However, this investigation would require deep analysis and development of climate change scenarios, which is beyond the scope of this thesis. Therefore, future research on the investigation of the most effective

strategies delivered from this study under various climate change scenarios would be beneficial.

10.3.4. Limitation of transferability

The skills brought to this investigation were broad, including technical skills related to the evaluation of energy and thermal performance of homes and energy modelling, economic assessment, and developing and undertaking field studies, surveys, and interviews. In larger projects in the real world, as part of interdisciplinary research, these tasks are probably performed by a team of researchers and scientists, where good communication between them is essential. Lack of collaboration and appropriate skills and training would result in limitations to the methodology developed in this study. On the other hand, this study has been focused on a specific country (Albania) and the steps undertaken throughout the research are closely related to the context, including economic and social-cultural aspects. Therefore, if the framework is transferred to another context, it may be relevant to investigate other aspects. Furthermore, less preliminary work might be necessary, depending on the level, depth, and accuracy of data available.

The investigation of the energy retrofitting strategies is undertaken only in owner-occupied homes as the prevalent occupation type in Albania. In the context of other countries, further investigation could be needed for social housing or privately-rented homes, as the cost and benefits of energy retrofits might differ.

10.3.5. Other limitations

- The electricity bills provided in Albania do not differentiate between energy used for heating or cooling and energy used for other purposes. Therefore, this study has calculated an estimated energy use for heating and cooling by subtracting the average energy use for an Albanian family that does not use heating or cooling of their home. However, the first field study collected data regarding the appliances and lighting in each reference building to use for baseline energy modelling, which enabled an estimation of energy use that might have been close to reality. This highlights the importance of pre-retrofit field studies to provide data that are close to reality and minimise the assumptions.
- The sample size was not found to be representative of Albanian housing stock, therefore the results should be interpreted as case studies, rather than as a representative of each archetype. At the same time, data collected provided

richer information about occupants' behaviour and preferences, as well as energy consumption. Although the analysis provides essential findings, interpretation of the results should be treated with caution as they depend on the representativeness of the sample as well as uncertainties related to the data collected. This research has revealed that although the energy retrofitting strategies have been cost-effective and offer a high potential for energy savings and improving comfort, they might not be accepted by the homeowners due to their behaviour, lifestyle, perceptions, or preferences. Therefore, extrapolating the results to the wider population of Albanian homes should be treated with caution. However, this study does find empirical evidence of the significant potential of retrofits to improve the energy performance of existing homes as well as their indoor environment.

- The small dwellings sample might have affected the heating and cooling temperature setpoints; for a larger sample, it might be different. However, using three different setpoints for heating and cooling provides a range of possible real life setpoints.
- The use of building energy modelling to investigate various energy retrofitting strategies has its limitations, however, using data collected through the field studies was intended to minimise assumptions.

10.4. Future research

Notwithstanding the significant contribution that this study makes to the field of energy retrofitting of the residential sector in Albanian and beyond, some limitations to the methodology advancement and empirical results were identified, which could be addressed in further research. This study contributes to the ongoing discourse about energy efficiency research by trying to explain the complexities of individual and homeowners' decision-making processes regarding energy retrofits and emphasising the social nature of energy-related decisions.

- A larger national-scale field study of thermal comfort in Albanian homes would be a valuable extension of the current work and could also be used to validate the findings of this study.
- Due to the small dwelling sample and number of participants in the third field study, the present study could not make a statistical analysis of the factors affecting the acceptability of energy retrofits by homeowners. Therefore, it would be interesting to see further research into the statistical relationships between the

occupants and those factors. Moreover, a larger sample might reveal other factors that were not able to be identified in this study.

- Although the acceptability analysis considered the homeowners to be the main stakeholder directly affected by the energy retrofit of their homes, future studies that consider other stakeholders including policymakers and property developers/providers, involved in the retrofit process would be essential to assess and then address any barriers affecting acceptability and applicability of retrofits in residential buildings.
- The next step is to create a country-level policy to support and encourage energy retrofitting measures.
- The study could be extended to the whole Albanian context, including all three climatic zones and all the main building archetypes.
- A residential toolkit can be developed in Albania, where homeowners can access information related to the energy performance of houses similar to their house, and possible interventions to improve its energy and thermal performance. Moreover, reliable information could be included, such as technical guidance and cost-benefit analysis, as well an explanation of financing strategies for each of the energy retrofitting strategies included in the toolkit. A further challenge would be optimising and implementing the most effective retrofit recommendations for buildings on a large scale. This toolkit would facilitate the policymakers in identifying retrofit alternatives.
- Due to climate change being a global challenge, further analysis would be needed to assess the long-term impacts of climate change on the building stock and investigate the performance of the energy retrofitting strategies to ensure optimal building performance for future climatic conditions.
- The transferability of lessons and experience from existing studies in the European context could be further examined, while optimisation of incentives and approaches for accepting and implementing energy retrofits in Albania should be further proposed and developed.
- Further studies into the existing housing stock from an energy point of view are essential in Albania. Creating a database of energy performance certificates that would facilitate the potential of energy savings through energy retrofits would be an important step in developing future energy policies.
- Many European countries have already created net-zero-energy standards for new buildings, and are looking at implementing them for the refurbishment of existing buildings in a few years' time. Therefore, it is important developing countries, like Albania, develop energy-education programs for building users.

This study could be a starting point for expanding investigations toward achieving net-zero buildings in Albania in the future.

In summary, this study showed there is significant potential to further encourage energy retrofits of existing residential buildings in Albania. However, a holistic and interdisciplinary approach must be taken to effectively advance their application and success.

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Appendix 1: List of published papers from this thesis

1. Murataj, J., Gupta, R. and Nicol, F. (2022). 'Developing Indoor Temperature Profiles of Albanian Homes for Baseline Energy Models in relation to Contextual Factors', *Energies*, 15(10), DOI: 10.3390/en15103668
2. Murataj, J., Gupta, R. and Nicol, F. (2018). 'Energy and thermal performance of apartment buildings in Albania: the case of a post-communist country', *Proceedings of 10th Windsor Conference 2018 - Rethinking comfort*, 865-883, Windsor, UK, 12th-15th April 2018
3. Murataj, J., Gupta, R. and Nicol, F. (2017). 'Influence of occupant behaviour on thermal comfort and energy use in Albanian homes', *Proceedings of International Conference for Sustainable Design of the Built Environment SDBE 2017*, 623-632, London 20th-21st December 2017
4. Murataj, J., Gupta, R. and Nicol, F. (2017). 'Energy and thermal performance assessment of existing residential buildings: the first step to introducing successful retrofitting strategies in Albania', *Proceedings of 33rd PLEA International Conference Design to Thrive*, Vol 1, 104-111, Edinburgh, 2nd-5th July 2017

Article

Developing Indoor Temperature Profiles of Albanian Homes for Baseline Energy Models in Relation to Contextual Factors

Jonida Murataj ¹, Rajat Gupta ^{2,*} and Fergus Nicol ¹

¹ School of Architecture, Oxford Brookes University, Oxford OX3 0BP, UK; 15005185@brookes.ac.uk (J.M.); jfnicol@brookes.ac.uk (F.N.)

² Low Carbon Building Group, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford OX3 0BP, UK

* Correspondence: rgupta@brookes.ac.uk

Abstract: Oversimplifying occupant behaviour using static and standard schedules has been identified as a limitation of building energy simulation tools. This paper describes the use of hierarchical cluster analysis to establish the most typical indoor temperature profiles of Albanian dwellings based on monitored indoor temperatures in winter and summer, along with building and occupant surveys undertaken in 49 randomly selected dwellings in Tirana. Three statistically different profiles were developed for each summer and winter, indicating that homes are used in different ways, as well as revealing possible comfort requirements. Furthermore, statistical analysis was undertaken to determine the strength of the association between the clusters and contextual factors related to the building, household, and occupancy. A statistically significant association was found between the presence of children and the clusters in winter, suggesting that families with dependents use more energy. Building-related factors including building type, building age, and wall insulation were found to be statistically significantly associated with clusters in summer. These profiles could provide more accurate outcomes of energy consumption of Albanian homes and energy savings from retrofits. They could also facilitate the development of low-energy strategies and policies for specific households.

Keywords: occupant behaviour; indoor temperature profiles; cluster analysis; energy modelling

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1. Introduction

Buildings' energy simulations are one of the most common methods for estimating the energy demand of existing buildings, as well as energy savings from retrofitting projects [1]. However, there is often a significant discrepancy between the predicted and actual energy consumption of buildings [2–12], which is influenced by different factors and is largely caused by the complex interdependencies that occur between the fabric, services, controls, and occupant behaviour [13,14]. The physical design factors such as building features and the effect of external weather are the focus of many building simulation tools, while it has been challenging to incorporate the interaction between occupants and buildings, even though there has been significant research on occupant behaviours in buildings in recent years [11]. Only 5 out of 27 factors that were suggested in previous studies reviewed by Wei, Jones and de Wilde [15], i.e., room type, occupancy, indoor relative humidity, outdoor climate, and time of day, have been used to model space-heating behaviour in building performance simulations (BPS). Generally, occupant behaviour is oversimplified and predefined through static schedules in building performance simulations, ignoring its stochastic nature, dynamics, and diversity [16]. Improving assumptions about building operation has been a key challenge in recent research [1,17–19].

The choice of setpoints and operation schedules used by the building simulation modeler is found to be one of the key factors in the performance gap [20]. Using a

sensitivity analysis, Firth et al. [21] found that the predicted energy consumption widely varied with different input parameters, where some of the determining factors of residential space heating demand were the characteristics and usage patterns of heating systems, including setpoint temperature and heating duration. Kelly et al. [22] found a statistically significant effect of setpoints on internal temperatures. Dodoo et al. [23] also found that the indoor air temperature significantly influenced the performance of energy efficiency measures. Wei et al. [24] argued that specifying the user's heating activity on the energy simulations as active when in reality it is passive results in a great overestimation of the energy saving potential of a retrofitting strategy. The authors of [18,25] have also claimed that the focus is on when occupants are active rather than just present in the house.

The analysis undertaken in this study also shows that despite occupants being at home, it does not necessarily mean that the heating or cooling is on. In this context, the aim of this paper is to develop the most typical indoor temperature profiles that can be used as baseline energy models developed to estimate the energy consumption of homes in Albania, as well as to closely estimate energy savings for future energy retrofitting programs. Hierarchical cluster analysis is used in this study to develop the most typical indoor temperature profiles, as one of the most used statistical analysis methods used previously in the development of occupancy, heating, and indoor temperature profiles [26–31]. Belaïd, Ranjbar, and Massié [32] have also used Ascending Hierarchical Classification to define French housing stock profiles based on 1400 dwelling representatives of the French residential sector, aiming to explore the cost-effectiveness of the energy efficiency implementation measures in the residential sector. The same method was used by Huebner et al. [31] in their study of 275 dwellings. Buttitta, Turner, and Finn [33] used an approach based on a statistical clustering technique to generate the representative UK occupancy profiles based on the amount of time spent at home by all occupants of the same household, resulting in 22 different occupancy profiles on weekdays and 24 on weekends, each assigned with the percentage of households with similar occupancy profiles for each dwelling type characterised by specific characteristics. They used k-means clustering as the main method of their statistical analysis in order to develop occupancy clusters, which is one of the two broad categories in which traditional clustering methods fall [30]. The other category is hierarchical clustering, used in this study, which is mainly used to develop clusters from small datasets. Although the sample size in this research is small ($N = 49$) compared to their study (6500 households), it will still provide an insight into the most typical indoor temperature profiles, which can be used for modelling the energy consumption of homes in Albania. Moreover, the hierarchical clustering method used in this research is mainly used for the clustering technique in small datasets.

Three statistically significantly different indoor temperature clusters were developed based on recorded indoor temperatures of 49 dwellings in Tirana, Albania. The analysis extends to finding associations between the identified clusters and buildings, households, and occupancy factors to understand the most important factors that drive indoor temperatures in both winter and summer. Andersen, Fabi, and Corgnati [34] also underline the importance of occupants' socio-demographics and household characteristics in order to identify specific target groups for energy-saving policy programmes and retrofit options. This approach therefore addresses the performance gap by considering various indoor temperature profiles rather than a default temperature setpoint contributing towards more user-centred approach to retrofits, as well as future programmes and policies, as has also been suggested by Ben and Steemers [35].

1.1. Influence of Occupant Behaviour in Building Energy Simulations

It is widely recognised that occupant behaviour has a significant impact on building energy demand and on indoor thermal comfort conditions [4,9,14,36,37]. Nonetheless, integrating occupant behaviour into building energy simulations has been found to be challenging [11], as it is usually oversimplified and predefined through static schedules in building performance simulations [9,37–41]. Due to a lack of pre-retrofit evaluation in the

early stage of the design and a lack of data about various aspects of the building, considerable assumptions and predictions are used [42–44]. Therefore, the improvement of occupants' presence and modelling their actions in building simulations is essential to enhance the accuracy of the building energy simulation process [12]. Yao and Steemers [45] claimed that the number of occupants and the length of the period in which the dwelling is occupied are the main factors influencing energy consumption. Yan et al. [12] also found that occupant–building interaction is affected by the arrival, departure, and duration of absence of occupants. Jia, Srinivasan, and Raheem [11] described how occupant presence/absence in rooms is not enough for occupant behaviour modelling and how further information is needed regarding the adaptation to the indoor environment and the occupants themselves.

In fact, indoor air temperature has been found to significantly influence the performance of energy-efficiency measures [23], and assuming one standard indoor temperature profile for energy modelling for all homes would contribute to the performance gap between the actual and estimate energy consumption in homes. Developing various indoor temperature profiles would overcome this assumption and would assist in better calculations of energy consumption in homes as well as closer predictions of energy savings through energy retrofitting.

However, indoor temperature is highly affected by occupant behaviour, which itself can be affected by various factors, including a building's characteristics, social and personal characteristics, rebound effects, personal comfort, lifestyle and cultural background, occupants' knowledge and skills, and occupants' experience [46]. According to [47,48], there are also social-psychological factors that may influence thermal comfort and energy behaviours, including beliefs, values, norms, social trust, habits, energy saving attitudes, motivations, perceived behavioural control, and environmental concerns. Furthermore, Ortiz, Itard, and Bluysen [49] support the claim that occupant behaviours are interplays of personal, environmental, and social factors and that their actions are influenced by the way the occupants understand energy, control, and comfort. Ebrahimigharehbaghi et al. [50] considers the multiple origins of the factors that influence occupant behaviour and categorises them as: motivations, barriers, and contextual and personal factors. Fabi et al. [51] classified these factors into five groups: physical environmental factors, contextual factors, psychological factors, physiological factors, and social factors. Tam, Almeida, and Le [52] grouped the factors influencing occupant behaviour into objective factors, including environmental conditions such as temperature, air velocity, climate, and noise, and subjective factors, which depend on the personal perception of comfort and are affected by age, metabolic activity, particular mood, habits, sensations, and social interaction. According to Schaffrin and Reibling [53], all forms of consumption energy practices demonstrate lifestyle choices and can be a form of self-expression.

In this context, to investigate the effect of occupant behaviour in indoor temperature in homes, this study investigates the association of indoor temperature profiles with socio-demographic characteristics (education level, household size, presence of children or retired persons, income, and monthly energy bill), as well as behavioural factors (cooling and heating usage patterns during the day and night) for each household selected, along with the effect of building characteristics (building type and size, period of construction, existence of wall insulation or double glazing, and type of heating or cooling).

1.2. Review of Factors Affecting Indoor Temperatures in Dwellings

Indoor temperature has been found to significantly influence the performance of energy retrofits [23]. The setpoint temperature for heating and the duration of the heating period are the greatest influential factors on energy consumption for space heating in homes [21,54–58]. An increase in energy consumption of 10% has been calculated for each degree of indoor temperature in a study undertaken by Tommerup, Rose, and Svendsen [59] on single-family houses in Denmark. Peng et al. [60] found significant variations in building performance using three classifications of occupant behaviours based on an air-

conditioning operation schedule, indoor temperature preference, and household loads based on the division type. Bruce-Konuah, Jones, and Fuertes [61] found that physical environmental variables, including indoor and outdoor temperature, indoor relative humidity, and solar radiation, affect occupants' behaviour in terms of manual space heating override during the heating season. They found an average increase in space heating energy consumption of 21.5% and 13.6% on weekday and weekend, respectively. There are also other factors that may lead to indoor temperature profiles differing from heating demand profiles [31], and having distinct temperature profiles would indicate not only that homes are used in different ways by different occupants, but could also indicate various comfort requirements. Kelly et al. [22] developed a model to predict the daily mean internal temperatures for a national building stock and found behavioural and socio-demographic properties of the occupants' significant variables among physical properties of the building, the external climate, and dwelling's geographic location to explain internal temperature demand. Hunt and Gidman [62], using a national field survey of house temperatures in the UK, found that a household's income was a strong indicator of room temperature, with lower-income homes found to be 3 °C lower on average in the heating season.

Notwithstanding the many uncertainties, default assumptions about how homes are heated and cooled, and at what temperatures, have been used for modelling energy consumption of housing stock [17]. Heating temperatures of 21 °C have been assumed for modelling of housing stock and estimating energy savings from retrofitting strategies in the UK [63]. Al-Mumin, Khattab, and Sridhar [64] found a variation in thermostat setpoints from below 19 °C to above 25 °C after investigating summer air-conditioning use in residential buildings. Moreover, Peng et al. [60] found that air-conditioning operation within a household varied every day. Default setpoint temperatures of 20 °C and 26 °C for heating and cooling, respectively, have been used in a study of energy retrofitting of residential stock in Albania [65]. This assumption leads to energy consumption and energy saving estimations largely different from the actual ones [31].

Notwithstanding that the heating setpoint effect has been largely acknowledged as one of the main factors that affects the interaction between the occupants and the building, there is still no standard method to assign the heating setpoint for building simulation [1]. Therefore, developing temperature profiles would decrease the estimations coming from the use of a single heating and cooling setpoints, as well as the default heating and cooling duration in homes.

2. Materials and Methods

A mixed-method approach combining qualitative and quantitative research methods was used to provide a more comprehensive understanding of the topic under investigation. The methodology for this study comprised two principal steps:

1. Data collection, including indoor temperature monitoring and surveys of 49 randomly selected dwellings to evaluate the actual energy use in case studies representing the main Albanian building types.
2. Data analysis, including cluster analysis, leading to the identification of clusters and relationships between clusters and contextual factors.

2.1. Data Collection

The data collection methods included the following:

- Building surveys to gather information on the buildings' properties and energy use. Quantitative data were collected regarding building materials and construction, orientation, floor area, appliances, and lighting, which allowed for a detailed picture of energy use and behaviours within the home. Electricity bills were also obtained.
- Occupants' survey to collect socio-demographic information, as well as to obtain an insight into how and when the house is used, occupants' attitudes and habits, and

other everyday practices in their home. Setpoint temperatures and duration of heating periods were recorded from each occupant's responses. The study adopted the method of questionnaire-guided interviews as the most appropriate technique for gathering all essential information in its full range and depth, as well as for obtaining insights into occupant behaviour. Only one occupant per dwelling participated in the survey to provide consistency across the research.

- Continuous monitoring of indoor temperature in the living room and main bedroom was also conducted for six weeks in summer (30 June to 12 August) and winter (5 January to 16 February) to assess the indoor environment in the house. Only the indoor temperature was monitored during the field studies in order to indicate the range of temperature present within homes. The focus of this research was not conducting a thermal comfort field study, but to gain an insight into how people evaluate their home and how it was really performing.

Sample Characteristics

Forty-nine dwellings of various building typologies were randomly selected in urban and rural areas of Tirana. Most of the sample comprises flats and detached houses. Differences in construction techniques used in Albanian residential buildings built pre-1990 and post-1991 are also reflected in the sample. All the dwellings built post-1991 were constructed using a concrete structural loading scheme with no-loading hollow bricks or blocks external walls, while pre-fabricated panels and solid brick walls with higher thermal mass were very common constructions in buildings built pre-1990. Electricity was the most common type of energy used for space heating, mainly due to lack of infrastructure or security for using other types such as gas and wood. On the other hand, electricity is widely used for cooling during the hot season. Main characteristics of the sample are given in Table 1.

Table 1. Frequency of different characteristics in the sample.

Category	Description	Frequency	%
Building type	Detached	17	34.6
	Semi-detached	2	4.1
	Terraced	1	2
Period of construction	Flat	29	59.3
	Pre-1991	16	32.7
	Post-1991	33	67.3
Number of stories	1 storey	9	18.4
	2 stories	9	18.4
	3–4 stories	5	10.2
	5 or more stories	26	53.1
Number of bedrooms	1	12	24.5
	2	24	49
	3	9	18.4
	4	2	4.1
	5	2	4.1
	Solid brick/stone external walls	8	16.3
Construction type	Pre-fabricated	3	6.1
	Silicate brick	5	10.2
	Concrete blocks	3	6.1
	Hollow brick	24	49
	Insulated walls	6	12.2
	Natural ventilation	3	6.1
Ventilation/cooling scheme	Mixed ventilation (natural + air conditioning)	46	93.9

2.2. Data Analysis

2.2.1. Descriptive Analysis of the Measured Indoor Temperatures during Summer and Winter

After statistically exploring all datasets for normality through exploring statistics, histograms, outliers, normal Q-Q plots, and detrended normal Q-Q, we decided to clean the dataset in terms of the extreme outliers to minimise the skewness of the data distribution. Outliers were not removed from the dataset, as they were not unusual for the period of monitoring. One-sample T-test was undertaken for each variable to check whether the mean temperature of each living room statistically significantly differed from before removing the extreme outliers. A statistically non-significant difference was found ($p > 0.05$) for each of the dwellings. The mean daily indoor temperature was then calculated for both the living room and the bedroom of each dwelling. The hourly mean temperature was also calculated for each hour to investigate the temperature profile during the day.

2.2.2. Cluster Analysis and Statistical Tests

Due to the high variability in indoor temperatures recorded in the sample, a hierarchical cluster analysis was conducted to limit the number and determine the most typical profiles of indoor temperatures of Albanian homes using the data collected. Hierarchical cluster analysis is an exploratory data tool for organising data into meaningful groups by maximising the similarity of cases within each cluster and maximising dissimilarities between groups that are not previously known [66]. This means that the dwellings are grouped into clusters based not on the building's characteristics, but on the way that homes are used, and the indoor temperature profiles of dwellings within the same cluster are as similar to each other as possible.

Cluster analysis is a statistical analysis method used in previous studies to determine occupancy and heating profiles [26–30], as well as indoor temperature profiles in living rooms [31]. There are two main cluster analysis methods, k-means and hierarchical. Hierarchical analysis was chosen over k-means because it is mostly used for small datasets, and the number of clusters created is determined after plotting the distances between each data point. In contrast, k-means is used more for large datasets and the number of clusters is decided before plotting the dataset. For hierarchical clustering, other studies suggest that a minimum of 10 observations in each cluster should be considered [30,31,67]. The indoor temperature profiles delivered from the cluster analysis undertaken in this paper, together with the occupants' surveys in summer and winter, were the main sources for developing indoor temperature profiles of Albanian homes.

Clusters were created based on the centralised temperatures, meaning that the average of each data point measurement was calculated for each day and then across the six weeks for each dwelling in summer and winter. Using the SPSS 24 statistical package, a hierarchical cluster analysis was performed with an agglomeration schedule and Ward's method, which uses the f-value to maximise the significance of differences between clusters. Because the dataset is made of interval data, square Euclidean distance was chosen as the distance measure. Variables (each weekday and the weekend) were standardised to Z-scores, so they all contribute equally to the distance or similarity between cases. Finally, clusters for both summer and winter were described by testing the differences in several buildings, socio-demographics, and occupant behaviour factors, using chi-square tests and one-way ANOVA tests for categorical and continuous variables, respectively. When the results are statistically significant ($p > 0.05$), this shows that there is a significant association between that building/socio-demographic/behaviour factor and the clusters. However, the chi-squared test only shows if there is an association or not between the two variables but does not give the strength of the association. For this purpose, the phi coefficient can be used, and because tables were larger than 2 by 2, Cramer's V were used in this analysis [66].

Fundamentally, the analysis still provide an insight into the most typical indoor temperature profiles, which can be used for energy models of Albanian housing stock, allowing for better energy estimations and predictions, which are closely related to occupant behaviours.

3. Results

3.1. Descriptive Statistics of Indoor Temperatures in Summer and Winter

The summer field study involved the monitoring of the indoor temperature of 49 living rooms from 30 June to 12 August at half-hourly intervals to cover the hottest season of the year in the Albanian climate. The outdoor temperature ranged from 19.6 °C to 41.1 °C, while the indoor temperature ranged from 19.5 °C to 37 °C. The indoor temperature is well above the recommended temperature of 20 °C, considered as the comfortable temperature in living rooms by Albanian regulation [68], as shown in Figure 1.

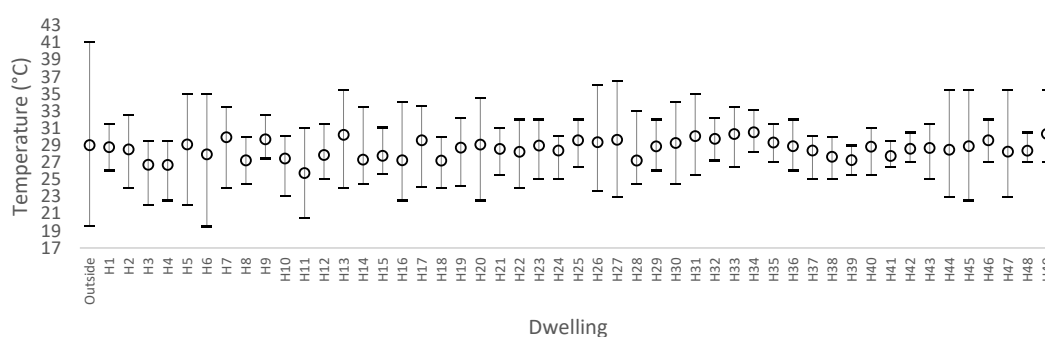


Figure 1. Minimum, maximum, and mean temperatures in living rooms of each monitored dwelling during the summer.

The house with the lowest indoor temperature (H11) in the sample still had indoor temperatures above 25 °C for more than 80% of the day. Furthermore, 37 dwellings experienced temperatures over 28 °C for more than 50% of the day. This clearly demonstrates that all dwellings in the sample are overheated during the summer.

Monitoring of the same dwellings from 5th January to 16th February at half-hourly intervals covered the coldest season of the year in the Albanian climate. The outdoor temperature ranged between −5.5 °C and 18.5 °C, while the indoor temperature ranged from −6 °C to 29.5 °C in living rooms. The actual indoor temperatures for living rooms during the monitoring time are shown in Figure 2. Elevated temperature variations were also observed. For some of the dwellings temperatures close to the outdoor temperature were recorded, meaning that they had little or no heating at all and/or that windows may have been left open during the day.

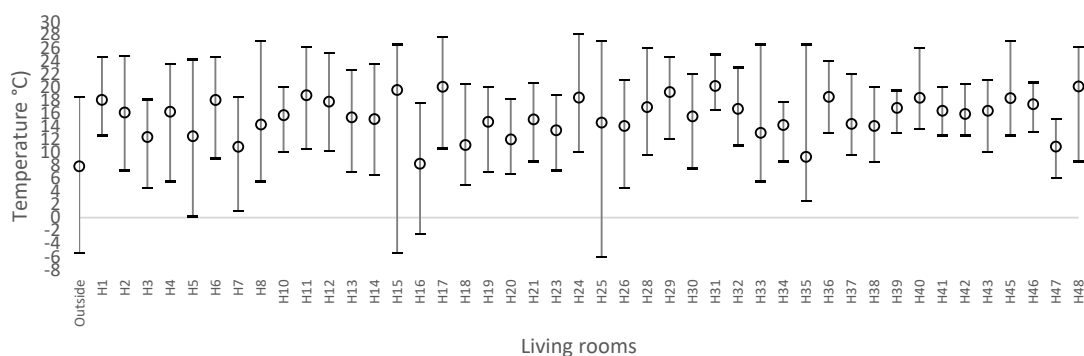


Figure 2. Minimum, maximum, and mean temperatures in living rooms of each monitored dwelling during the winter.

Hourly Profiles of Indoor Temperatures in Summer and Winter

To investigate the temperature profile during the day, the mean hourly temperatures of living rooms in summer and winter were calculated, as shown in Figure 3. Each line represents the mean hourly temperature of the selected dwellings, while the bold red line represents the mean outdoor temperature during the same period of monitoring. In summer, all the dwellings had a continuous mean indoor temperature of above 25 °C throughout the day, and most of them exceeded 28 °C. There is a smaller range of indoor temperatures throughout the day and between dwellings compared to winter, where a higher temperature range is noticeable, as well as various temperature profiles. Hourly profiles that have very low temperature during the day are present, as well as profiles with temperatures above 20 °C. This indicates the large variation of hourly profiles in Albanian dwellings, which could be a result not only of different building properties, but also of different behaviours within the household.

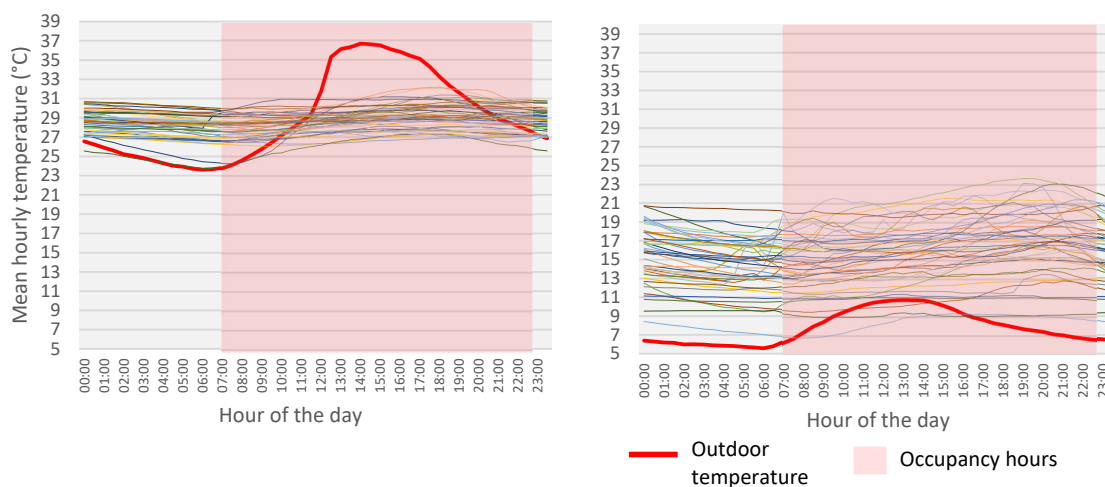


Figure 3. Mean hourly temperatures in living rooms during the summer (left) and winter (right). (Different colour lines represent the mean hourly temperature of the selected dwellings)

3.2. Cluster Analysis in Summer

Using centralised temperature from the dataset from the summer field study, three clusters were produced using hierarchical clustering and following the rule of each cluster with a minimum of ten observation [30,31,67]. The membership of each cluster is shown in Table 2 and is produced through an agglomeration schedule and Ward's method,

which uses the F-value to maximise the significance of differences between clusters. It is the uneven distribution of the sample into clusters that identifies the most typical indoor temperature profile in Albanian homes. Cluster 1 represents the largest cluster, which comprises over half of the sample (49% in weekend clusters), with an hourly temperature of around 29 °C. Clusters 2 and 3 represent 29% and 20% of the sample (29% and 22% of the sample for weekends), with hourly mean temperatures of 27.5 °C and 30 °C, respectively. Clusters for both weekdays and weekends have been created, which do not differ much from each other in terms of membership. However, further analysis is undertaken to statistically evaluate the differences between them.

Table 2. Clusters' membership of the cases for weekdays and weekends in summer.

	Weekday			Weekend		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
H1		H3	H9	H1	H3	H7
H2		H4	H25	H2	H4	H17
H5		H6	H26	H5	H6	H25
H7		H8	H27	H9	H8	H26
H13		H10	H31	H13	H10	H27
H14		H11	H32	H19	H11	H31
H17		H12	H33	H20	H12	H32
H19		H15	H34	H21	H14	H33
H20		H16	H46	H22	H15	H34
H21		H18	H49	H23	H16	H46
H22		H28		H24	H18	H49
H23		H38		H29	H28	
H24		H39		H30	H38	
H29		H47		H35	H39	
H30				H36		
H35				H37		
H36				H40		
H37				H41		
H40				H42		
H41				H43		
H42				H44		
H43				H45		
H44				H47		
H45				H48		
H48						
Frequency	25	14	10	24	14	11

Figure 4 shows the daily and hourly mean temperatures of each cluster for both weekdays and weekends. All three clusters for both weekdays and weekends have the same sensitivity but in different temperature ranges, and the temperature profiles of weekends are very close to those of weekdays. Cluster 3 follows very closely the mean daily external temperature profile, which indicates that these dwellings might have been cooled for small periods or not at all. Cluster 1, representing most of the dwellings, has a mean daily temperature up to 3 °C lower than the external one during the hottest days of the summer. On the contrary, Cluster 2, which is the second most common cluster in the sample, has temperatures lower than the other two clusters, indicating actions from the occupants to maintain a cooler indoor temperature than in the other cases. The hourly mean temperature tends to be lower in the morning and starts to increase in the early

afternoon, reaching a peak in the evening in Clusters 1 and 3 and in the late afternoon in Cluster 2.

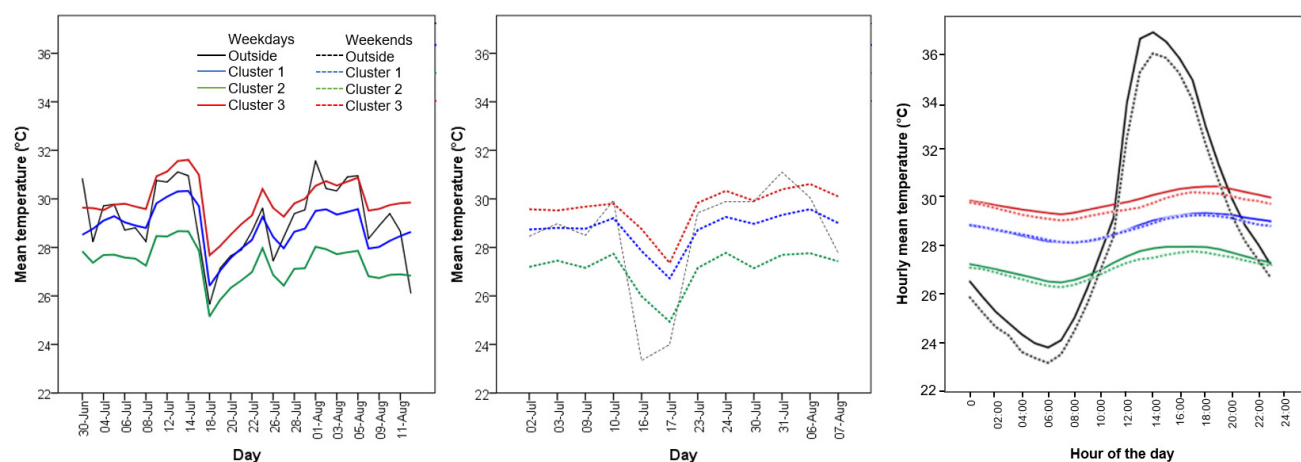


Figure 4. Mean daily temperature for weekdays (left) and weekends (centre); mean hourly temperature profiles for both weekdays and weekends (right) of the three clusters, together with external temperature.

Statistical analysis was undertaken to determine whether the three clusters are significantly different from each other, which means that they represent three distinctive temperature profiles. To determine the type of statistical test to use (parametric or non-parametric), the assumption of equality of variances has been tested using Levene's F-test for equality of variances, as shown in Table 3. The test showed non-homogeneity of variances for weekdays ($F = 7.2$ and $p = 0.002$) and homogeneity of variances for weekends ($F = 1.4$ and $p = 0.270$). Therefore, the Games–Howell test (non-parametric) and Scheffe tests (parametric) were used for post hoc pairwise comparisons for weekdays and weekends, respectively.

Table 3. Descriptive analysis of the mean temperature of each cluster based on the mean temperature of each dwelling and Levene's test results in summer.

		N	Mean	SD	F	Sig.
Weekdays	Cluster 1	25	28.3	0.4	7.230	0.002
	Cluster 2	14	26.8	0.7		
	Cluster 3	10	29.7	0.3		
Weekends	Cluster 1	24	29.3	0.3	1.349	0.270
	Cluster 2	14	27.6	0.6		
	Cluster 3	11	30.5	0.4		

Both Games–Howell and Scheffe tests undertaken for pairwise comparison between clusters showed significantly different mean temperatures ($p = 0.000$) between clusters for both weekdays and weekends profiles.

Relationship of Clusters in Summer to Contextual Factors

- Building characteristics

Seven main building-related variables were tested, as shown in Table 3. Each column gives the proportion of households for each value of the variable. Because all the building-related variables were categorical, only chi-squared analysis has been performed, and the results are given in Table 4.

Cluster 2 had significantly more detached houses (64.3%) than the other two clusters (28% and 34.7%, respectively, for cluster 1 and 3), while Clusters 1 and 3 are equally represented by flats. Moreover, the majority of dwellings in Cluster 2 were constructed post-1991, while most of the dwellings constructed pre-1990 form the membership of Cluster 3. The largest share of dwellings that have both wall insulation and double glazing is in Cluster 2, which in fact had the lowest indoor temperature in terms of mean daily and hourly profiles.

Table 4. Chi-squared analysis of building variables between clusters in summer.

	Clusters			Chi-Squared Test Results			Cramer's V	
Variable	Cluster 1	Cluster 2	Cluster 3	χ^2	d.f.	p	Value	Approx. Sig.
Building type								
Detached	28.0%	64.3%	34.7%	13.9	6	0.030	0.38	0.030
Semi-detached	0.0%	7.1%	2.0%					
Terraced	8.0%	0.0%	4.1%					
Flat	64.0%	28.6%	59.2%					
Period of construction								
Pre-1990	32.0%	7.1%	60.0%	7.72	2	0.021	0.40	0.021
Post-1991	68.0%	92.9%	40.0%					
Wall insulation								
No	80.0%	42.9%	80.0%	6.5	2	0.039	0.18	0.457
Yes	20.0%	57.1%	20.0%					
Double glazing								
No	56.0%	21.4%	60.0%	5.2	2	0.06	0.33	0.076
Yes	44.0%	78.6%	40.0%					
Dwelling size								
1 bedroom	32.0%	7.1%	40.0%	12.2	8	0.142		
2 bedrooms	48.0%	50.0%	50.0%					
3 bedrooms	20.0%	21.4%	0.0%					
4 bedrooms	0.0%	14.3%	0.0%					
>4 bedrooms	0.0%	7.1	10.0%					
Cooling type								
No cooling	4.0%	7.1	0.0%	5.6	6	0.465		
Air conditioning	56.0%	57.1	70.0%					
Electric fans	20.0%	0.0	20.0%					
Air conditioning + electric fan	20.0%	35.7	10.0%					

Note: χ^2 —Chi-square value, d.f.—degrees of freedom, p —the probability value (the significance level).

Generally, dwellings in Cluster 1 are smaller (up to three bedrooms) in size than those in the other two clusters. Most of the dwellings in each cluster are air-conditioned; however, the largest share of air-conditioned dwellings is in Cluster 3.

Chi-squared test for independence showed a statistically significant association ($p < 0.05$) between clusters and building-related factors, such as building type, period of construction, and wall insulation. This means that the clusters are dependent on these factors. No statistically significant association was found between clusters and dwelling size and type of cooling.

Effect size analysis using Cramer's V was performed for building factors that had a statistically significant association with the clusters, as shown in Table 5. Criteria for determining the effect size are shown in the last three columns. According to Pallant [66], to

determine which criteria to use for judging the effect size, whichever of R-1 (subtracting 1 from the number of categories in the row) or C-1 (subtracting 1 from the number of categories in the column) is smaller should be correlated to the values for small, medium, or large effect.

Building type and the period of construction have a statistically significant large effect on the clusters, while wall insulation, and double glazing have a statistically significant small and medium effect, respectively.

Table 5. Cramer's V test results of building variables between clusters in summer.

Information for Each Variable (Table)				Criteria for Effect Size			
Variable	R-1	C-1	Cramer's V	Sig	Small	Medium	Large
Building type	3	2	0.38	0.030	0.07	0.21	0.35
Period of construction	1	2	0.40	0.021	0.01	0.30	0.50
Wall insulation	1	2	0.18	0.457	0.01	0.30	0.50
Double glazing	1	2	0.33	0.076	0.01	0.30	0.50

Note: R-1: Number of categories in the row − 1, C-1: Number of categories in the column − 1.

- Socio-demographic factors

Notwithstanding that several studies have shown an association between socio-demographic factors and energy consumption and temperatures, no significant differences between clusters were found in this sample, as shown in Table 6. Cluster 3 has the highest proportion of households with the highest education and single occupancy. Moreover, 70% of households in this cluster have over four members and children. The proportion of households with a retired member is higher in Cluster 3 as well.

Table 6. Chi-squared analysis of socio-demographic variables between clusters in summer.

Clusters				Chi-Squared Test Results		
Variable	Cluster 1	Cluster 2	Cluster 3	x ²	d.f.	p
Education level						
Elementary	4.0%	0.0%	0.0%	1.76	4	0.780
High school	32.0%	35.7%	20.0%			
University	64.0%	64.3%	80.0%			
Household size						
1 person	0.0%	0.0%	20.0%	13.64	8	0.092
2 people	24.0%	7.1%	0.0%			
3 people	28.0%	35.7%	10.0%			
4 people	24.0%	28.6%	40.0%			
≥5 people	24.0%	28.6%	30.0%			
Presence of children						
No	44.0%	35.7%	30.0%	0.67	2	0.716
Yes	56.0%	64.3%	70.0%			
Presence of a retired person						
No	72.0%	85.7%	60.0%	2.04	2	0.361
Yes	28.0%	14.3%	40.0%			

For continuous variables, one-way ANOVA, with post hoc tests corrected with Bonferroni, was used to test for difference between clusters. The results are given in Table 7. No statistically significant difference was found in the three clusters in the monthly incomes and electricity bills.

Table 7. One-way ANOVA test results of continuous socio-demographic variables between clusters in summer.

Variable	Clusters			One-Way ANOVA test results		
	Cluster 1	Cluster 2	Cluster 3	F	d.f.	p
Monthly income (EUR)	521.4	537.0	500.0	0.08	2	0.926
Monthly electricity bill (EUR)	49.2	64.3	51.5	1.59	2	0.216

- Occupant behaviour factors

Two main variables were tested, as shown in Table 8. However, chi-squared tests showed that none of the variables under investigation had a statistically significant association with the clusters. Even though no statistically significant association was found between these factors and the clusters during summer, chi-squared tests are useful to describe the clusters relating to these variables. Most of the households in all three clusters were cooled in the afternoon and in the afternoon and evening. However, Cluster 2 has the largest share of households that cool the space during the night.

Table 8. Chi-squared analysis of occupant behaviour variables between clusters in summer.

Clusters				Chi-Squared Test Results		
Variable	Cluster 1	Cluster 2	Cluster 3	x²	d.f.	p
When do you cool your house during the day?						
No cooling	4.0%	7.1%	10.0%	5.8	10	0.829
Midday	4.0%	0.0%	0.0%			
Afternoon	32.0%	35.7%	40.0%			
Evening	8.0%	7.1%	0.0%			
Afternoon and evening	48.0%	28.6%	40.0%			
All day	4.0%	21.3%	10.0%			
Night cooling						
No	80.0%	57.1%	80.0%	2.7	2	0.262
Yes	20.0%	42.9%	20.0%			

3.3. Cluster Analysis in Winter

Three identical weekday and weekend clusters were created using the hierarchical cluster analysis of the winter indoor temperatures dataset, as shown in Table 9. The same method was followed as for the summer cluster analysis. Cluster 2 represents the largest cluster, with nearly 45% of the sample, and corresponds to the middle range of indoor temperatures of around 15°C. Clusters 1 and 3 represent 33% and 22% of the sample, respectively.

Table 9. Clusters' membership of the cases for weekdays and weekends in winter.

Weekday			Weekend		
Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
H1	H2	H3	H1	H2	H3
H6	H4	H5	H6	H4	H5
H11	H8	H7	H11	H8	H7
H12	H10	H16	H12	H10	H16
H15	H13	H18	H15	H13	H18
H17	H14	H20	H17	H14	H20
H24	H19	H23	H24	H19	H23
H29	H21	H33	H29	H21	H33

	H31	H25	H35	H31	H25	H35
	H36	H26	H47	H36	H26	H47
	H40	H28		H40	H28	
	H44	H30		H44	H30	
	H45	H32		H45	H32	
	H46	H34		H46	H34	
	H48	H37		H48	H37	
		H38			H38	
		H39			H39	
		H41			H41	
		H42			H42	
		H43			H43	
Frequency	15	20	10	15	20	10

Figure 5 shows the daily and hourly mean temperatures of each cluster for both weekdays and weekends. Although both weekdays and weekends have the same membership of dwellings, the profiles are produced using absolute (instantaneous) temperature data, which differ between weekdays and weekends. The daily mean temperature is almost within the same range for both weekdays and weekends for each cluster. It was also observed that dwellings in Cluster 1 had temperatures above 15 °C during the coldest week of the monitoring time, while dwellings in Cluster 3 follow the external temperature profile more closely, indicating that some or all dwellings included in this cluster had little or no heating.

Regarding hourly mean temperatures, weekday and weekend profiles have almost the same sensitivity as each other for all three clusters. Cluster 1 is characterised by a higher temperature throughout the day compared with the other two clusters. There is a steep rise in temperatures at 7 a.m., and they continue to steadily increase until 10 p.m. However, in Cluster 2, which represents most of the dwellings, there is only a small peak in the morning, and as is the case in Cluster 1, the temperature increases gradually until evening. For weekends in Cluster 2, there is a small peak in temperature in the morning, and the profile is then close to the weekdays' profile for the rest of the day. On the contrary, Cluster 3 represents the dwellings with the lowest indoor temperature throughout the day. There is almost a flat line throughout the day for both weekday and weekend profiles, with a small peak in the evening. This indicates that these dwellings barely heat the space during the winter.

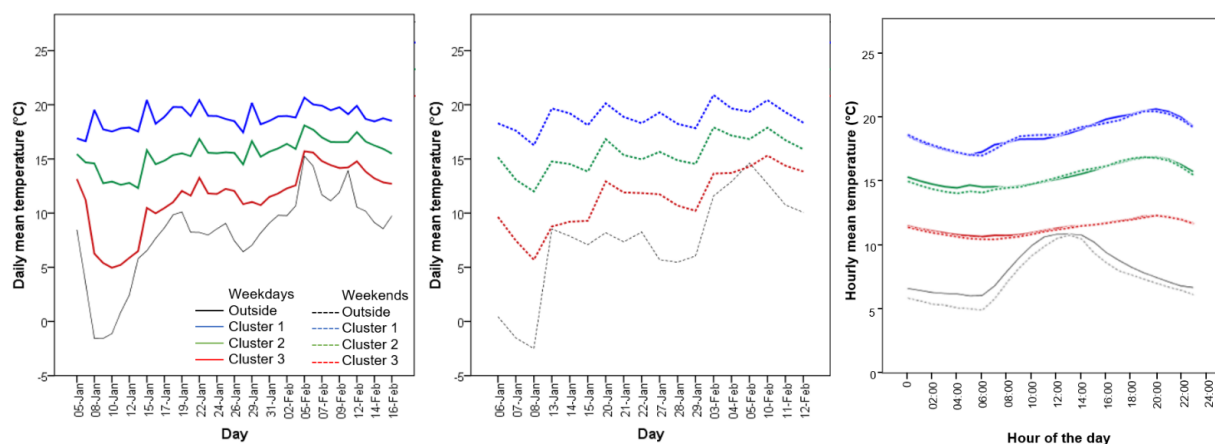


Figure 5. Mean daily temperature for weekdays (left) and weekends (centre); mean hourly temperature profiles for both weekdays and weekends (right) of the three clusters, together with external temperature.

As in the summer cluster analysis, Levene's F-test for equality of variance was used. The test showed the homogeneity of variances ($p > 0.05$) for weekdays and weekends ($F = 2.2$ and $p = 0.130$ and $F = 3.0$ and $p = 0.06$, respectively). Therefore, Scheffe tests were performed for pairwise comparison between clusters and showed significantly different mean temperatures ($p = 0.000$) between clusters for both weekday and weekend profiles (see Table 10).

Table 10. Descriptive analysis of the mean temperature of each cluster based on the mean temperature of each dwelling and Levene's test results in winter.

		N	Mean	SD	F	Sig.
Weekdays	Cluster 1	15	18.8	1.0	2.146	.130
	Cluster 2	20	15.4	1.0		
	Cluster 3	10	11.4	1.6		
Weekends	Cluster 1	15	18.9	0.9	3.004	.060
	Cluster 2	20	15.6	1.0		
	Cluster 3	10	11.4	1.6		

Relationship of Clusters in Winter to Contextual Factors

- Building characteristics

A chi-squared test was performed to describe the difference between clusters for categorical variables, with the results given in Table 11. Each column shows the proportion of dwellings for each value of the variable. In total, seven building-related factors were tested.

There is almost an equal spread of detached houses in the three clusters, while the proportion of flats in Clusters 1 and 2 is bigger than in Cluster 3. On the other hand, mainly semi-detached and terraced houses compose Cluster 3. There is a close representation of both periods of construction in all clusters. However, Clusters 2 and 3 have the highest proportion of pre-1990 and post-1991 dwellings, respectively. The highest proportion of dwellings that had wall insulation and double glazing was in Cluster 1, followed by Cluster 3. It is interesting that a high proportion of dwellings with better thermal properties are associated with Cluster 3, which recorded the lowest indoor temperatures. However, the chi-tests showed no statistically significant association between clusters and thermal properties of the dwellings in winter. Small dwellings are associated more with Clusters 1 and 2, while bigger dwellings were associated with Cluster 3, in which the recorded indoor temperatures are very low and may be related to the high ratio of space volume to heat. Heat pumps were also more popular in Cluster 1.

To summarise, the proportion of dwellings for most of the categories of each tested variable is equally spread between the three clusters, regardless of the building factors. For this reason, chi-squared tests did not find a statistically significant association between clusters and each of the tested building factors. This indicates that there might be other factors that influence the indoor temperatures of dwellings in Albania in winter.

Table 11. Chi-squared analysis of building variables between clusters in winter.

Variable	Clusters			x ²	Test Results	
	Cluster 1	Cluster 2	Cluster 3		d.f.	p
Building type						
Detached	40.0%	30.0%	40.0%	5.9	6	0.431
Semi-detached	0.0%	0.0%	10.0%			
Terraced	0.0%	5.0%	10.0%			
Flat	60.0%	65.0%	40.0%			
Period of construction						

Pre-1990	26.7%	35.0%	20.0%	0.8	2	0.676
Post-1991	73.3%	65.0%	80.0%			
Wall insulation				0.9	2	0.635
No	60.0%	75.0%	70.0%			
Yes	40.0%	25.0%	30.0%	0.4	2	0.818
Double glazing						
No	40.0%	50.0%	50.0%	4.9	8	0.762
Yes	60.0%	50.0%	50.0%			
Dwelling size				8.1	14	0.883
1 bedroom	33.3%	30.0%	10.0%			
2 bedrooms	46.7%	45.0%	60.0%			
3 bedrooms	13.3%	20.0%	20.0%			
4 bedrooms	6.7%	0.0%	10.0%			
>4 bedrooms	0.0%	5.0%	0.0%			
Heating type				8.1	14	0.883
Heat pump (conditioning device)	60.0%	45.0%	50.0%			
Electric heater	6.7%	15.0%	10.0%			
Wood stove	13.3%	5.0%	10.0%			
Heat pump and electric heater	0.0%	5.0%	10.0%			
Heat pump and gas heater	6.7%	10.0%	0.0%			
Heat pump and wood stove	6.7%	15.0%	20.0%			
Electric heater and gas stove	6.7%	0.0%	0.0%			
Central heating	0.0%	5.0%	0.0%			

- Socio-demographic factors

Chi-squared tests and one-way ANOVA statistical tests were performed to test the association between clusters and socio-demographic factors for categorical and continuous variables, respectively (see Table 12). Household occupants in all three clusters were found to have similar education levels. Cluster 2 has the highest proportion of small households of up to two occupants and big households of more than three occupants at the same time. The highest proportion of households with children is in Cluster 1, with 90% of all households in this cluster's membership. In addition, the association between clusters and the presence of a child in the household was found to be statistically significant ($p = 0.016$). On the contrary, no association was found between clusters and the presence of a retired member in the households. Based on the occupants' surveys, this might have been associated with the inability to keep adequate thermal comfort because of economic factors in these households.

Table 12. Chi-squared analysis of socio-demographic factors between clusters in winter.

Variable	Clusters			Chi-Squared Test Results			Cramer's V	
	Cluster 1	Cluster 2	Cluster 3	Value	d.f.	<i>p</i>	Value	Approx. Sig.
Education level								
Elementary	0.0%	5.0%	0.0%	3.8	4	0.428		
High school	33.3%	20.0%	50.0%					
University	66.7%	75.00%	50.0%					
Household size								
1 person	0.0%	5.0%	0.0%	10.8	8	0.216		
2 people	6.7%	25.0%	0.0%					

3 people	46.7%	10.0%	40.0%	8.3	2	0.016	0.429	0.016
4 people	20.0%	30.0%	40.0%					
≥5 people	26.7%	30.0%	20.0%					
Presence of children								
No	10%	60.0%	26.7%	3.4	2	0.179		
Yes	90%	40.0%	73.3%					
Presence of a retired person								
No	86.7%	65.0%	90.0%	3.4	2	0.179		
Yes	13.3%	35.0%	10.0%					

For continuous variables, one-way ANOVA was used to test for differences between clusters. No statistically significant difference was found in the three clusters for the monthly incomes and electricity bills (see Table 13).

Table 13. One-way ANOVA test results of continuous socio-demographic variables between clusters in winter.

Variable	Clusters			One-Way ANOVA Test Results		
	Cluster 1	Cluster 2	Cluster 3	F	d.f.	p
Monthly income (EUR)	520.9	559.5	498.0	0.27	2	0.769
Monthly electricity bill (EUR)	54.3	56.0	50.0	0.16	2	0.850

- Occupant behaviour factors

Two main variables were tested, as shown in Table 14. Chi-squared tests showed that none of the variables under investigation had a statistically significant association with the clusters. In Cluster 1, which was characterised by a daily profile of high temperatures throughout the day and two peaks in the morning and evening, included most of the households that heated the space in the morning and evening. However, more than half of the households turned the heating on at different times during the day, including 13.3% that kept the heating on all day. Almost the same situation can be seen in Cluster 2. On the contrary, most of the households in Cluster 3 heated their home in the afternoon or later, with 40% turning the heating on in the morning and evening, while 10% kept the heating on all day. In all three clusters, 20% of households or less turned the heating on during the night.

Table 14. Chi-squared analysis of occupants' behaviours and thermal variables between clusters in winter.

Variable	Clusters			Test Results		
	Cluster 1	Cluster 2	Cluster 3	χ^2	d.f.	p
When do you heat your house during the day?						
Morning	0.0%	5.0%	0.0%	10.7	12	0.548
Midday	6.7%	0.0%	0.0%			
Afternoon	13.3%	5.0%	20.0%			
Evening	6.7%	25.0%	0.0%			
Afternoon and evening	13.3%	25.0%	30.0%			
Morning and evening	46.7%	25.0%	40.0%			
All day	13.3%	15.0%	10.0%			
Night heating						
No	86.7%	85.0%	80.0%	0.2	2	0.900
Yes	13.3%	15.0%	20.0%			

4. Discussion

4.1. Description of Indoor Temperature Profiles

Using the data collected through indoor temperature monitoring and surveys in 49 dwellings in Albania, this study aimed to develop indoor temperature profiles in summer and winter that could be used to assess the energy performance of existing residential buildings in Albania through energy modelling. Due to the high variability of indoor temperatures measured, hierarchical cluster analysis was performed to produce three statistically different clusters each for summer and winter. The clusters were further examined for relationships with a selection of contextual factors related to the building, household, and occupancy. As in other studies [31,69,70], weekday and weekend profiles were distinguished. In this study, a statistically non-significant difference between weekday and weekend profiles was found, suggesting that the building fabric has a high impact on the indoor environment. Very small differences were also found in other studies between weekdays and weekends in terms of average temperatures [70] and heating durations [70,71]. The fact that three significantly different clusters were produced may indicate that homes were used in different ways, which supports findings revealed by many other studies, including [4,9,14,36,37], which emphasised the role of occupant behaviour on indoor environment as well as energy consumption in homes. Furthermore, the different clusters could be associated with various comfort requirements.

An analysis of the clusters shows that the highest membership falls in the middle range of temperatures, suggesting that most occupants heat or cool their dwellings to some extent. However, there is also a high proportion of hardly treated dwellings, with 20% and 33% of the sample in summer and winter, respectively, mostly due to the inability to do so for economic reasons. All clusters in summer have the same sensitivity on the hourly profiles, but in various temperature ranges. They fall in the morning and gradually increase throughout the day until they reach a peak in the evening. In summer, hourly temperatures of around 29 °C, representing Cluster 1, were found in over half of the sample. The temperature profile of Cluster 3 was very close to the external temperature profile and indicates that 20% of the sample cooled the space for short periods or not at all. The fact that temperatures in all profiles did not fall below 26 °C likely indicates that passive natural ventilation at night was barely performed.

The wider range of over 10°C within the day of indoor temperatures in winter was also reflected in the clusters. Cluster 2, with a range of temperatures of around 15 °C, represented nearly 45% of the sample. Similar to the summer clusters, 22% of the sample in winter, represented by Cluster 3, indicated little to no heating due to the closeness of the cluster with the external temperature profile. However, contrary to summer hourly profiles illustrated in the clusters, the hourly profiles in winter did not have the same sensitivity. Cluster 1, which represents 33% of the sample, had a steep rise in temperatures in the morning and fluctuations throughout the afternoon and evening, indicating the use of heating for various periods during the occupied hours. However, Clusters 2 and 3 both had a small peak in the morning and another peak in the evening. However, Cluster 2 had a steady rise in temperatures starting in the afternoon, which indicates the use of heating from the afternoon onwards. As described in [31], indoor temperatures are a substitution of heating and cooling system usage but do not indicate the status of heating or cooling system usage because other factors, such as incidental gains and ventilated heat losses, might also affect the indoor temperature. Cleaning the dataset of extreme outliers and cross-analysing the indoor temperature profiles and results from the occupants' surveys allowed for the development of a more accurate picture of temperature profiles.

4.2. Contextual Factors Affecting Indoor Temperature Profiles

Statistical tests were performed to find associations between cluster membership and various building, socio-demographic, and behaviour factors for both summer and winter. A statistically significant association was found between clusters in summer and building-

related factors such as building type, the period of construction, the archetype, and the wall insulation, with p -values equal to 0.03, 0.021, 0.04 and 0.039, respectively. Shipworth et al. [71] found that detached houses were heated for longer periods than mid-terraced houses, which could be due to more exposed walls in the detached houses, and these houses should therefore be targeted for energy-efficiency improvements. On the other hand, indoor temperatures in flats were found to be higher in winter and summer due to less thermal loss and less cross ventilation in winter and summer, respectively. It is also to be expected that newer constructions with wall insulation and double glazing will have lower indoor temperature during the summer and higher indoor temperatures during the winter. Dwellings that have greater energy efficiency measures have also been found to have higher internal temperatures during winter [57,72]. Other studies have likewise found an association between building-related factors and indoor environments, as well as energy consumption in homes [22,26,31,36,71–73].

No statistically significant association was found between the clusters and socio-demographic factors such as education level, household size, and income. However, the presence of children was found to be statistically significant ($p = 0.016$) for clusters in winter, whereas the presence of retired household members was not found to be statistically significant for both winter and summer. A similar result was found in a study by Zahiri and Elsharkawy [74], which showed that the presence of children had a strong correlation with energy consumption and indoor environment, while less energy was used for heating as the age of occupants increased. Association tests between clusters and occupant behaviour factors, including time of heating/cooling and night heating/cooling in winter and summer, did not show a statistically significant association. However, most of the membership in the cluster with the lowest indoor temperature during the summer and highest indoor temperature during the winter was associated with dwellings that used heating and cooling devices for the highest period of time, as well as night heating/cooling, which suggests irregular heating/cooling periods in homes. Although some of the associations might not be statistically significant, a chi-squared analysis also described the proportion of each category in each variable's result. For example, in summer, Cluster 2, which represents the cluster with the lowest hourly temperature profile, comprises mostly detached houses. This suggests that cross ventilation during the summer had a significant effect in maintaining lower temperatures throughout the day.

Temperature clusters developed and examined in this study can be used for distinct temperatures and operation times for each cluster and can subsequently be used in energy simulation tools to estimate the energy demand of residential buildings in Albania, as well as to calculate energy saving estimations from retrofitting projects. Using a single setpoint temperature in energy models has been shown to have a significant discrepancy from the actual energy consumption. A living room heating setpoint temperature of 21 °C and heating operation of 9 and 16 h for weekdays and weekends, respectively, is assumed for living rooms according to BREEDEM models of housing stock in the UK [63], even though the indoor temperatures vary widely to this [55,70]. In a previous study undertaken on the actual energy consumption of building types in Albania [65], the setpoints were assumed to be 20 °C and 26 °C for heating and cooling, respectively. Two options were considered for heating: partial (only one room) and full (the entire dwelling), with both assumed to have the heating on all day, or otherwise correction factors would be applied. However, these assumptions do not consider various occupant behaviours related to different heating or cooling setpoints and durations. Indeed, this study shows that much higher indoor temperatures were recorded in Albanian dwellings during the summer, as well as significantly lower indoor temperatures during the winter compared to the setpoints assumed. Assigning different temperature profiles in energy modelling for dwellings with various building characteristics, as well as various socio-demographic and behaviours of the occupants, would provide a closer estimation of actual energy consumption.

5. Conclusions

Developing indoor temperature profiles for energy models offers a great prospect to minimise the difference between estimated and actual energy consumption, as well as actual energy savings and estimations in the case of retrofits. Three main temperature profiles in summer and winter were developed in this study for weekdays and weekends using hierarchical cluster analysis based on indoor temperatures recorded in both summer and winter in 49 dwellings located in Tirana, Albania. The clusters were further tested and analysed for significant differences from each other and were further described by testing the differences in several factors, including building, socio-demographic, and occupant behaviours. Although this study uses continuous measurements of indoor temperature to develop the clusters, indoor temperatures are a substitution of heating and cooling system usage but do not indicate the status of heating or cooling system usage because other factors, such as incidental gains and ventilated heat losses, might also affect the indoor temperature [31,61,70]. However, they are an indication of its usage [31]. Nevertheless, the use of indoor temperature profiles in building energy performance simulations could produce more accurate calculations of energy performance, as well as predictions of indoor environmental conditions, of residential buildings in Albania. Should the future energy retrofitting programmes account for occupant behaviour, the gap between the estimated and achieved energy savings through each retrofitting strategy will be minimised, increasing the reliability of the impact that occupant behaviour has on achieving the intended results. The findings obtained in this study can also be used by policy-makers to inform programmes aimed at understanding occupant behaviour and their effect on energy consumption, as well as energy-saving policies that give tailored advice to specific household types. Various indoor temperature profiles might also indicate different comfort requirements as well as different thermal performance of various building types and could assist policy-makers in developing relevant energy retrofitting strategies for specific household types.

This is the first study that tries to develop indoor temperature profiles in Albania, as well as to explain them for various building and socio-demographic variables. Building characteristics and socio-demographic and occupant behaviour factors were all found to be explanatory of various indoor temperature profiles, even though only some of them were found to have a significant effect on them. However, further research should be undertaken to integrate the dynamic nature of occupant behaviour into simulation interfaces.

The limitation of this research lies primarily in the representativeness of the sample. It is a relatively small sample and is from Tirana, which is the capital of Albania, but is not wholly representative of the wider population of Albania. Nonetheless, this research does not aim to be exhaustive in terms of typology, nor does it aim to detect all typical patterns of indoor temperatures in winter and summer. It also cannot claim to have identified all factors affecting the indoor temperature profiles. Instead, it aims to provide indications of the different ways homes are used and how they perform, which would be central to introducing future energy-saving policies and retrofitting options. Further research should use a larger sample size and more comprehensive data for socio-demographic and behavioural variables that rely on other validated sources such as monitoring of household behaviours. This would help to improve the accuracy of the effect that occupants have on the indoor temperature profiles in homes. This approach might identify other statistically significant relationships that in this research were found to be insignificant. Fundamentally, these profiles will allow for better energy estimations and predictions, which are closely related to occupant behaviour.

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Energy and thermal performance of apartment buildings in Albania: the case of a post-communist country

Jonida Murataj¹, Rajat Gupta², Fergus Nicol²

¹ School of Architecture, Oxford Brookes University, Oxford, UK, jonida.murataj-2015@brookes.ac.uk

² Low Carbon Building Group, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford, UK, rgupta@brookes.ac.uk, jfnicol@brookes.ac.uk

Abstract: This paper undertakes a comparative evaluation of the energy and thermal performance of apartment buildings in Albania built both Pre-90 and Post-91 (a year that marks the change of the political system from communism to democracy in Albania). Building surveys, occupant surveys and continuous monitoring of outdoor and indoor environmental conditions during the summer and winter to allow for seasonal variations, were conducted in 29 case study flats randomly selected to represent both periods. Electricity bills were also provided for a full year. It was found that electricity consumption has been 22% lower in flats built Pre-90 and that the average temperature in living rooms were found to be very close to 29°C in summer and 16°C in winter in both Pre-90 and Post-91. Notwithstanding that measured average temperatures were similar in the two building cohorts, higher range and variance on mean indoor temperature has been found in summer in the flats built Pre-90, which has affected the thermal sensation votes of occupants living in them. It was found that over 60% of residents living in apartment buildings built Pre-90 were feeling cold in winter and hot in summer, compared to 30-40% of residents living in apartment buildings built Post-91, who felt cold in winter and hot in summer respectively. Although the findings cannot be treated as statistical generalization, the analysis provides an in-depth contextual insight into environmental, thermal and energy performances of flats in Albania, which would help inform future energy retrofitting programmes.

Keywords: Energy performance, thermal comfort, occupant's behaviour, apartment buildings, post-communism

1. Introduction

As in many countries in Europe, improving the existing stock in Albania is considered as the highest potential contributor to the energy saving targets of the National Energy Efficiency Plan (Energy Community, 2011), given the fact that building sector is the second largest energy consumers in Albania with over 40% of total carbon emissions (Energy Community, 2015; Global Buildings Performance Network, 2015). Even more, reducing energy reduction in buildings is considered essential to increase the energy security of the country (Energy Charter Secretariat, 2013). Although Albania, as a developing country, has no obligations towards reducing any quantity of greenhouse gas emissions (United Nations Human Rights, 2015), the built area and the energy consumption in the building sector is expected to increase as a result of the continuous development of the country. Moreover, Gupta (2013) remarked that we expect people to spend more time in the buildings in the future in the developing countries, as in developed countries (90% of the time), consequently increasing the energy consumption and health issues.

Furthermore, the economic situation of Albania makes it difficult to consume the necessary amount of energy to provide the adequate thermal comfort in houses. At least 25% of the population cannot afford to pay for energy and 95% of those with access to electricity

say it is too expensive to use (Fankhauser and Tepic, 2005). Today, the housing stock is in a poor condition also due to long-term lack of renovation, mainly because of lack of financing for this purpose. Therefore, it is inevitable to improve the energy performance, as well as increase the thermal comfort in the existing homes in Albania.

However, regional, social and cultural variation including differences in climatic conditions, income level, building materials and techniques have probably underestimated (Kohler, 1999) when designing energy retrofitting programmes. In line with this, in a post-communist society, where, on one hand people took control over their lives, property and economy and on the other hand, were left with feelings of weakness and powerless to self-organize because of for a long time previously being controlled by the state, it is important to know whether their expectations of the comfort that their indoor environment must provide has also changed. The last 27 years have marked many changes in Albania, not only in the built environment, but also in the way people live and respond to their environment.

In this context, this paper presents a comparative analysis of energy and thermal performance between the flats built Pre-90 and Post-91. The aim is to create an insight of energy and thermal performance of flats in Albania built during two main political periods and whether there is a correlation between how people feel in terms of thermal comfort and building period. Although flats represent only 6% of the residential buildings in Albania, they accommodate over 35% of the total households in Albania (Novikova et al., 2015). A socio-technical approach consisting of building and occupants' surveys, electricity data' collection, as well as indoor and external temperature measurements, was followed to give an overall picture of environmental, energy and thermal performance of flats across both periods. Statistical analyses have been undertaken to find correlations between them and other factors, such as, demographic, building or behavioural factors.

1.1. Apartment buildings built Pre-90 and Post-91

Most of buildings in Albania, and especially apartment buildings, have been the product of a quick and cheap construction strategy because of the housing shortage during the communist regime (Pre-90) and after, from the rapid urbanization that happened with the beginning of the democracy, which paid no attention to the quality of life of their occupants. Homes built during communist regime (53% of all apartment buildings' stock in Albania) were minimalist, demonstrating the power of the system over people's life and space. The approved standards were 4-6 m² per person (United Nations, 2002), causing discomfort of life related to living conditions in them. On the other hand, the size of households were large due to the fact that more than one generation shared the same dwelling (Aliaj, 1999), mainly because for cultural reasons and strong traditional values of marriage and family, as well as economic reasons. Apartment buildings constructed during this period were mainly prototype designs of low-rise blocks of flats, typically with loadbearing brick constructions or pre-fabricated concrete elements.

With the change of the political system to democracy, there was a massive and uncontrolled flow of population from rural to urban areas. Therefore, the biggest intent was to build bigger houses at a low cost, with no concern to neither the design nor energy efficiency nor thermal comfort. Apartment buildings were characterised by high-rise (above 8 floors) concrete frames structures with hollow bricks in-fill and no wall insulation.

Although the Building Code was revised in 1989, the Energy Building Code came to life in 2003, but it was never implemented. Therefore, most of the residential buildings in Albania are uninsulated and built with no concern to energy efficiency. Table 1 gives an overview of building and socio-economic characteristics of both periods considered in this paper.

Table 1: Building and socio-economic characteristics of two main construction periods in Albania

Period	Building characteristics	Socio- economic characteristics
Pre-90	• Low-rise blocks of flats (six floors max) • Typically, loadbearing brick construction or pre-fabricated elements • Prototype designs • Limited space standards • High technical standards due to the strict control • Average household size in the sample is 3.2 members • Average number of bedrooms is 1.6 • Average density is 0.054 people/m²	• Immigration was totally controlled by the communist government • No housing markets • Big families in small flats • Low-cost buildings • Buildings of this period supported the 'collective' aspect of communism ideology: 'Let's build quickly, good and cheap' slogan



Post-91	• Many ground-floor flats were converted to non-residential use • Most common construction is concrete frames with hollow brick in-fill • Limited building controls • Average household size in the sample is 3.4 members • Average number of bedrooms is 1.8 • Average density is 0.049 people/m²	• Rapid and massive free movement from rural to urban areas • Overpopulation of cities • Most of public stock was privatized • Most new housing has been produced by the private sector • Individualist society



2. Methodology

The analysis presented in this paper relate to 29 owner-occupied case study flats out of 49 dwellings selected to represent Albanian housing stock for an on-going research by the authors that aims to investigate the most effective retrofitting strategies for energy savings and improving thermal comfort in residential buildings in Albania. From the group of 29 flats, 13 have been built Pre-90 and 16 Post-91. The year 1990 is taken as the reference year where a massive social, economic and cultural change has happened in Albania affecting also the construction industry, as the result of the political change from the communist regime to democracy.

A socio-technical approach was used to collect quantitative and qualitative data from 29 flats in Tirana, Albania, in summer and winter, in order to have an overall picture of energy and thermal performance of the flats in the most energy consuming seasons of the year. Data collection consisting of:

Building surveys to gather information regarding the building properties and energy use. Quantitative data were collected regarding building materials and construction, orientation, floor area, appliances and lighting, which creates a detailed picture of energy use and behaviours within the flat. The survey was undertaken only once (in June-July) because the information gathered would be the same in both seasons for the same flats. Electricity bills were also obtained for 22 out of 29 flats.

Occupants' survey through questionnaire-guided interviews to get insights of how and when the house has been used, as well as occupants' behaviours in their home. The study adopted the method of questionnaire-guided interviews, as the most appropriate technique for gathering of all essential information in full range and depth, as well as getting insights of occupants' behaviours. The survey included also a transverse questionnaire, with questions to assess their comfort sensation and preference in summer and winter. Only one occupant per dwelling participated in the survey, to provide consistency across the research, and a total of 29 responses for each season was gathered.

Continuous monitoring of the outdoor and indoor temperature in the living room and main bedroom of the flats in summer and winter, to assess the thermal comfort in the house. iButtons, with accuracy of $(\pm 0.5)^{\circ}\text{C}$ and a measurement range of $(-10)^{\circ}\text{C}$ to $(+65)^{\circ}\text{C}$, were used to record the indoor temperature of the main living room and bedrooms of the flats in summer and winter for 6 weeks per season at half-hourly intervals to allow for seasonal variations. Data loggers were placed by the researcher in secure places in the living rooms and bedrooms away from external walls, direct solar radiation and devices that generate heat or air conditioning, to minimise any local effects on the measurements. Outside air temperature was also measured at 30-minute interval for 6 weeks in summer and 6 weeks in winter. The decision on the instrument was made on the minimum interference and upsetting of occupants' activities and life, as well as cost.

An overview of data collected for each flat is given in Table 2:

Only the living room measurements are considered for the scope of this study and all the analysis presented in this paper has been undertaken using SPSS Statistics, Version 24.

Table 2: Data collected for each flat

	Building survey	Occupant's survey	Transverse thermal comfort survey		Continuous measurement of living room temperature		Continuous measurement of bedroom temperature		Monthly electricity data
			Summer	Winter	Summer	Winter	Summer	Winter	
F1	✓	✓	✓	✓	✓	✓	✓	✓	✓
F2	✓	✓	✓	✓	✓	✓	✓		
F3	✓	✓	✓	✓	✓	✓	✓	✓	✓
F4	✓	✓	✓	✓	✓	✓	✓	✓	✓
F5	✓	✓	✓	✓	✓	✓	✓	✓	✓
F6	✓	✓	✓	✓	✓	✓	✓	✓	✓
F7	✓	✓	✓	✓	✓	✓	✓		
F8	✓	✓	✓	✓	✓	✓	✓	✓	✓
F9	✓	✓	✓	✓	✓	✓	✓	✓	✓
F10	✓	✓	✓	✓	✓	✓	✓	✓	✓
F11	✓	✓	✓	✓	✓	✓	✓	✓	✓
F12	✓	✓	✓	✓	✓	✓	✓	✓	✓
F13	✓	✓	✓	✓	✓	✓	✓	✓	
F14	✓	✓	✓	✓	✓	✓	✓	✓	✓
F15	✓	✓	✓	✓	✓	✓	✓		
F16	✓	✓	✓	✓	✓	✓	✓	✓	
F17	✓	✓	✓	✓	✓	✓	✓	✓	✓
F18	✓	✓	✓	✓	✓	✓	✓	✓	✓
F19	✓	✓	✓	✓	✓	✓	✓	✓	✓
F20	✓	✓	✓	✓	✓	✓	✓	✓	✓
F21	✓	✓	✓	✓	✓	✓	✓	✓	✓
F22	✓	✓	✓	✓	✓	✓	✓	✓	✓
F23	✓	✓	✓	✓	✓	✓	✓	✓	✓
F24	✓	✓	✓	✓	✓	✓	✓	✓	✓
F25	✓	✓	✓	✓	✓	✓	✓	✓	✓
F26	✓	✓	✓	✓	✓	✓	✓	✓	✓
F27	✓	✓	✓	✓	✓	✓	✓	✓	
F28	✓	✓	✓	✓	✓	✓	✓	✓	✓
F29	✓	✓	✓	✓	✓	✓	✓	✓	
Flats built pre-1990									
Flats built post-1991									

2.1. Survey sample

From 22171 apartment buildings in Albania, over 30% of them are in Tirana (Instat, 2012). Flats were randomly selected from various parts of Tirana, the capital of Albania. Most of them were mixed-used with shops on ground floor and residential on the others. From the sample, 13 flats are built Pre-90 and 16 flats are built Post-91.

Table 3 presents the frequency of different characteristics in the sample. Pre-fabricated concrete panels and solid brick walls were very common constructions during the communist regime of Pre-90, while insulation has only started to be applied in the last ten years or so. Date of construction ranged from 1950 to 2013. Most of the flats have 1-2 bedroom. The household size in the sample is 1-5 members and are of different ages (children to elderly members).

Table 3: Frequency of different characteristics in the sample

Categories		Count n	Percentage %
Period	Pre-90	13	44.8%
	Post-91	16	55.2%
Main construction material	Stone	0	0.0%
	Full brick	5	17.2%
	Hollow brick	14	48.3%
	Pre-fabricated	3	10.3%
	Hollow brick and insulation	2	6.9%
	Silicate brick	5	17.2%
How many bedrooms?	1 bedroom	10	34.5%
	2 bedrooms	17	58.6%
	3 bedrooms	2	6.9%
What is the highest education level in your household?	Elementary	0	0.0%
	High school	6	20.7%
	University	23	79.3%
Household size	1	2	6.9%
	2	6	20.7%
	3	7	24.1%
	4	9	31.0%
	5	5	17.2%
How many persons younger than 18 live in the household?	0	13	44.8%
	1	9	31.0%
	2	7	24.1%
How many persons older than 65 live in the household?	0	19	65.5%
	1	6	20.7%
	2	4	13.8%
Type of heating	No heating	0	0.0%
	Heat pumps	19	65.5%
	Electric heater	6	20.7%
	Gas heater	0	0.0%
	Wood stove	0	0.0%
	Heat pumps and electric heater	2	6.9%
	Heat pumps and gas heater	1	3.4%
	Individual central heating	1	3.4%
Type of cooling	No cooling	1	3.4%
	Air conditioning	19	65.5%
	Electric cooler	4	13.8%
	Air conditioning and electric cooler	5	17.2%

Electricity was the most commonly type of energy used for space heating mainly due to lack of infrastructure or security for using other types such as gas and wood, and air-

conditioning devices are the most common heating and cooling in the flats in the sample. Almost in all dwellings, electricity consumption increases during the winter months (November-March) with its peak in January and in summer (June – August) in July, associated with heating and cooling respectively. The normalised electricity use by area has reached values from 50 to 120kWh/m²/year in flats built both Pre-90 and Post-91, however the yearly average electricity consumption in flats built Post-91 has been found to be 22% higher than in those built Pre-90.

3. Temperature distribution and thermal comfort during the summer

The indoor temperature of 29 living rooms and 26 main bedrooms were monitored from 30 June to 12 August 2016 at half-hourly intervals, to cover the hottest season of the year in the Albanian climate. The outdoor temperature ranged between 19.6°C to 41.1°C, while the indoor temperature ranged from 23°C to 36.5°C (mean 29.1°C) and 24.5°C to 35.5°C (mean 28.7°C) in living rooms of flats built before and after 1990 respectively.

Figure 1 gives temperature distribution of the whole set of the indoor (living rooms) and outdoor temperature recordings during the summer for both flats built Pre-90 and Post-91, followed by a descriptive analysis of the mean indoor temperature. Each dot represents the average of the recorded temperature of all flats built Pre-90 (blue) and Post-91 (green) every 30 minutes, against the recorded outdoor temperature. It is found a wider range (5.4°C) and larger variance (1.1°C) in the indoor temperatures in flats built Pre-90 compared with flats built Post-91 with range and variance of 3.2°C and 0.4°C respectively.

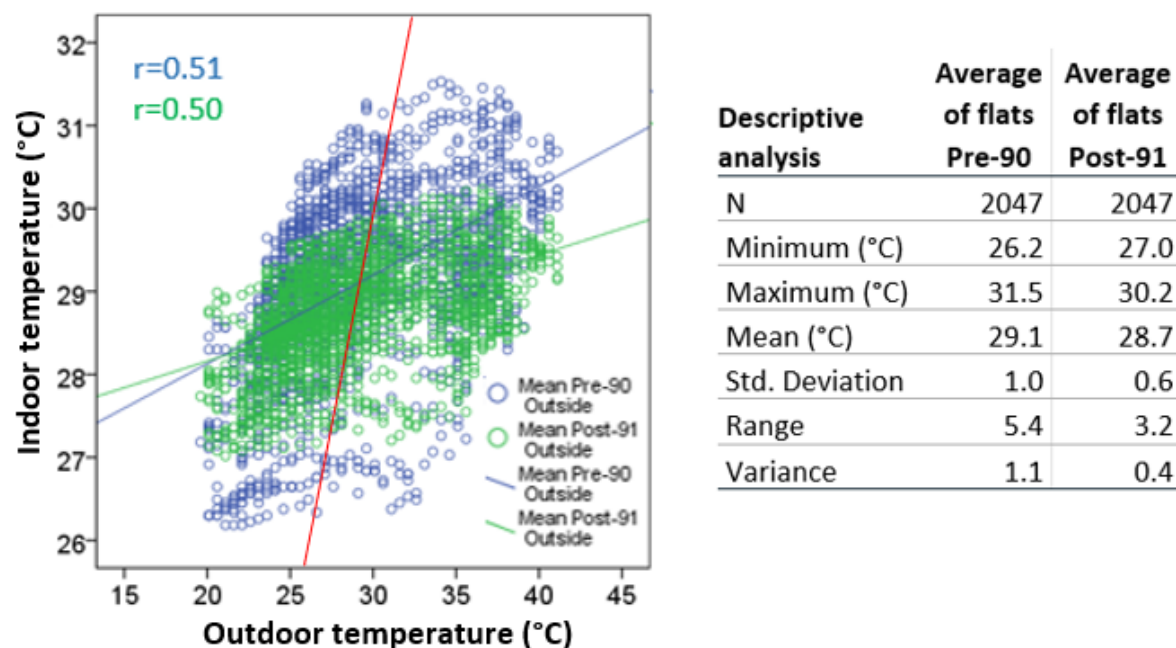


Figure 1: Average of recorded indoor temperature of flats built both Pre-90 (blue) and Post-91 (green) plotted against recorded external temperature. The red line shows where the indoor and outdoor temperatures are equal. The table presents the descriptive analysis of the recorded indoor temperatures averaged for flats built in both cohorts

Indeed, there is a higher proportion of indoor temperatures experienced towards the hot end of the spectrum in the flats built Pre-90, as shown in the population pyramid given in Figure 2. The average of the recorded indoor temperature has a wider variance in flats built Pre-90, but it has a higher concentration around 29°C in flats built Post-91.

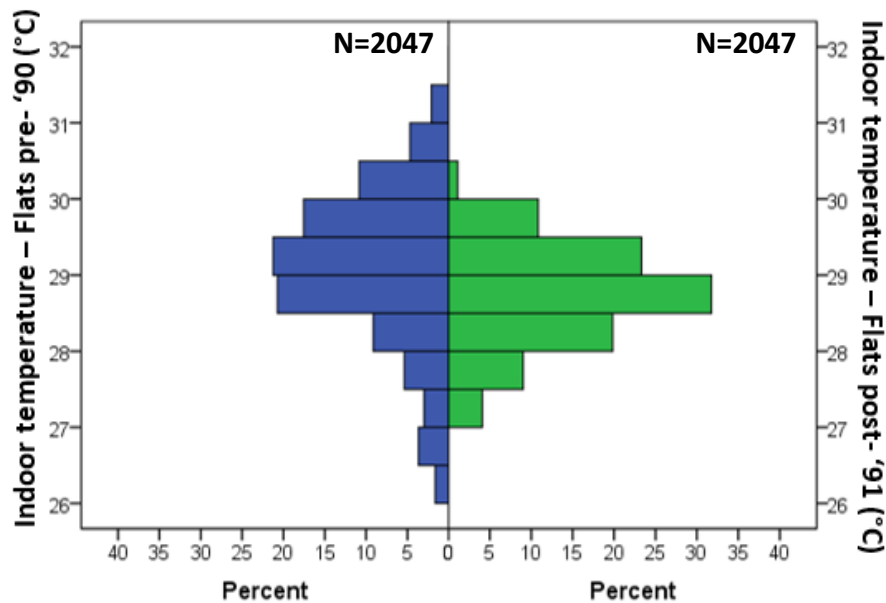


Figure 2: Comparison of indoor averaged indoor temperature distribution in summer between flats built Pre-90 and Post-91

Looking at the running daily mean temperature during the monitoring period (See Figure 3) there are found recorded indoor temperatures above 25°C almost all the time in all the flats, being well above the recommended figures from the guidelines (23°C -25°C) (CIBSE, 2006). Notwithstanding that most of them have the ease with which indoor temperatures can be lowered by adjusting the air conditioning system, indoor temperatures up to 31°C have been found very common in summer. Furthermore, the daily mean temperatures have been up to 1°C higher in flats built pre-1990.

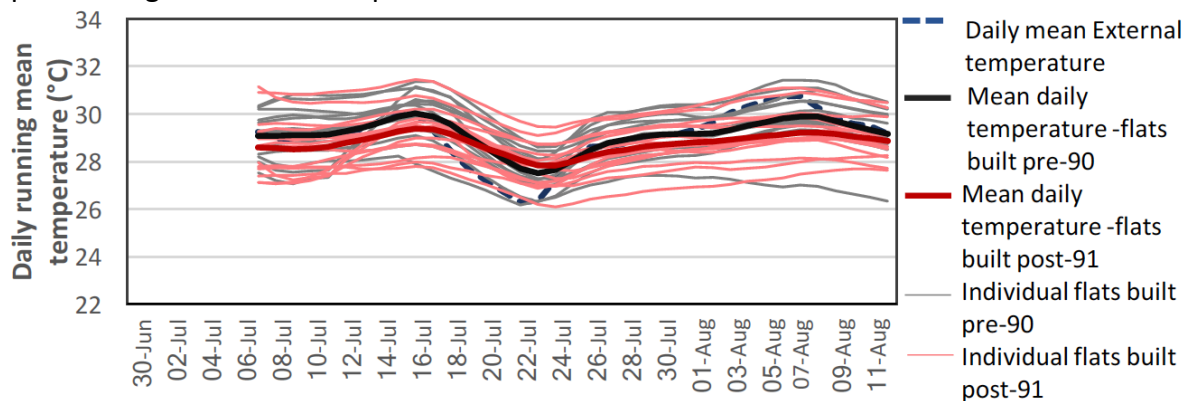


Figure 3: Daily running mean indoor temperatures in summer for each flat and averaged for flats built Pre-90 and Post-91

3.1. Thermal comfort in summer

Subjective evaluation of the thermal environment was provided using a 7-point ASHRAE scale for the thermal sensation evaluation and a 5-point scale for thermal preference (ASHRAE, 1992). From the thermal sensation vote distribution given in Figure 4, followed by a descriptive analysis, it is shown that about 90% of the participants reported feeling warmer than neutral during the summer, from which over 50% of them were feeling hot, for a mean temperature of 28.9°C (SD=1.0). Only two occupants were feeling neutral for mean temperature of 26.9°C (SD=0.3) and one slightly cool for mean temperature of 25.4°C.

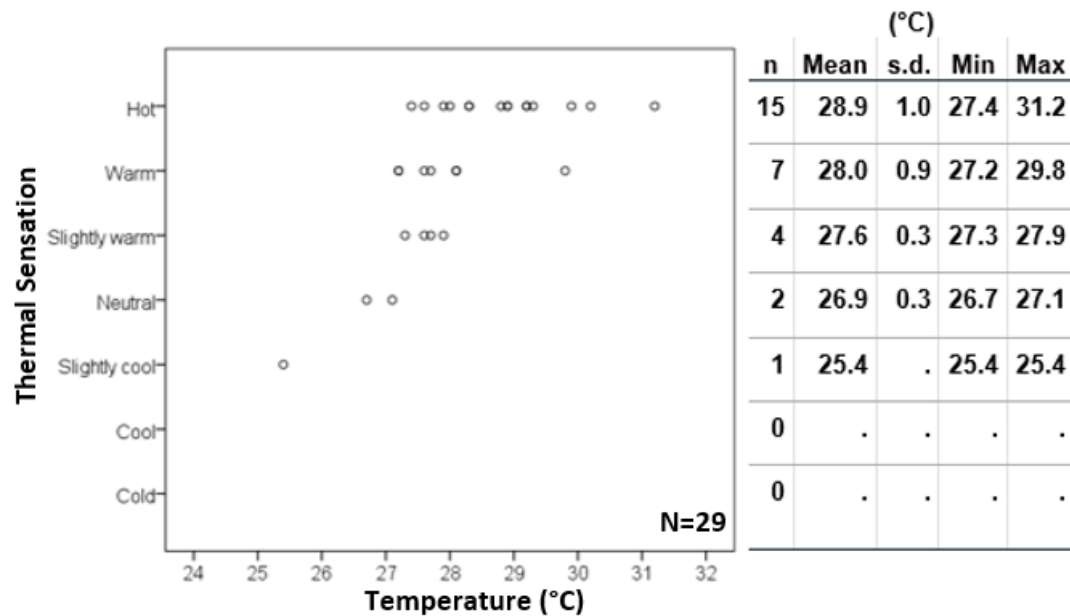


Figure 4: Total thermal sensation votes in summer and descriptive statistics for each scale

In Figure 5 are shown the thermal preferences votes corresponding with each thermal sensation votes reported during the survey in summer. All the participants that were feeling hot ($T=28.9^{\circ}\text{C}$) and most of them that were feeling warm ($T=28.0^{\circ}\text{C}$), wanted to feel much cooler. All the others ($T=26.9\text{--}28.0^{\circ}\text{C}$) wanted to feel a bit cooler, except the person that was feeling slightly cool who wanted no change ($T=25.4^{\circ}\text{C}$)

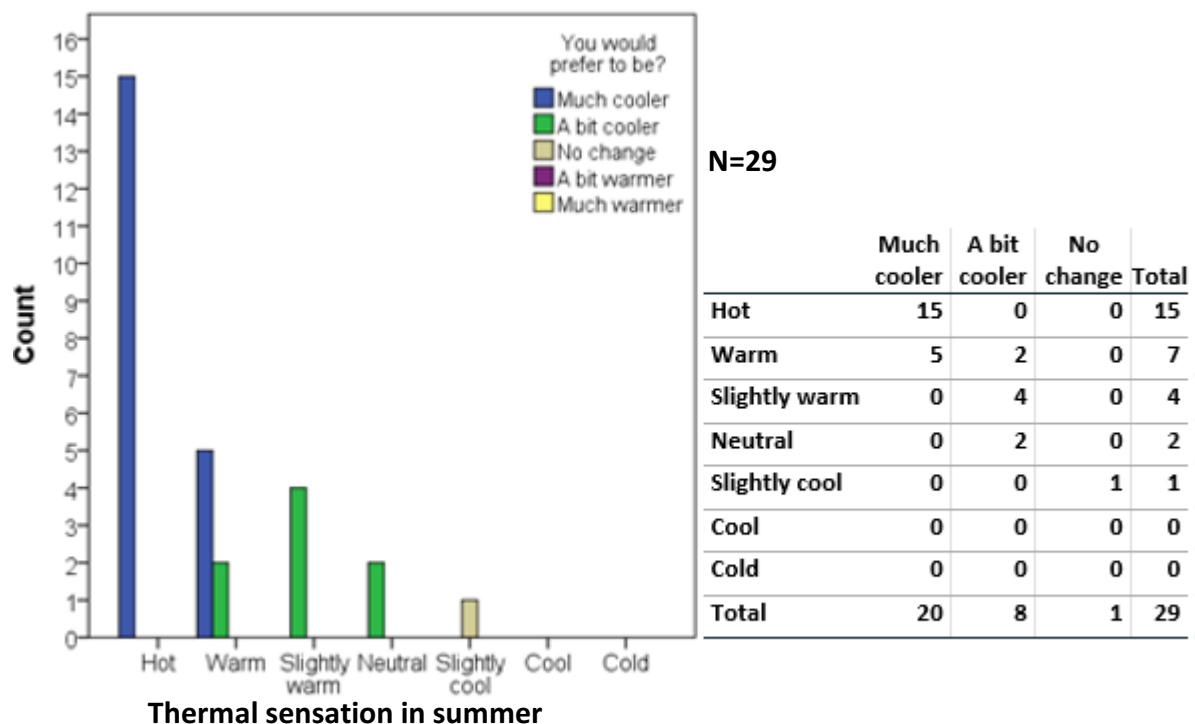


Figure 5: Thermal sensation votes reported in summer and crosstabulation with thermal preference votes

Comparing thermal sensation votes of participants living in flats built Pre-90 and Post-91 (Figure 6), it was found that the proportion of people feeling hot was higher in the flats built Pre-90 (70%) than those living in flats built Post-91 (44%). However, the mean

temperature was also higher in those flats. Only two persons reported feeling neutral in flats built Post-91 for a mean temperature of 26.9°C.

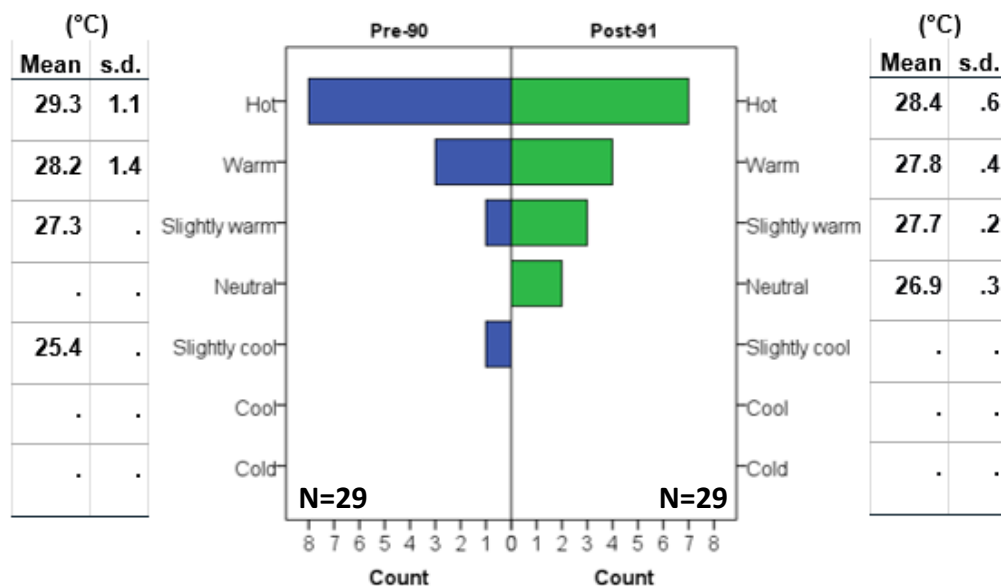


Figure 6: Comparison of thermal sensation votes in summer for flats built Pre-90 and Post-91, together with descriptive statistics of indoor temperature for each ASHRAE thermal sensation scale

A descriptive analysis is given in Table 4, comparing indoor temperature and thermal sensation votes in flats built both Pre-90 and Post-91, for several variables. Interestingly, mean indoor temperature and thermal sensation votes are not affected by the size of the household in both periods.

The presence of children and elder members in the household is higher in the flats built Post-91 and the mean indoor temperature was generally lower in those flats compared to the indoor temperature in flats built Pre-90. However, the thermal sensation in households with children and elder members was higher in flats built Post-91 than those built Pre-90. Over 80% of the flats were air conditioned, however mean indoor temperatures have been over 28°C. There were only three flats where air conditioning was on all day, while most of them were cooled for a few hours mainly in afternoon and evening. Windows were left open for the rest of the time. However, six of the participants reported to open windows and doors all day, even when the cooling was on.

Higher thermal sensation votes and higher mean indoor temperatures (0.5-1°C higher) have been found in air-conditioned flats built Pre-90 compared with flats built Post-91. Interestingly, higher mean indoor temperatures and thermal sensation votes have been found in insulated flats built Post-91 compared to uninsulated ones.

Table 4: The mean and standard deviation of the indoor temperature, and thermal sensation votes for flats built Pre-90 and Post-91, for different variables in summer

	Pre-90						Post-91					
	Temperature (°C)			ASHRAE*			Temperature (°C)			ASHRAE*		
	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.
Household size												
1	1	29.8	.	1	3.00	.	1	30.3	.	1	3.00	.
2	3	28.7	.5	3	2.33	.58	3	27.9	.4	3	2.33	.58
3	3	29.1	.9	3	3.00	.00	4	28.8	.4	4	1.50	.58
4	5	29.2	1.2	5	2.00	1.73	4	28.5	.3	4	1.75	1.50
5	1	29.0	.	1	1.00	.	4	29.1	1.4	4	2.25	1.50
How many persons younger than 18 live in the household?												
0	6	29.1	.7	6	2.67	.52	7	28.6	.9	7	1.86	1.07
1	3	28.4	1.2	3	1.67	2.31	6	29.0	1.1	6	2.00	1.26
2	4	29.6	.6	4	2.25	.96	3	28.5	.4	3	2.33	1.15
How many persons older than 65 live in the household?												
0	6	29.5	.7	6	2.67	.52	13	28.8	.9	13	1.85	1.14
1	5	28.9	1.0	5	1.80	1.79	1	27.3	.	1	3.00	.
2	2	28.4	.2	2	2.50	.71	2	29.0	.9	2	2.50	.71
Type of cooling												
No cooling	1	28.6	.	1	2.00	.	0	.	.	0	.	.
Air conditioning	7	29.2	1.0	7	2.14	1.46	12	28.7	.7	12	2.00	1.13
Electric cooler	2	29.2	1.3	2	3.00	.00	2	29.9	.9	2	2.00	1.41
Air conditioning and electric cooler	3	29.0	.7	3	2.33	1.15	2	28.0	1.0	2	2.00	1.41
Are the walls being insulated?												
No	13	29.1	.8	13	2.31	1.18	11	28.7	.8	11	1.82	1.17
Yes	0	.	.	0	.	.	5	28.9	1.1	5	2.40	.89
Have you got double glazing?												
No	11	29.2	.7	11	2.55	.69	7	28.8	1.0	7	2.14	1.21
Yes	2	28.5	1.8	2	1.00	2.83	9	28.7	.8	9	1.89	1.05
When do you switch the cooling on during the day?												
No cooling	0	.	.	0	.	.	2	29.9	.9	2	2.00	1.41
Afternoon	6	29.2	.8	6	2.67	.52	3	28.7	.9	3	2.33	.58
Evening	1	29.3	.	1	2.00	.	1	28.6	.	1	.00	.
Afternoon + evening	4	29.1	.6	4	2.50	1.00	9	28.7	.7	9	2.00	1.12
All day	2	28.6	2.0	2	1.00	2.83	1	27.3	.	1	3.00	.
Do you cool the house during the night?												
No	10	29.2	.7	10	2.70	.48	11	28.8	.7	11	2.00	1.00
Yes	3	28.7	1.4	3	1.00	2.00	5	28.5	1.2	5	2.00	1.41
When do you open the windows in summer?												
Afternoon	1	28.9	.	1	3.00	.	1	28.7	.	1	1.00	.
Evening	0	.	.	0	.	.	1	30.3	.	1	3.00	.
During the night	1	27.2	.	1	-1.00	.	0	.	.	0	.	.
Morning + evening	4	29.5	.2	4	2.75	.50	7	28.6	.5	7	1.43	1.27
All day	3	29.1	.9	3	2.33	1.15	3	29.0	.6	3	2.67	.58
All day and night	3	29.5	.9	3	2.33	.58	1	30.5	.	1	3.00	.
Evening and night	1	28.4	.	1	3.00	.	3	27.8	.6	3	2.33	.58

*ASHRAE seven-point scale: Hot=3; Warm=2; Slightly warm=1; Neutral=0; Slightly cool=-1; Cool=-2; Cold=-3

On the other hand, the presence of double glazing might have affected the indoor temperatures and thermal sensation votes, as they were higher for flats with single glazing

compared to those with double glazing. Expectable, flats that had cooling on all day, had lower indoor temperatures, compared to those that had cooling on only for some hours a day. Notwithstanding that indoor temperature has been lower in the flat built Post-91 that had cooling on all day, the occupant participating in the survey reported to feel hot. From 29 flats (13 built Pre-90 and 16 built Post-91), most of them have been not cooled during the night in summer and the thermal sensation votes have been higher in flats built Pre-90 compared to those built Post-91. Opening the windows all day, have caused the indoor temperature to be higher, associated with higher thermal sensation votes, in both cohorts. In the other hand, opening the windows only during the night has resulted in lower indoor temperatures and thermal sensation votes.

4. Temperature distribution and thermal comfort during the winter

The indoor temperature of 29 living rooms have been monitored from 5 January to 16 February 2017 at half-hourly intervals, to cover the cold season. The outdoor temperature ranged between -5.5°C to 18.5°C, while the indoor temperature ranged from 4.5°C to 28°C (mean 16.1°C) and 2.5°C to 27.5°C (mean 15.9°C) in living rooms of flats built Pre-90 and Post-91 respectively.

The same analysis approach as per summer is taken also for the data collected during the winter survey. Figure 7 gives temperature distribution of the whole set of the indoor and outdoor temperature recordings during the winter for both flats built Pre-90 and Post-91, followed by a descriptive analysis of the mean indoor temperature.

Notwithstanding that there has been found a very close mean indoor temperature to 16°C for flats built in both cohorts, there is a wider range and variance of the mean indoor temperatures of flats built Pre-90 (8.1°C and 2.7°C respectively) compared to the range and variance of flats built Post-91 (7°C and 1.8°C respectively).

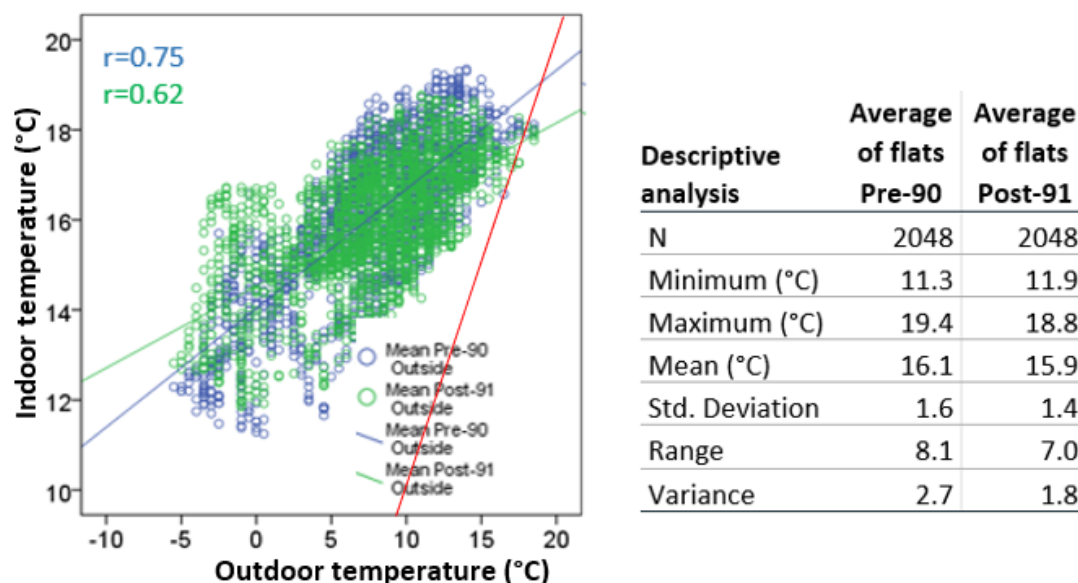


Figure 7: Average of recorded indoor temperature of flats built both Pre-90 (blue) and Post-91 (green) plotted against recorded external temperature. The red line shows where the indoor and outdoor temperatures are equal. The table presents the descriptive analysis of the recorded indoor temperatures averaged for flats built in both cohorts during the winter

The correlation r between the indoor and the outdoor temperature is noticeably higher in winter than in the summer. This suggests that the indoor temperature is more influenced

by the outdoor temperature in winter than in summer. The similarity in temperature distribution is also illustrated in the population pyramid shown in Figure 8. The mean indoor temperatures are between 14°C and 18°C for most of the time in flats of cohorts.

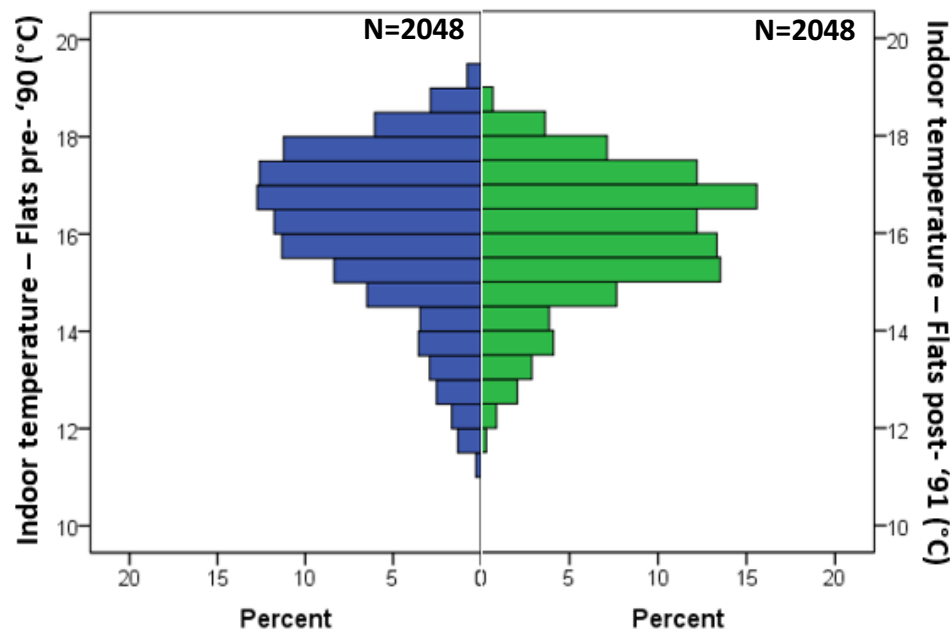


Figure 8: Comparison of indoor temperature distribution in winter between flats built Pre-90 and Post-91

Figure 9 give a line graph of recorded temperature of each flat distinguished by line colours representing flats built Pre-90 and Post-91. Generally, indoor temperature recorded in flats built Pre-90 reach lower values than the flats built Post-91, except two flats built Post-91 that have recorded very low indoor temperatures throughout the monitoring period. The flats were occupied by working couples that typically returned home in evenings.

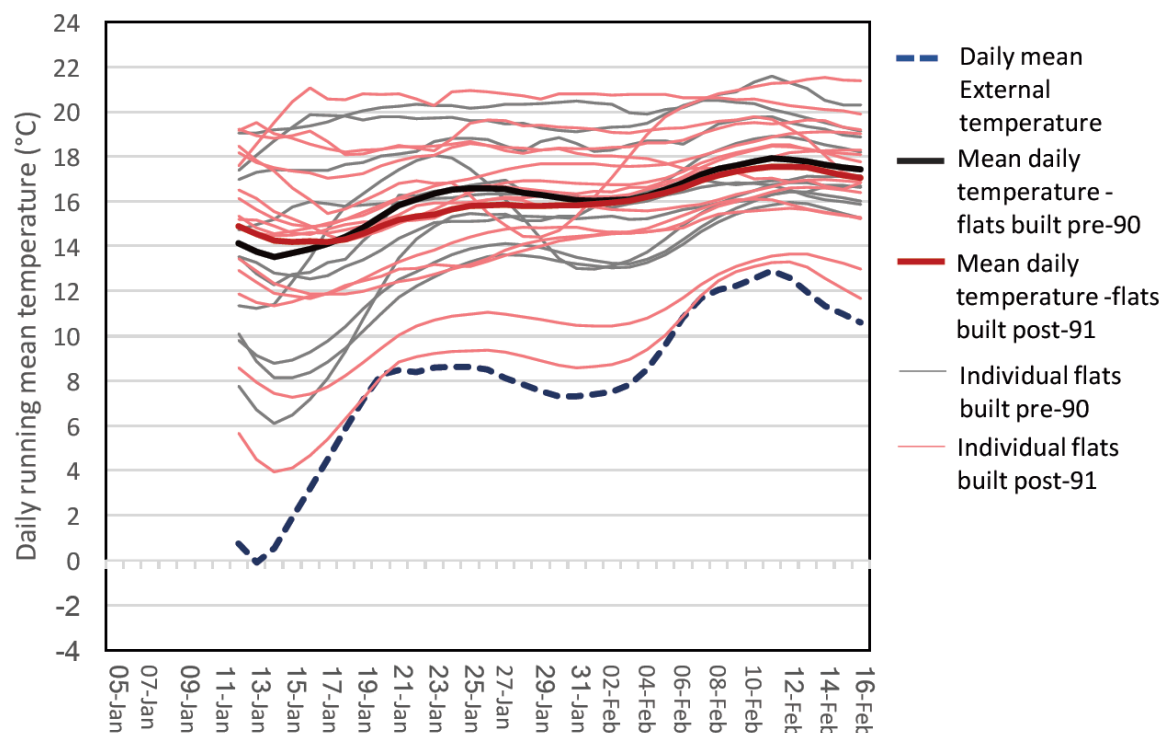


Figure 9: Daily running mean indoor temperatures in winter for each flat and averaged for flats built Pre-90 and Post-91

4.1. Thermal comfort in winter

Subjective evaluation of the thermal environment was provided using the 7-point ASHRAE scale for the thermal sensation evaluation and a 5-point scale for thermal preference. From the thermal sensation vote distribution given in Figure 10, followed by a descriptive analysis, it is shown that over 80% of the households reported to feel colder than neutral during the winter, from which about 45% of them were feeling cold, for a mean temperature of 15.6°C (SD=2.0). Only four occupants were feeling neutral for mean temperature of 17.5°C (SD=0.8) and one slightly warm for mean temperature of 18.9°C.

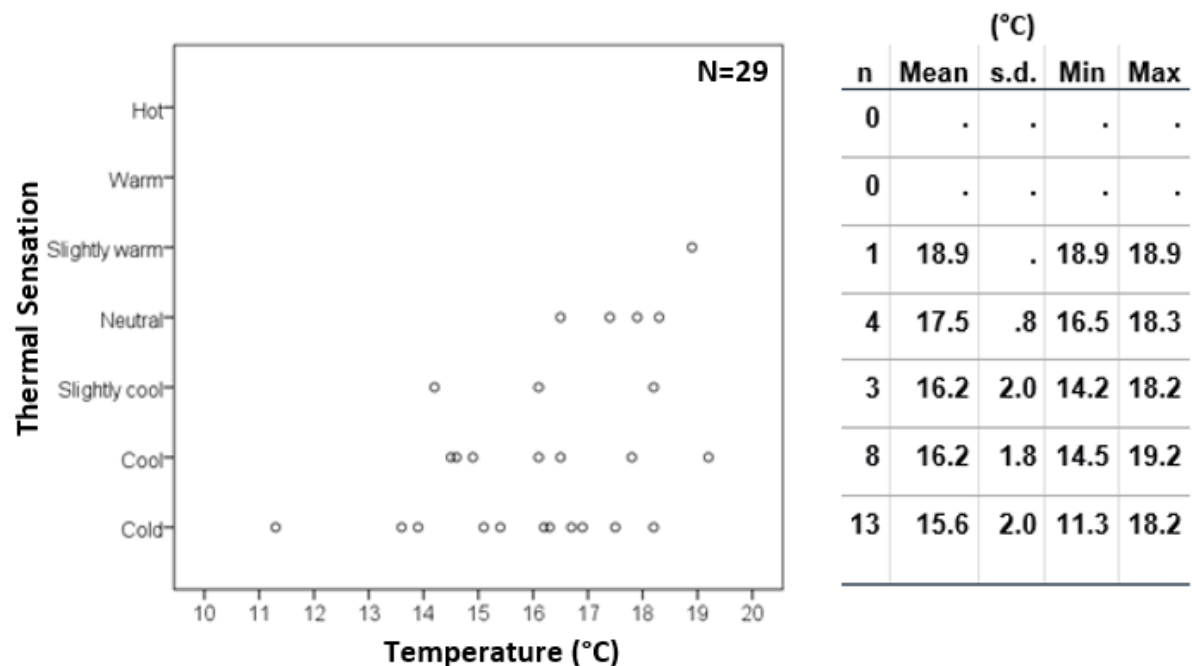


Figure 10: Total thermal sensation votes in winter and descriptive statistics for each scale

Thermal preferences votes corresponding with each thermal sensation votes reported during the survey in winter are shown in Figure 11. Only one of the participants was feeling cold ($T=15.6^{\circ}\text{C}$) and wanted to feel a bit warmer, while all the others wanted to feel much warmer. On the other hand, the participant that was feeling slightly warm ($T=18.9^{\circ}\text{C}$), wanted no change. Half of the respondents feeling cool ($T=16.2^{\circ}\text{C}$) wanted to be much warmer, while all other respondents wanted to feel a bit warmer.

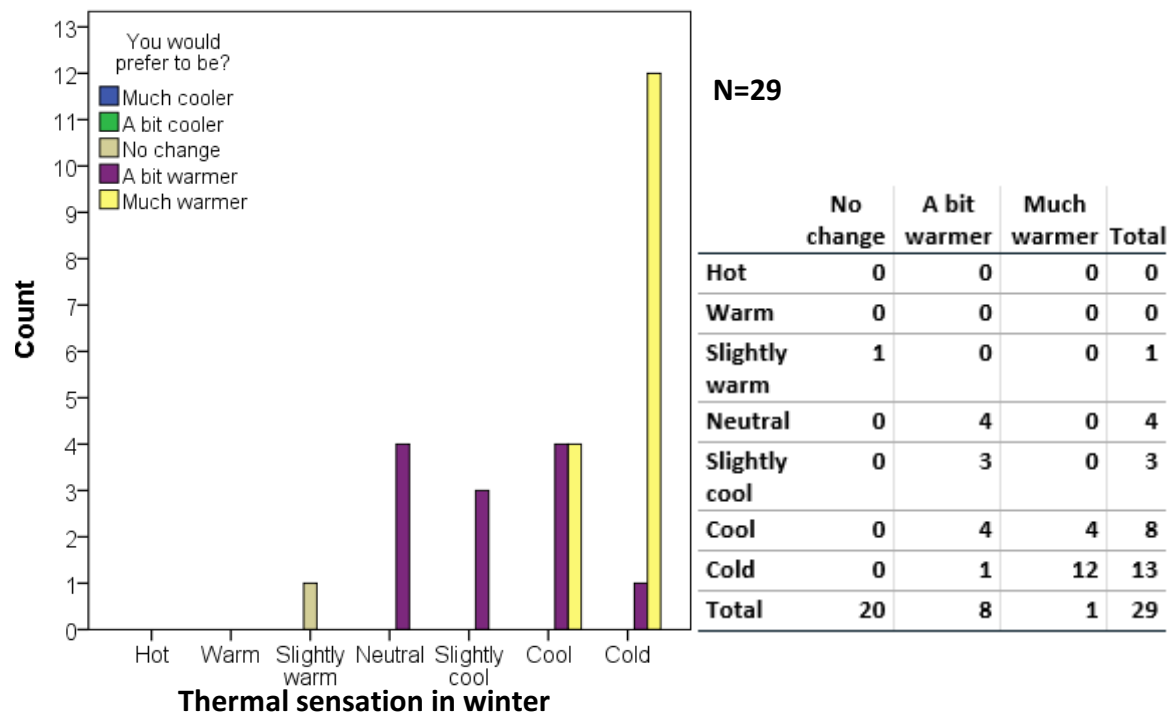


Figure 11: Thermal sensation votes reported in winter and crosstabulation with thermal preference votes

Comparing thermal sensation votes of participants living in flats built Pre-90 and Post-91 (Figure 12), it was found that the proportion of people feeling cold was higher in the flats built Pre-90 (62%) than those living in flats built Post-91 (31%), even though, the mean temperature corresponding to the thermal sensation vote (cold) was one degree higher in flats built Pre-90 ($T=16^{\circ}\text{C}$) than in flats built Post-91 ($T=15^{\circ}\text{C}$). Only two persons in each cohort reported to feel neutral, and the neutral temperature was slightly higher in flats built Post-91 than those Pre-90.

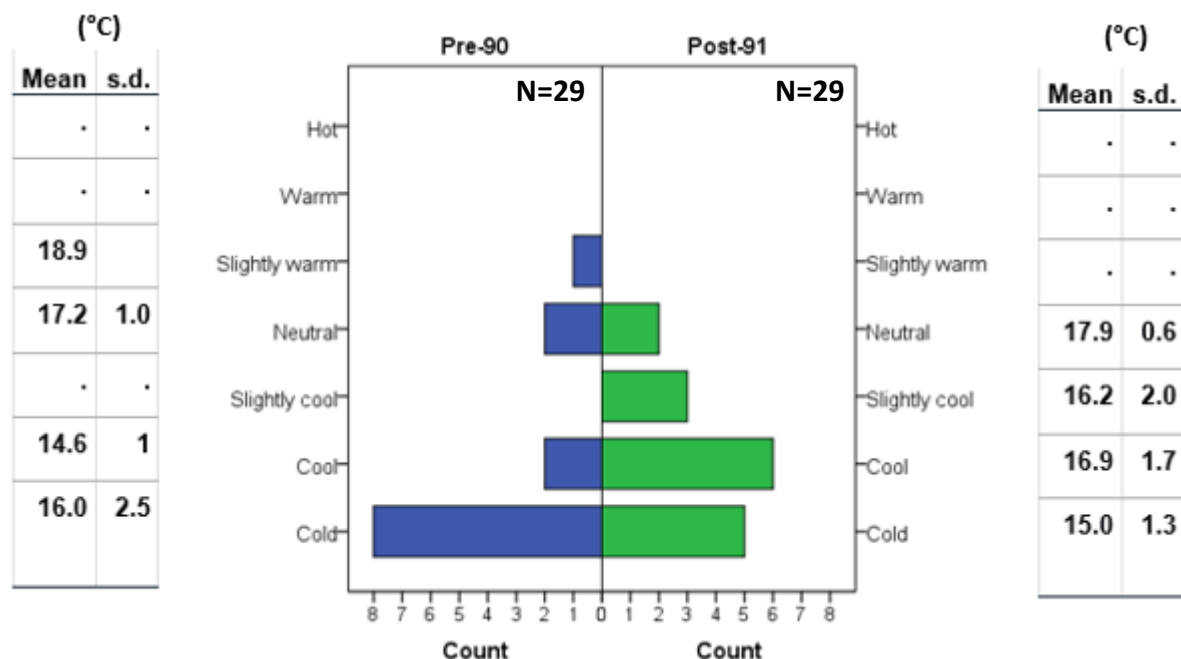


Figure 12: Comparison of thermal sensation votes in winter for flats built Pre-90 and Post-91, together with descriptive statistics of indoor temperature for each scale

A descriptive analysis is given in Table 5, comparing indoor temperature and thermal sensation votes in both flats built Pre-90 and Post-91, affected by several variables. Most of the households are made of three or more members. The mean indoor temperature is correlated in opposite directions with the household size for flats built Pre-90 and Post-91. It decreases with larger households in flats built Pre-90 and increases in flats built Post-91. However, the thermal sensation votes increase from cold to cool (-3 to -2) for larger households in both flats built Pre-90 and Post-91. For larger households, the mean indoor temperature is lower in flats built Pre-90 and higher in flats built Post-91. Interestingly, the mean indoor temperature is higher (19.2°C) in households made of three members compared to smaller and larger households built Pre-90. Commonly, these families are made of two parents and a child, and tend to create more comfortable thermal conditions than in the other flats. In fact, the presence of children in the household shows to affect the indoor temperatures, but the same cannot be said for the presence of the elder person. Out of 29 households, 16 had a least one child and ten of them had at least one elder member. The mean indoor temperature shows a decrease for their presence. Moreover, there is a lower thermal sensation vote from the households made of children and elder persons.

All flats used convective heating using air conditioning and electric heater devices to heat the space in winter. Even the flat that had individual central heating, was fuelled by electricity. The mean indoor temperature in dwelling that used air conditioning devices has been 1°C lower in flats built Pre-90 ($T=15.9^{\circ}\text{C}$) compared to those built Post-91 ($T=16.9^{\circ}\text{C}$) and they had the same thermal sensation vote (-2).

There have been almost the same mean indoor temperature and thermal sensation votes for flats without wall insulation in flats of both cohorts. However, has been a higher mean indoor temperature ($T=16.5^{\circ}\text{C}$) for flats with wall insulation and higher thermal sensation vote (-1.8). the presence of double glazing has possibly highly affected the mean indoor temperature in flats built Post-91 ($T=17^{\circ}\text{C}$), compared to mean indoor temperature of 24.8°C in flats with single glazing of the same cohort. In the contrary, a difference of only one degree is found in the mean indoor temperature of flats with ($T=16.8^{\circ}\text{C}$) and without ($T=15.9^{\circ}\text{C}$) double glazing in flats built Pre-90. In flats built both Pre-90 and Post-91, the thermal sensation votes are higher for the presence of double glazing.

Higher mean indoor temperatures and thermal sensation votes are associated with flats that are heated in evenings. Two flats built Pre-90 heat the space all day and this is also reflected in higher mean indoor temperatures (18.5) and thermal sensation votes (-1).

Table 5: The mean and standard deviation of the indoor temperature, and thermal sensation votes for flats built Pre-90 and Post-91, for different variables in winter

	Pre-90						Post-91					
	Temperature (°C)			ASHRAE*			Temperature (°C)			ASHRAE*		
	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.
Household size												
1	1	16.6	.	1	-3.00	.	1	.	.	1	-2.00	.
2	3	15.3	.4	3	-2.33	.58	3	14.9	1.3	3	-1.67	.58
3	3	19.2	.9	3	-2.00	1.73	4	15.7	4.4	4	-1.50	1.29
4	5	14.6	1.7	5	-2.20	1.79	4	16.3	4.0	4	-2.50	1.00
5	1	13.4	.	1	.00	.	4	16.7	1.8	4	-1.75	1.26
How many persons younger than 18 live in the household?												
0	6	17.3	2.3	6	-2.17	1.17	7	15.9	1.6	7	-1.86	1.07
1	3	17.7	1.1	3	-1.67	2.31	6	15.9	3.6	6	-1.67	1.03
2	4	13.7	.7	4	-2.25	1.50	3	16.4	4.9	3	-2.33	1.15
How many persons older than 65 live in the household?												
0	6	15.9	2.8	6	-2.83	.41	13	15.9	3.3	13	-1.77	1.09
1	5	16.5	2.4	5	-1.00	1.87	1	16.8	.	1	-3.00	.
2	2	15.0	.	2	-2.50	.71	2	15.9	2.2	2	-2.00	.00
Type of heating												
No heating	0	.	.	0	.	.	0	.	.	0	.	.
Air conditioning	8	15.9	2.3	8	-2.00	1.60	11	16.9	2.7	11	-2.00	1.00
Electric heater	4	17.2	2.6	4	-2.75	.50	2	11.8	3.5	2	-1.50	.71
Gas heater	0	.	.	0	.	.	0	.	.	0	.	.
Wood stove	0	.	.	0	.	.	0	.	.	0	.	.
AC + electric heater	1	13.4	.	1	.00	.	1	16.3	.	1	.00	.
AC + gas heater	0	.	.	0	.	.	1	16.8	.	1	-3.00	.
Central heating	0	.	.	0	.	.	1	14.0	.	1	-2.00	.
Are the walls being insulated?												
No	13	16.1	2.4	13	-2.08	1.44	11	15.8	3.2	11	-1.91	1.22
Yes	0	.	.	0	.	.	5	16.5	2.9	5	-1.80	.45
Have you got double glazing?												
No	11	15.9	2.6	11	-2.27	1.19	7	14.8	3.6	7	-2.57	.79
Yes	2	16.8	.2	2	-1.00	2.83	9	17.0	2.2	9	-1.33	.87
When do you switch the heating on during the day?												
Morning	1	16.6	.	1	-3.00	.	0	.	.	0	.	.
Afternoon	1	19.2	.	1	.00	.	2	12.8	4.9	2	-.50	.71
Evening	2	16.7	2.4	2	-2.50	.71	5	15.2	1.1	5	-2.00	.71
Morning and evening	4	13.6	.8	4	-2.25	1.50	5	18.8	.8	5	-1.80	1.30
All day	2	18.5	2.3	2	-1.00	2.83	0	.	.	0	.	.
Afternoon and evening	3	14.8	1.1	3	-2.67	.58	4	14.8	3.0	4	-2.50	.58
Do you heat the house during the night?												
No	12	15.7	2.1	12	-2.00	1.48	12	16.4	2.6	12	-2.00	.95
Yes	1	20.1	.	1	-3.00	.	4	14.7	4.0	4	-1.50	1.29
When and for how long do you open the windows in winter?												
Morning	12	16.2	2.5	12	-2.08	1.51	15	15.8	3.1	15	-1.80	1.01
All day	1	15.0	.	1	-2.00	.	0	.	.	0	.	.
When it is too hot	0	.	.	0	.	.	1	18.3	.	1	-3.00	.

*ASHRAE seven-point scale: Hot=3; Warm=2; Slightly warm=1; Neutral=0; Slightly cool=-1; Cool=-2; Cold=-3

5. Discussion

First of all, the analysis undertaken in this study has demonstrated the 'bad' environmental performance of flats in Albania, regardless the construction cohort. Very high indoor temperatures were recorded during the summer reaching 36.5°C and very low indoor temperature down to 2.5°C in winter. However, it was found that the indoor temperatures in flats built Pre-90 had an elevated temperature range and variation, especially in summer. The flats were constantly overheated, with indoor temperatures over 25°C all the time in summer. A better picture is in winter, where the mean indoor temperatures in most of the flats were above 15°C. The low range and variance of the indoor temperatures during the summer have probably affected the lower proportion of participants feeling hot during the summer in flats built Post-91 (44%) compared to those built Pre-90 (70%). Moreover, the occupants were feeling neutral for indoor temperature close to 27°C. The same thermal performance has been found in winter in flats built Pre-90, where 60% of the participants reported to feel cold. In contrary, only 30% of them were feeling cold in flats built Post-91.

Interestingly, the mean of normalised electricity use by floor area was found non-statistically significance different in flats built in both cohorts, even though the average yearly electricity consumption has been found to be 22% higher in flats built Post-91.

Therefore, what makes the flats built Pre-90 perform worse than those built Post-91 in terms of environmental and thermal performance?

Firstly, the deteriorated conditions of flats built Pre-90, the lack of wall insulation and lack of double glazing have made their contribution in their indoor environmental and thermal performance.

Secondly, seven out of 13 flats (46%) in the sample built Pre-90 were occupied by the same family since they were constructed and had at least one elder member. Usually they wear heavier clothing in summer than younger persons, probably causing thermal discomfort. Furthermore, the clothing norms have changed over the years. Younger people might wear only a sleeveless vest when are indoors, while this could be different for elder people.

Thirdly, the indoor temperature is higher in summer and lower in winter in flats built Pre-90 than in flats built Post-91 because of the shorter time of cooling and heating the space respectively. This is also reflected in considerably lower electricity bills (22%) compared to flats built Post-91.

6. Conclusions

It has been acknowledged that behavioural and social factors affect home energy consumption by as much as $\pm 50\%$ (Gill et al., 2010). Therefore, understanding the context is important not only for more accurate energy reductions by the proposed energy retrofits, but also to indicate the ways people adapt their environment (Nicol and Roaf, 2017). The analysis in this paper was focused on two main periods of Albanian political, economic and social life, that have inevitably affected also the construction industry and typology. Although the number of cases is relatively small, and the findings cannot be treated as statistical generalization, the analysis provides an in-depth contextual insight into environmental, thermal and energy performances of flats in Albania, and discusses the factors affecting them. However, conducting a study with a sample that can be statistically representative of the population would be needed to create a body of evidence on the energy and environmental performance of apartment buildings in Albania, which would help inform future energy retrofitting programmes. Furthermore, a detailed field study of thermal comfort would be essential to determine the range of temperature that people find comfortable in homes in Albania.

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Influence of occupant behaviour on thermal comfort and energy use in Albanian homes

Jonida Murataj¹, Rajat Gupta² and Fergus Nicol²

¹ School of Architecture, Oxford Brookes University, Oxford, UK

² Low Carbon Building Group, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford, UK

Abstract: This paper focuses on occupants' behaviours that affect the energy and thermal performance of residential buildings in Albania. Results were extracted from monitoring of the building and occupant surveys in one selected bungalow in Tirana, a form-built that represents over 80% of residential buildings in Albania. It was built in the post-communist area and has a concrete block construction. An annual electricity consumption 35% higher than the average for Albanian houses was found and a high variation of indoor temperatures during summer and winter. Key reasons for these findings were occupants' behaviours, that were determined by occupants' lifestyle, preferences and perceptions of comfort as well as cultural factors. The lack of information regarding behaviours that decrease energy consumption, and the lack of determination to consistently practice what they knew, resulted in a high energy consuming and uncomfortable. Window operation was found to have the largest impact in energy load and achieving comfort. These findings strengthen the need to understand the relationship that residents have with their properties, as well as the socio-cultural context, in order to suggest energy retrofitting strategies that will be accepted, implemented and really work for them over their lifetime in the properties. These results should be used to inform and validate the baseline energy modelling rather than using untested assumptions to minimise the performance gap between the expectations and outcomes created at the design stage.

Keywords: Occupant behaviour, energy performance, thermal comfort, monitoring, retrofit

Introduction

Buildings are one of the biggest energy users, consuming over one-third of final global energy and nearly half of the electricity consumption (EEA, 2011; IEA, 2013; IPCC, 2014). Across Europe, high performance building retrofits have already demonstrated the ability to deliver up to 90% reduction in energy consumption, hence, improving the building stock can be the best measure to achieve energy efficiency (BPIE, 2011). In particular, residential buildings offer great potential for standardization, while improving comfort and achieving energy savings. As in many countries in Europe, improving the existing stock in Albania is considered as the highest potential contributor to the energy saving targets of the National Energy Efficiency Plan (Energy Community, 2011), given the fact that building sector is the second largest energy consumers in Albania with over 40% of total energy consumption (Energy Community, 2015; Global Buildings Performance Network, 2015), with residential buildings consuming 30% of the total energy consumption. Most of this energy, about 40%, is used for space heating (Shehi, Gjoka and Schweizer, 2011) and the average electricity consumption is 4600kWh per household per year (International Energy Agency, 2008).

Although Albania, as a developing country, has no obligations towards reducing any quantity of greenhouse gas emissions (United Nations Human Rights, 2015), the built area and the energy consumption in the building sector is expected to increase as a result of the continuous development of the country. Therefore, a special consideration is given to these countries, recognizing the importance of reducing emissions and building resilience to climate change impacts on them (European Commission, 2016).

In this acknowledged reality, where improving the energy performance of existing housing stock provides the greatest potential to energy savings, several energy retrofitting programs have shown that they are lower than anticipated (Gupta and Gregg, 2012; Sunikka-Blank and Galvin, 2012), even when they are technical and financial viable. Buildings not only influence the final energy consumption through the technical energy efficiency of the product itself, but they also influence energy consumption through the way they structure the practices of the householders (Vlasova and Gram-Hanssen, 2014). On the other hand, their performance is complex, depending on a number of different technical and non-technical factors that can change over time (Janda and Topouzi, 2015). It is founded that even for neighbouring houses with nearly identical construction, the energy consumption may vary dramatically (Gram-Hanssen, 2013; Ingle et al., 2014), because houses are for people and people behave in different ways and there is no 'standard' household (Shove, Pantzar and Watson, 2012). Different occupants living in exactly the same type of house, can have energy consumption that changes by a factor of three or more mainly because occupants behave in more complex ways than designers account for (Janda, 2011), suggesting that it is the user that determines the energy consumption in homes (Gram-Hanssen, 2010). Furthermore, 'habits' can lead to a constant daily routine followed by the households, emphasizing the difference in requirements for different households (Guerra-Santin et al., 2016). However, the statement from (Janda, 2011) 'Buildings don't use energy: people do' has finally shifted the attention from the building to the people living in it.

This paper evaluates the energy and thermal performance of a case study bungalow using a mixed-method approach. Occupant feedback is cross-analysed with physical measurements and monitoring during heating and cooling season to draw a set of findings that will influence the way houses will be retrofitted in Albania.

Methodology

A socio-technical approach was used to collect quantitative and qualitative data through building surveys, occupant surveys and in-situ monitoring of indoor temperature (every 30 minutes) from one case study bungalows in Tirana. The case study is selected among 49 residential buildings studied, part of an ongoing doctoral research on retrofitting residential buildings in Albania, as one of the most common building form, but also as an example of a household with some common cultural issues affecting its energy behaviours. External temperature was also measured to make the right investigation of the set inside temperature. Data was collected into two rounds, from June 2016 to August 2016 (round 1, 47 days) and from January 2017 to February 2017 (round 2, 42 days), to gather empirical data about the energy and thermal performance of the houses, and occupants' perspective, to get insights of how and when the house is used, occupants' attitudes and habits, as well as to assess their comfort sensation and preference in summer and winter. Electricity use data were also collected for one year using fuel bills.

Case study's characteristics

In Albania, there are 598,267 residential buildings containing 1,012,400 dwellings in total (Instat, 2012). The housing stock has been developed in line with the political, social and economic phases of the country. Most of them are the product of a quick and cheap construction strategy because of the housing shortage during the communist regime and after, from the rapid urbanization that happened after '90, which had no intention in the quality of life of their occupants. 80% were one-storey detached houses, with only one

dwelling. The case study house is located in Tirana and is built in 1994. It has a concrete block construction, and has gone through a partial renovation two years ago, including a 30mm EPS external insulation on the external walls. However, although the homeowner undertook the intervention purely to stop the moisture on the external walls, it was not completely achieved because of cold bridges created with other uninsulated elements of the construction (floor, roof and windows). Detailed information regarding the case study is given in Table 1.

Table 1: Case study information

	
Typology	Bungalow built after 1990
Year built	1994
Area (m ²)	103m ²
Number of bedrooms	Three
Orientation	North-East (front façade)
Occupancy	Four adults
Occupancy patterns	Weekdays: 07:00-17:00 25% 17:00-07:00 100% Weekends: 24h
Walls:	Hollow concrete blocks with 30mm EPS insulation on the outside and sand cement render in both sides, U-value: 0.85W/m ² K
Roof	Un-insulated pitched roof, U-value: 2.93W/m ² K
Floor	Uninsulated concrete floor with ceramic tiles, U-value: 0.8W/m ² K
Windows	Single glazing with aluminium frames, U-value: 5W/m ² K

Energy performance

Biomass and electricity were used to heat the space, while cooling was performed using air conditioning devices. However only electricity consumption data were provided from electricity bills for a full year, given in Table 2 and Figure 1. It is noticed that electricity consumption of the house is nearly 35% higher than average electricity use for a house in Albania (4,600kWh).

Table 2: Energy consumption of the case study houses

Electricity consumption	January-December 2016
Total (kWh/year)	7,055
Total (kWh/m ² /year)	68.5
Total treated (kWh/ m ² /year)	140

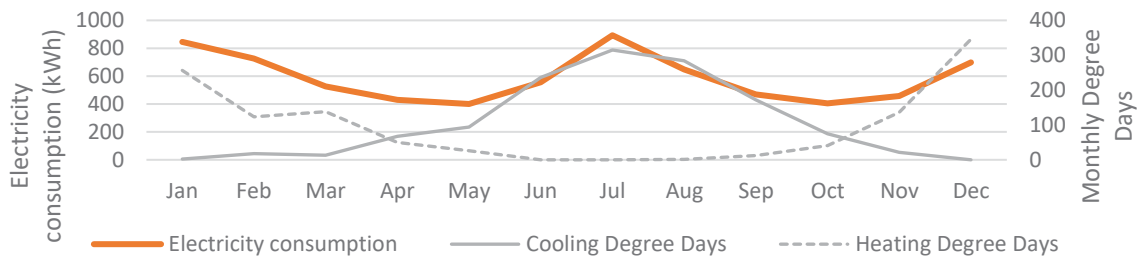


Figure 1: Electricity consumption from January-December 2016
Source of degree days: (www.degreedays.net, 2017)

Using an electric boiler 24h for heating domestic water and using electric devices to heat and cool the space (in several rooms) are the main reasons for the high electricity consumption of house. Furthermore, multiple non-efficient appliances (Figure 2) were present in the house and electricity was used for cooking. Characteristics for energy use in each house is given in Table 3.



Figure 2: Example of appliances present in the house

Table 3: Characteristics for energy use

Lighting	Mix of fluorescent and incandescent lights
Appliances	Multiple appliances (two TV, two fridge-freezers, two laptops and a desktop computer)
DHW	Continuously on electric boiler
Cooking	Electric oven/hob
Heating	Inverter air conditioner (Living room and bedroom 1), oil filled radiator (bedroom 2) and biomass woodstove in bedroom 3
Cooling	Air conditioning (living room and bedroom 1)

Environmental and thermal performance in summer

External and indoor temperature of living room and two bedrooms of the house were monitored from 30th of June to 12th of August 2016 at half-hourly intervals, to cover the hottest season of the year in the Albanian climate. The outdoor temperature ranged between 19.6°C to 41.1°C (with a mean temperature of 29°C), while the indoor temperature ranged (24.5°C-33.5°C) in the living room, (24°C-29.5°C) in bedroom 1 and (24°C-33.5°C) in bedroom 2, well above the recommended temperatures from the guidelines (23°C -25°C) for living rooms and 21°C-23°C for bedrooms) (CIBSE, 2006).

However, the mean daily temperatures have been between 28°C and 30°C most of the time, as shown in Figure 3. The graph indicates the use of air conditioning in the living room and bedroom 1, while the temperatures in bedroom 2 have almost the same profile as the

external temperature, meaning that this room has hardly been cooled at all. Table 4 presents the descriptive statistics in the main spaces during the summer.

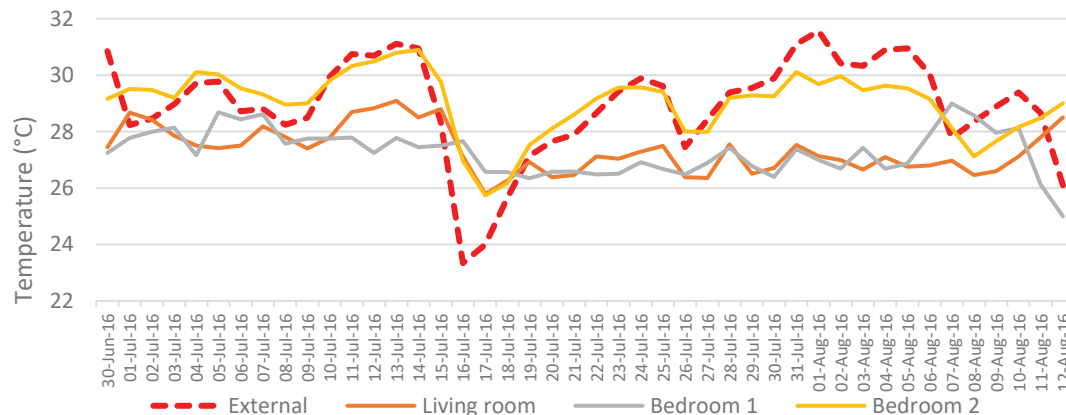


Figure 3: Mean daily temperatures in summer

Table 4: Descriptive statistics of indoor and external daily mean temperatures in summer

	Mean (°C)	Maximum (°C)	Minimum (°C)	Percentile 25 (°C)	Percentile 75 (°C)	St. Dev
External	28.97	31.60	23.30	28.25	30.15	1.78
Living room	27.36	29.10	25.80	26.75	27.80	0.80
Bedroom 1	27.29	29.00	25.00	26.65	27.80	0.81
Bedroom 2	29.03	30.90	25.70	28.35	29.65	1.13

Hourly indoor temperatures averaged over the monitored period revealed that air conditioning has been used almost all day as shown in Figure 4. The living room has been cooled almost all day, with a peak in the evening, when there is the maximum occupancy in the house. The main bedroom has also been cooled most of the day. All the rooms were overheated as they had temperatures over 25°C all the time. Furthermore, temperatures over 28°C for more than 20% of the occupied hours in the treated rooms and over 50% of the time in the non-treated bedroom. Temperatures exceeding 25°C occurs for 5% of the occupied hours (and 28°C/1%) is the guidance for assessing overheating (CIBSE, 2006).

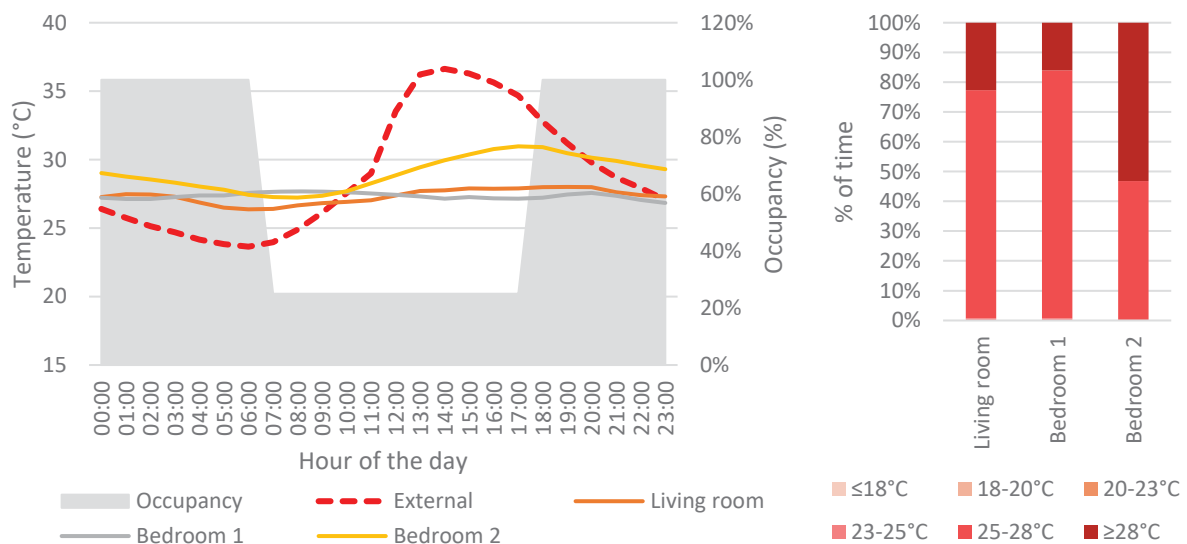


Figure 4: Mean temperatures during the day

Subjective evaluation of the thermal environment was collected by the homeowner of the house using a 7-point ASHREA scale for the thermal sensation evaluation and a 5-point scale for thermal preference. The survey showed that the occupant who completed it were feeling hot during the summer and wanted to feel much cooler. Because the questionnaire was time-stamped, it was found that indoor temperature at the time of completion was 27.8°C.

Environmental and thermal performance in winter

Indoor temperature of living room and two bedrooms of the house were monitored from 5th of January 2016 to 16th of February 2017 at half-hourly intervals, to cover the coldest season of the year in the Albanian climate. The outdoor temperature ranged between -5.5°C to 18.5°C (with a mean temperature of 7.8°C), while the indoor temperature ranged from 6.5°C to 23.5°C in living room and from 11°C to 26.5°C and from 6°C to 21°C in bedroom 1 and 2 respectively. The indoor temperature has reached values well under the recommended temperatures from the guidelines of 22°C -23°C for living rooms and 17°C-19°C for bedrooms (CIBSE, 2006). Furthermore, the indoor temperature variation is very high.

The daily average profiles in Figure 5 show that the external average temperatures have reaches temperatures below 0°C, while it did not exceed 15°C. Bedroom 1, in difference to the living room and bedroom 2, has been heated all the time. Table 5 presents the descriptive statistics in the main spaces during the winter.

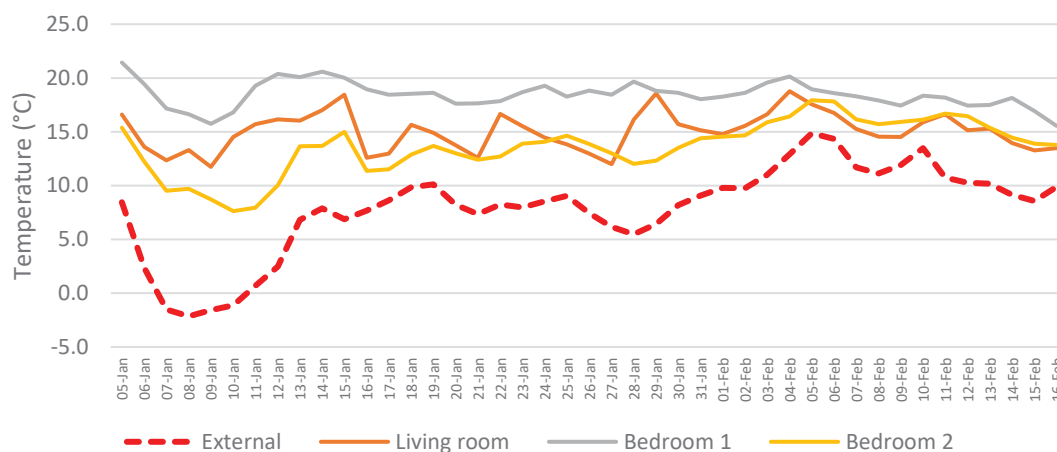


Figure 5: Mean daily temperatures in winter

Table 5: Descriptive statistics of indoor and external daily mean temperatures in summer

	Mean (°C)	Maximum (°C)	Minimum (°C)	Percentile 25 (°C)	Percentile 75 (°C)	St. Dev
External	7.85	14.90	-2.10	6.80	10.20	4.16
Living room	15.06	18.80	11.70	13.60	16.20	1.77
Bedroom 1	18.45	21.40	15.50	17.70	19.30	1.22
Bedroom 2	13.59	17.90	7.60	12.30	15.40	2.49

Looking at the hourly temperature profiles in Figure 6, it is discovered that temperatures in the living room and bedroom 2 are affected by the occupancy, meaning that they are higher when the house is fully occupied. The temperature profile in these two spaces have two peaks, one in the morning and the other in the evening. Bedroom 1 has had higher temperatures during the day and evening, indicating the use of the room throughout the day.

Notwithstanding that the heating has been on most of the time, temperatures below the recommended ones (22-23°C) have occurred for over 95% of the occupied hours in all the rooms.

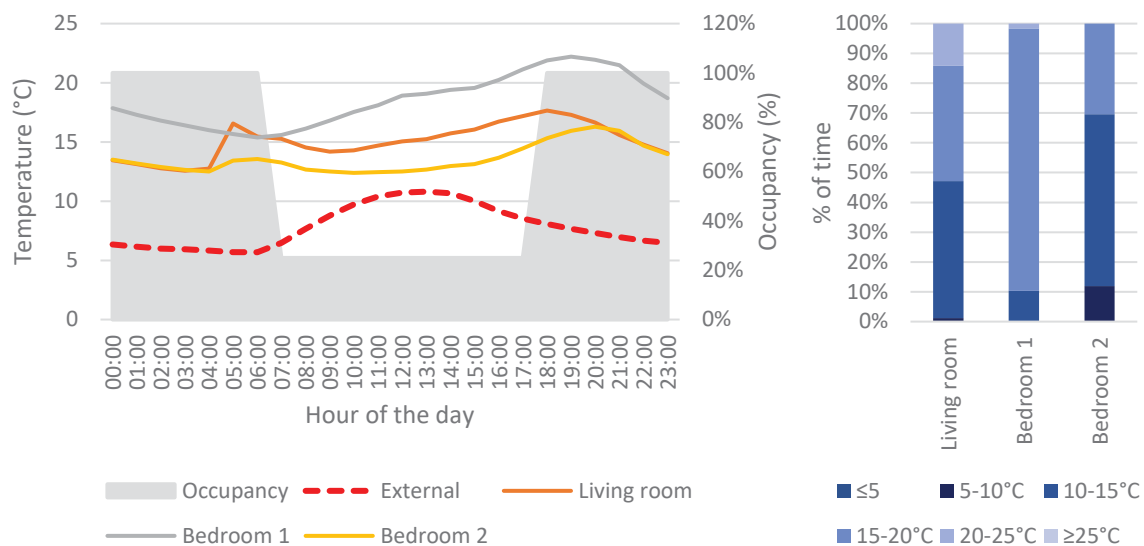


Figure 6: Mean temperatures during the day

The occupant completing the questionnaire was feeling cold and wanted to be much warmer, in an indoor temperature of 16.4°C.

Energy behaviours in summer and winter

An investigation of the occupants' behaviour during the summer and winter was also undertaken and the main results are given in Table 6 for summer and winter respectively. The occupants did not think much about energy and how it is used. They used to open windows and doors most of the time when heating or cooling was on during the day. Furthermore, they used a very high heating setpoint in winter and a very low cooling setpoint in summer.

Table 6: Occupants' behaviours during the summer and winter

	Cooling	Heating
Cooling/heating on during the year	June-September	November-May
Cooling/heating on during the day	All day	All day
Cooling/heating on during the night	Yes	Yes
Control of room temperature	Never gets cold. It is always too hot. Always select a lower setpoint temperature when it gets too hot. The setpoint the used the most was 16°C.	They used a setpoint of 30°C all the time, and when it gets too hot they open the windows. In the bedroom they used the sleep-mode option in their inverter air conditioning device
Window operation during the day	Open most of the day	Very often during the day
Opening windows when cooling/heating is on	Yes	Yes

Heating and cooling were performed for seven and four months of the year respectively and the house was heated and cooled during the day and night. However, they found the house to be hot in summer and cold in winter, and the main reason for that is the careless operation of windows and doors.

They never opened the windows during the night in summer because of safety issues, while there was a cultural issue in this family regarding to hospitality. A carpet was placed that prevented closing the door (Figure 7).

“...it is not nice to close the front door.....this would show people they are not welcomed...”

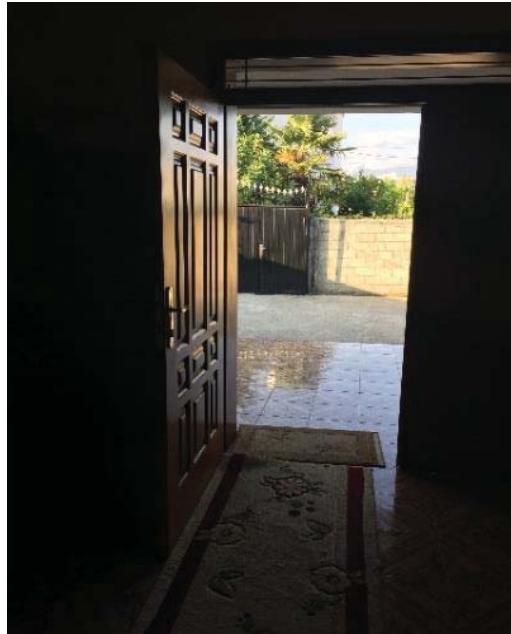


Figure 7: The use of carpet to prevent closing the door

Because there is a localised (by room) heating/cooling solution in most of Albanian houses, generally it is treated only the living room and one of the bedrooms, and occupants tend to stay all in the same room to save energy. However, in this household, all the rooms are heated/cooled. Bedroom 1 that was heated and cooled all the time, was used as a study room by the daughter of the homeowner, preparing for the exams. However, this was not the only period when all the rooms were occupied:

“...my daughter is using more energy than all of us together...”

“...but exams are not the only reason. Both of my children tend to spend lots of time in their bedrooms when they are home...”

Notwithstanding they claimed not to have enough information on how to save energy, they were feeling powerless to change habits and to be consistent on what they knew was wasting their energy in their home.

Conclusion

An analysis of the energy and thermal conditions, as well as occupants' energy behaviours of a case study bungalow in Tirana was undertaken in this paper using data collected through two field studies conducted in June-August 2016 and January-February 2017, to cover the cooling and heating season respectively in Albanian climate. In-sight of energy consumption together with thermal comfort were given for both seasons, as well as an examination of the

human behaviour effect in achieving the adequate comfort. It was revealed that the house had an annual energy consumption nearly 35% higher than the average energy consumption in Albanian households. Very low indoor temperatures in winter and very high ones in summer, associated with a high variation throughout the day has been the product of not only the building's properties, but occupants' behaviours in particular. Consistency in energy behaviours is found to be key that is missing in achieving an acceptable and comfortable environment in the house. On the other hand, it reveals that windows and doors operation might not be a result of misinformation or lack of knowledge in their effect in energy performance of the house, but it could be because of social and cultural norms. They might have been underestimated.

The research also approves the fact that other studies have shown, that successful buildings are those where occupants are well-informed, either intuitively or by their management and insufficient understanding, as well as poor maintenance can contribute towards energy use exceeding expectations (Bordass et al., 1994).

These preliminary findings substantiate the need to consider occupants' behaviours and their willingness to change their behaviours before selecting any retrofitting strategies, so that the estimated energy savings and thermal comfort are reachable. That is why treating each household as in-depth case study (Gupta and Barnfield, 2013; Tweed, 2013; Ingle et al., 2014) and proposing the solution specifically for them, is needed to understand the people who live in the properties.

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Design to Thrive

Energy and thermal performance assessment of existing residential buildings: the first step to introducing successful retrofitting strategies in Albania

Jonida Murataj¹, Rajat Gupta², and Fergus Nicol²

¹ School of Architecture, Oxford Brookes University, Oxford, UK

² Low Carbon Building Group, Oxford Institute for Sustainable Development, Oxford Brookes University, Oxford, UK

Abstract: This paper presents the findings of a study conducted in Albanian residential buildings. It aims to get insights of energy and thermal performance of the existing housing stock, as well as the effect that human behaviour has on the indoor environment. The methodology adopted comprised building surveys, occupant survey and continuous monitoring of outdoor and indoor environmental conditions during the summer and winter to cover for seasonal variations. 49 case studies were randomly selected to represent various Albanian housing typologies defined for this study. It is found that energy consumption was up to 97% over the baseline, and more than two third was consumed for heating the space in winter. The findings also indicate a disparity between the preferred thermal conditions and those experienced, especially in winter where residents found it very difficult to prevent the very high fluctuation of temperatures. Other occupants' behaviours associated with individual perceptions and cultural bearings are highlighted. Therefore, using these findings to inform and calibrate the baseline energy modelling will provide better estimations on energy savings for future retrofitting programmes.

Keywords: Energy performance, comfort, human behaviour, pre-retrofit survey, monitoring

Introduction

Notwithstanding that energy retrofitting of existing housing stock offer a great potential in energy savings, several energy retrofitting programs have shown that they are lower than anticipated (Gupta and Gregg, 2012; Sunikka-Blank and Galvin, 2012), partly because of considerable assumptions and predictions used for energy modelling, due to a lack of data about various aspects of the building (Zero Carbon Hub, 2014). Furthermore, regional, social and cultural variation including differences in climatic conditions, income level, building materials and techniques, building stocks are complex and the boundaries are difficult to define and probably they have been underestimated (Kohler, 1999). Therefore, the model calibration with the real data on energy and environmental performance gathered through pre-retrofit monitoring of the building (Gupta and Gregg, 2016), including the possibility of integrating the occupants' behaviours into building simulations based on measured observations rather than assumptions (Guerra-Santin et al, 2016), is vital in minimising the performance gap between the expectations and outcomes.

Within this context, this paper investigates the energy and thermal performance of various archetypes in Albania through continuous monitoring of indoor and outdoor environmental conditions, building surveys and occupant survey, and examines the occupant's behavioural effect in achieving thermal comfort.

Methodology

This research is part of an ongoing PhD study that aims to investigate the most effective retrofitting strategies for energy savings and improving thermal comfort in residential buildings in Albania. A socio-technical approach was used to collect quantitative and qualitative data from 49 households representing eight various archetypes of residential buildings in Albania, consisting of:

Building surveys to gather information regarding archetypes and energy use. Electricity bills were also obtained for 36 out of 49 dwellings.

Questionnaire-guided interviews to get insights of how and when the house is used, occupants' attitudes and habits, and other everyday practices in their home, as well as to assess their comfort sensation and preference in summer and winter.

Continuous monitoring of the outdoor and indoor temperature in the living room and main bedroom of 49 dwellings in summer and winter, to assess the thermal comfort in the house.

Based on dwellings statistics, the sample chosen for monitoring is closely representative of Albanian housing apart from semi-detached houses, which are under-represented.

Table 1. Statistics of residential buildings in Albania

Type	Albanian residential buildings		Dwellings		Sample	
	Frequency	%	Frequency	%	Frequency	%
Detached	88,804	80.5	88,804	33.9	17	34.6
Semi-detached	10,184	9.2	25,666	9.8	1	2
Terraced	4,351	3.9	14,142	5.4	2	4.1
Flat	6,944	6.3	133,291	50.9	29	59.3
Total	110,283		261,903		49	

Table 2. Frequency of key characteristics in the sample

Category	Description	Frequency	%
Year of construction	Pre-1960	4	8.2
	1961-1990	12	24.5
	After 1991	33	67.3
Construction type	Solid brick / stone external walls	8	16.3
	Concrete blocks	3	6.1
	Pre-fabricated	3	6.1
	Silicate brick	5	10.2
	Hollow brick	24	49
	Insulated walls	6	12.2
Ventilation / cooling scheme	Natural ventilation	3	6.1
	Mixed ventilation (natural + air conditioning)	46	93.9

Energy consumption

Energy consumption data is used to get insight of air-conditioning usage during summer and winter. In almost all dwellings, electricity consumption increases during the winter months (November-March) with its peak in January and in summer in July, associated with heating and cooling respectively.

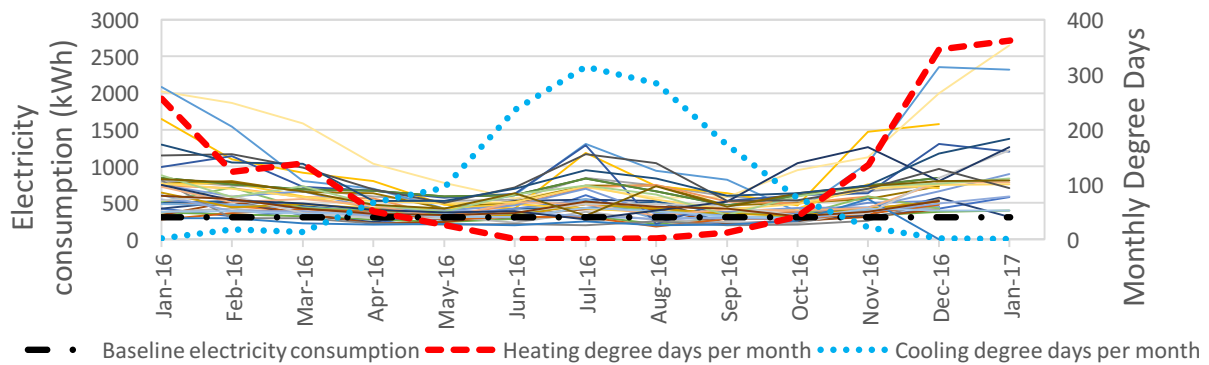


Figure 1. Electricity consumption from January 2016 to January 2017

Source of degree days: (www.degreedays.net, 2017)

43% of the dwellings are heated for half of the year and two of them are heated for as long as eight months of the year and most of the dwellings are cooled for three (20%) and four (45%) months of the year. Based on the baseline electricity consumption of 300kWh (ERE, 2009), needed in one household that does not perform heating or cooling with electricity, an estimation of electricity consumption used for heating and cooling of each dwelling in the sample.

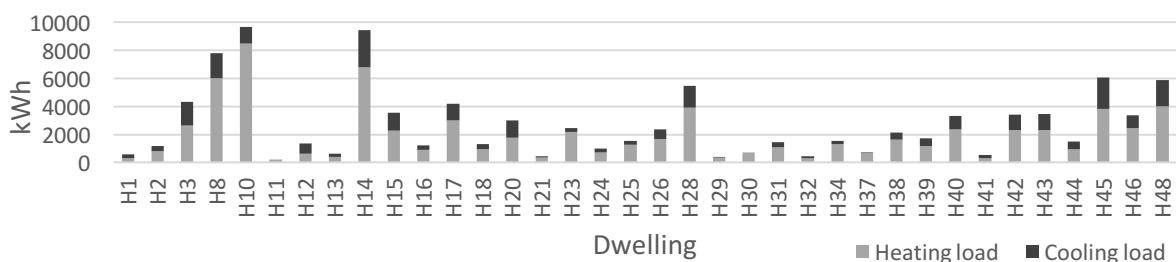


Figure 2. Estimated heating and cooling loads (kWh) based on electricity bills

Notwithstanding that energy data available include only electricity consumption, it can be noticed that most of energy consumed over the base load is for heating rather than cooling the homes. Furthermore, 65% of households also consider heating of their homes more important than cooling.

Temperature variations and thermal comfort in summer

The indoor temperature of 49 living rooms and 42 main bedrooms were monitored from 30 June to 12 August 2016 at half-hourly intervals, to cover the hottest season of the year in the Albanian climate. The outdoor temperature ranged between 19.6°C to 41.1°C, while the indoor temperature ranged from 19.5°C to 36.5°C in living rooms and 19.5°C to 37°C in bedrooms. The indoor temperatures were well above the recommended figures from the guidelines (23°C -25°C) (CIBSE, 2006). Even more, half of the dwellings had indoor temperatures constantly over 25°C. The dwellings that experience the highest temperatures, had the largest temperature variation.

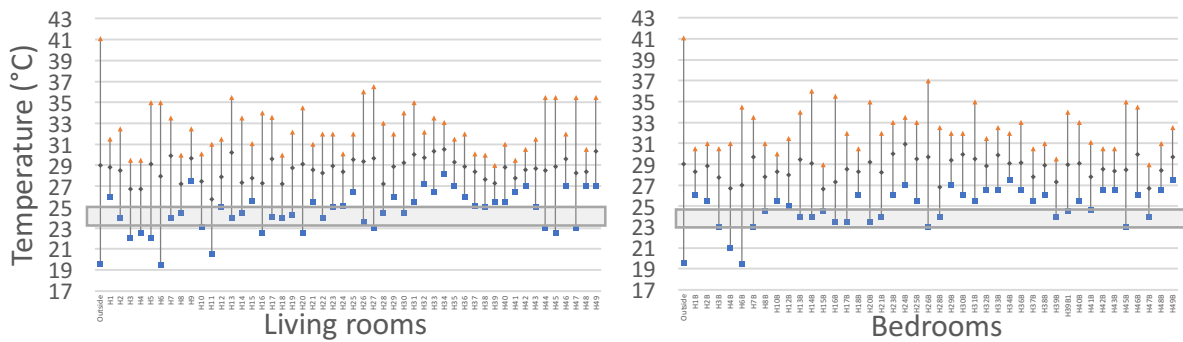


Figure 3. Minimum, maximum and mean temperatures for each dwelling during the summer

Subjective evaluation of the thermal environment was provided using a 7-point ASHREA scale for the thermal sensation evaluation and a 5-point scale for thermal preference. 86% of the households reported to feel warmer than neutral during the summer, from which more than 40% of them were feeling hot. Only 6% of the households required no change and approximately 60% wanted to feel much cooler.

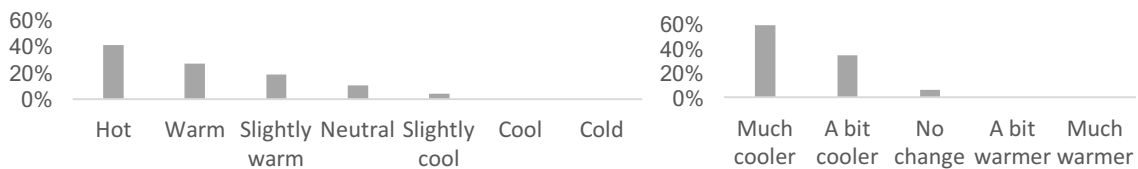


Figure 4. Percentage distribution of thermal sensation votes (left) and thermal preference votes(right)

The standardized indoor mean temperatures for each thermal sensation vote were calculated (Table 3), and it was found that occupants were feeling hot in an indoor mean temperature of 29°C (with a standard deviation of 1.1) and a maximum and minimum mean temperature of 30.5°C and 27.3°C respectively. The temperature range for the dwellings in which the households reported to be feeling warm or slightly warm were very similar. Interestingly, the occupants felt neutral for temperature close to the dwellings in which the resident were feeling hot. There were only two dwellings in which the occupants were feeling slightly cool, and indeed the mean, maximum and minimum temperatures were lower than in the other cases.

Table 3. Mean indoor temperatures of dwellings for each value of thermal sensation vote reported

How do you feel during the summer?														
Slightly warm			Neutral			Slightly cool			Cool			Cold		
Mean temperatures in living rooms														
Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
29.0	30.5	27.3	28.4	29.7	27.2	28.4	29.9	26.7	28.7	29.1	27.9	26.5	27.2	25.8
Standard Deviation														
1.1			0.8			1.2			0.5			1.0		

Temperature variations and thermal comfort in winter

The indoor temperature of 45 living rooms and 42 main bedrooms was monitored from 5 January to 16 February 2017 at half-hourly intervals, to cover the cold season. The outdoor temperature ranged between -5.5°C to 18.5°C, while the indoor temperature ranged from -

6°C to 29.5°C in living rooms and -5.5°C to 29.5°C in bedrooms. For most of the dwellings, the indoor temperature was below the recommended temperatures from the guidelines (22°C - 23°C) for living rooms and (17°C -19°C) for bedrooms (CIBSE, 2006). 19 out of 45 dwellings monitored did not reach temperatures 22°C or above. Some of the dwellings have registered temperatures close to the outdoor temperature, meaning that they have little or no heating at all and windows could possibly have been left open during the day. A very high temperature variation can be noticed in living rooms varying from 6.5 degrees (H39) to 33 degrees (H25), indicating a big problem in keeping the adequate thermal comfort in Albanian homes in winter. Moreover, the dwelling that had the largest indoor temperature variation, had recorded temperatures as low as 0°C to -6, which is the same as the outside temperature.

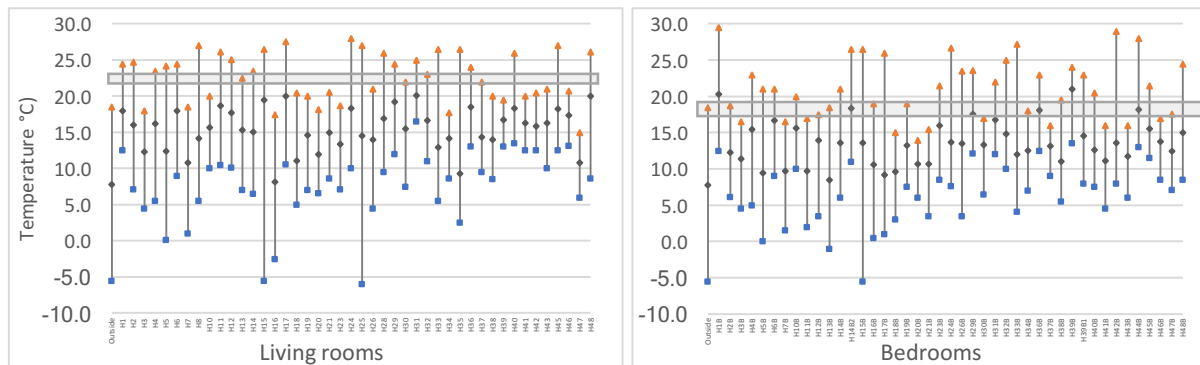


Figure 5. Minimum, maximum and mean temperatures for each dwelling during the winter

A considerable but low correlation ($r=0.33$) is found between the mean temperature and the main construction material. More importantly, the dwellings that had applied wall insulation had higher indoor mean temperatures, which highlights the need of fabric improvement for improvement thermal comfort in Albanian homes.

75% of the households reported to feel colder than neutral during the winter, from which 39% were feeling cold. Nearly half of them (49%) preferred to feel much warmer and 37% preferred a bit warmer. Only 12% of the participants were feeling neutral during the winter and 4% preferred no change of temperatures.

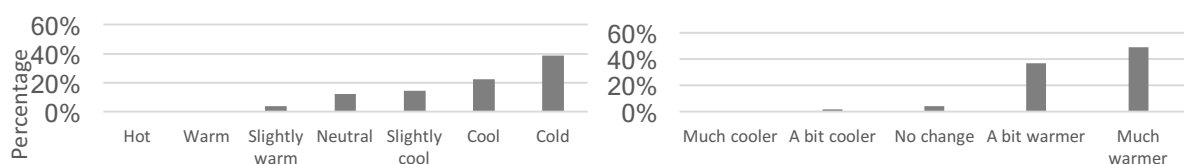


Figure 6. Percentage distribution of thermal sensation votes (left) and thermal preference votes(right)

Most of the occupants that were feeling cool or cold during the winter wanted the environment to be much warmer. Comparing the indoor mean temperatures for each thermal sensation vote (Table 4), it is found that occupants were feeling cold in an indoor mean temperature of 15.1°C (with a standard deviation of 3.1) and a maximum and minimum temperature of 20.1°C and 8.2°C respectively. However, there is not a large variation of indoor mean temperatures for which the occupants were feeling neutral, slightly cool or cool. The determinant factor for the thermal sensation votes distribution might be the value of the minimum mean temperature, which is higher for the dwellings in which the occupants were feeling slightly warm and neutral with values of 16.9°C and 10.8°C respectively.

Table 4. Mean indoor temperatures of dwellings for each value of thermal sensation vote reported
How do you feel during the winter?

Slightly warm			Neutral			Slightly cool			Cool			Cold		
Mean temperatures in living rooms														
Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
17.8	18.7	16.9	16	19.2	10.8	15.2	20.1	9.3	16	19.5	14	15.1	20.1	8.2
Standard Deviation														
1.3			3.3			4.1			2.0			3.1		

Human behaviour effect

Focus should be in different practices and behaviours related to comfort to understand the energy consumption of households (Gram-Hanssen, 2010). Air conditioning was the most popular cooling type in the sample and still, maximum mean temperatures exceeded the value of 30 degrees. This was mainly because localised cooling or heating were performed in all cases, most of the time using convective cooling and heating, which produced relatively lower temperatures in living rooms than bedrooms in summer and vice versa in winter. Residents tended to open windows in the morning, evening and night, due to the cool outdoor air. However, the dwellings with higher variation of temperature, had on average four months of cooling and dwellings with shorter cooling period had an indoor mean temperature variation between five degrees to eleven degrees. The indoor mean temperatures during the winter are relatively lower in bedrooms than in living rooms because bedrooms were mainly unheated. In some of the dwellings, internal doors of the bedrooms that had direct access in living rooms were kept open to circulate the air. However most of the time it was a localised heating.

"We can't afford to keep the electric oil filled radiator on all the time. So, we switch it on only when it is very cold and we cover it with a blanket, so we heat up quickly"

Most of the households turned the heating off as soon as the occupants achieved a temporary thermal comfort, to save energy. One resident said:

"We simply cannot afford to keep the air conditioning on all the time"

Most of the dwellings start to be heated in November and the heating is greatly on until March or April. Most of the dwellings are heated in morning and evening which is the time when they are fully occupied and there are no indecent solar gains. Only seven dwellings were heated during the nights and there are noticed higher main temperature in bedrooms of these dwellings compared with the ones that are not heated during the night. Most of the households opened the windows in the morning just for fresh air exchange. In contrast, in most of the dwellings that were heated all day, the indoor temperature was controlled by opening and closing the windows. There is a low correlation factor ($r=0.255$) between the type of heating and type of control. However, it is interesting to investigate whether certain control options are related to the types of heating. Indeed, using the convective cooling and heating systems can give the commodity to easily turn it on/off or change the temperature settings, while the heat produced from the wood stoves is more difficult to be controlled, making the resident opening the windows when it is too hot.

There are other considerations related to cultural norms for some of the families, especially those who live in detached houses (where the security issues are not a concern), to leave the door open for visitors and showing them their hospitality. Thermal preferences were also very different within some of the households. One female participant said:

“I want fresh air all the time and keep the windows open all day in summer and mostly in winter. I don’t care what my husband thinks or feels. He can get a blanket”

Table 5: Standardized indoor temperature in living rooms by behavioral practices in summer and winter

Summer						Winter					
	n	Mean	Max	Min	SD		n	Mean	Max	Min	SD
Main type of cooling / heating											
No cooling	2	27.2	28.6	25.8	2.0	Convective heating	31	15.4	20.1	10.1	3.4
Air conditioning	51	28.4	30.1	27.0	0.9	Wood stove	10	15.6	20.1	8.2	5.3
Electric cooler	7	29.5	30.5	28.2	0.9	LPG heater	4	16.3	18.0	14.2	1.9
How do you control the room temperature?											
No control	2	27.2	28.6	25.8	2.0	Open doors / windows	13	14.5	20.1	8.2	3.9
Open doors / windows	16	29.0	30.5	27.3	0.9	Turn the heating on / off	27	15.4	20.1	9.3	2.8
Turn the cooling on / off	26	28.5	30.3	26.7	1.1	Turn the heating up/down	5	14.0	14.0	14.0	.
Turn the cooling up/down	5	28.4	30.1	27.2	1.2						
When do you switch the cooling / heating on during the day?											
No cooling	3	28.5	30.5	25.8	2.4	Morning	1	16.6	16.6	16.6	.
Mid-day	1	28.8	28.8	28.8	.	Mid-day	1	18.0	18.0	18.0	.
Afternoon	17	28.6	30.3	26.7	1.1	Afternoon	5	15.0	19.2	9.3	4.1
Evening	3	28.4	29.3	27.2	1.1	Evening	6	15.7	18.4	14.2	1.6
Afternoon and evening	20	28.8	30.3	27.2	0.8	Morning and evening	16	15.8	20.1	8.2	3.3
All day	5	27.9	30.1	27.2	1.3	All day	6	16.8	20.1	12.4	3.0
						Afternoon and evening	10	14.5	18.7	10.8	2.7
Do you cool / heat the house during the night?											
No	36	28.8	30.5	26.7	1.0	No	38	15.7	20.1	8.2	2.9
Yes	13	28.1	30.3	25.8	1.3	Yes	7	15.2	20.1	9.3	3.7
When do you open the windows in summer / winter?											
Afternoon	2	28.8	28.9	28.7	0.1	Morning	41	15.6	20.1	8.2	3.1
Evening	2	29.5	30.3	28.7	1.1	Afternoon	1	14.7	14.7	14.7	.
During the night	2	26.5	27.2	25.8	1.0	All day	1	15.0	15.0	15.0	.
Morning and evening	21	28.5	29.9	26.7	1.0	When it is too hot	2	16.7	18.3	15.1	2.3
All day	8	29.1	30.2	28.2	0.8						
All day and night	5	29.2	30.5	27.3	1.3						
When the cooling is off	1	29.1	29.1	29.1	.						
Evening and night	8	28.2	29.7	27.2	0.9						

Discussion

It is revealed from this research that there were particularly bad thermal conditions in winter with very low temperatures and high fluctuation during the day up to 33 degrees. Convective cooling and heating was mainly used and it was used for longer period in winter than in summer, suggesting that heating was more crucial than cooling in Albanian houses.

Furthermore, cooling and heating were performed locally in all dwellings and for short periods of time during the day in most of them.

No significant correlation was found between indoor temperatures and building characteristics such as typology, year of construction and number of stories, apart from a weak correlation between indoor mean temperatures and the main construction material.

In summer, statistically similar temperatures were both reported as neutral and hot (around 29°C). However, only 10% was feeling neutral at this temperature, meaning that it could be related to individuals and their preferences. In addition, residents were feeling slightly cool for mean temperatures of 26.5°C. In winter, the occupants were feeling cold for temperatures 15°C and neutral for mean temperatures of 16°C. Economic factor was determinant for not being able to keep the house comfortable in summer and winter. However, cultural issues were associated with some behavioural practices which might be determined in achieving successful outcomes for future retrofitting projects.

Conclusion

The analysis carried out for this research provides evidence of the energy and thermal performance of residential buildings in Albania, as well as occupants' thermal perceptions and preferences. It was found that heating the Albanian dwellings is more crucial than cooling and a way to achieve energy savings is to aim to decrease the duration in months, especially for heating. Furthermore, special attentions to be considered for unintended consequences such as overheating, which could increase the energy consumption for cooling. Given these findings, it is essential to use them to inform and calibrate the baseline energy models, prior to investigating any retrofitting strategies, to minimise the performance gap created by assumptions and predictions.

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Appendix 2: Invitation letter for initial screening

Oxford Brookes University
Headington Campus
Oxford
OX3 0BP
UK
Tel: +44 (0) 1865741111



16 June 2016

LETTER OF INVITATION

Title of Study: Energy Efficiency of Residential Buildings in Albania
Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University
Faculty Supervisors: Prof. Rajat Gupta, Professor of Sustainable Architecture and Climate Change, Oxford Brookes University
Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

I am a research student from Oxford Brookes University in Oxford, UK. I am very interested in the energy performance of the existing residential stock in Albania and I am contacting you to invite you to take part in a research project called Energy Efficiency of Residential Buildings in Albania.

The research aims to find the most effective measures that can be applied to existing buildings in order to improve their energy performance and achieve energy and CO₂ emission reduction from housing in Albania. I hope to use the information from this research to define strategies that are not only technically-feasible, but also affordable and acceptable by householders. I have included an information sheet with this letter with information regarding the project.

Should you choose to participate, you will be asked to take part in an interview.

Moreover, you could benefit from being one of 60 home-owners taking part in the monitoring of your house in terms of indoor temperature for the hottest and coldest season of the year. The monitoring will involve the installation of a small device with the size of a coin in your main living area and bedroom, which will continuously capture the temperature every 30 minutes for two months during summer (July-August) and two months during winter (January-February). The investigator will also need your permission to do a building survey to gather information regarding construction and house layout.

At the end of the research, you will be provided with the results of the temperature monitoring and a summary report regarding energy use in your household.

However, in order to be selected for the house monitoring, could you please complete the questions below?

1 Do you own the house you're living at the moment? ☐ Yes ☐ No	8 Would you like your house to be monitored? ☐ Yes ☐ No
2 What type of building do you live in? ☐ Detached ☐ Semi-detached ☐ Terraced ☐ Flat	9 How many generations live in your household? ☐ 1 ☐ more than 1
3 When was your house built? ☐ Before 1980 ☐ 1981-1990 ☐ 1991-2011 ☐ After 2011 ☐ Don't know	10 What is the highest education level in the household? ☐ Elementary ☐ High school ☐ University degree
4 How many stories is your house/apartment building? ☐ 1 story ☐ 2 stories ☐ 3 stories ☐ 4-5 stories ☐ over 5 stories	11 What is your monthly income? ☐ less than €300 ☐ €300-€700 ☐ more than €700
5 What is the main construction material of your house/apartment building? ☐ stone ☐ block ☐ brick ☐ silicate brick ☐ Hollow brick ☐ prefabricated ☐ other (please specify)	12 What is the main energy type you use for heating? ☐ wood ☐ electricity ☐ gas ☐ other
6 Are you from Tirana? ☐ Yes ☐ No If No, please specify _____	13 How many persons live in the household in the following age group? Age 12 and less _____ Age from 13 to 18 _____ Age from 19 to 65 _____ Age more than 65 _____
7 When did you move in this house/flat?	

Thank you
Jonida Murataj (Jaupi)

Appendix 3: Information sheet

Oxford Brookes University
Headington Campus
Oxford
OX3 0BP
UK
Tel: +44 (0) 1865741111



INFORMATION SHEET

Study title

Investigating the Most Effective Retrofitting Strategies for Improving Comfort and Energy Use in Residential Buildings in Albania

Invitation paragraph

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

This PhD study aims to investigate the most effective retrofitting strategies for improving comfort and energy use in residential buildings in Albania and to inform stakeholders (designers, housing providers, homeowners and policymakers) on technical options for decarbonising existing residential stock that are affordable and accepted by homeowners.

By **effective** it is meant that strategies are:

- Technical feasible
- Economic feasible
- Acceptable in terms of cost, cultural and appearance

The research will focus on residential buildings in Albania. Representative housing archetypes will be defined, and different energy retrofitting strategies will be assessed for technical feasibility through dynamic thermal simulations; economic feasibility through cost-benefit analysis and acceptability through surveys and semi-structured interviews with the main stakeholders, in terms of costs, appearance and culture. There are 3 main stages to meet the objectives of the study as shown in the process chart below:

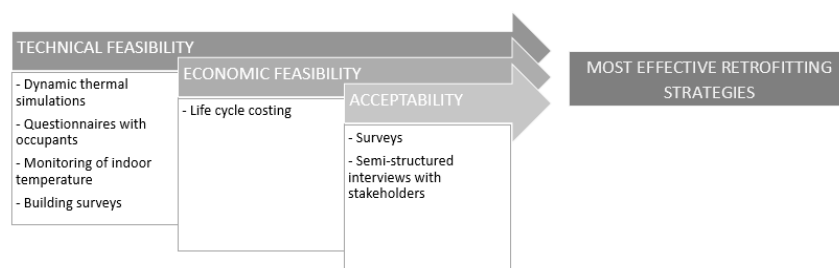


Figure 1: Outline of the methodology

Stage 1: Technical feasibility

Technical feasibility will be assessed for representative housing archetypes, using dynamic thermal simulation (such as IES or Design Builder), and informed by building surveys, monitoring of indoor temperature and semi-structured interviews with occupants (to understand how they use their homes) to develop validated baseline energy models. Actual energy use data will be collected for a selected

sample of dwellings, to validate the baseline energy models. Thereafter, a series of strategies for improving energy performance and thermal comfort in homes will be modelled first singularly, and then in combination..

Stage 2: Economic feasibility

Cost-benefit Analysis will be undertaken to assess the cost-effectiveness of each retrofitting measures. The level of retrofitting will be analyzed in order to have the maximum, cost-effective and optimum energy reductions as well as thermal comfort improvement.

Stage 3. Acceptability

The acceptability of the technical and economical results of each retrofitting strategies will be tested through semi-structured interviews with homeowners, mainly in terms of costs, appearance and cultural aspects including any cultural bearing that the social period of the house's construction period had on the families who lived in the houses.

Why have I been invited to participate?

You are chosen as a homeowner of a house that is be representative of the main archetypes of Albanian housing stock.

Do I have to take part?

It is up to you to decide whether to take part. If you do decide to participate, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

You can contribute to the research by answering the questions related to your house, whether you have undertaken any energy renovation of the house and if not, whether you would consider them in the future. Moreover, question about why you would consider one retrofitting strategy over the other will be asked. (These are some of the topics where the questions will be focused, however the full list of questions will be designed on the results of the stage 1 and 2 of the research).

The interview is estimated to take up to 1 hour. The information collected will serve to define the most effective retrofitting strategies that are technical and economic feasible, but also accepted by homeowners. However, it is up to you if you decide to participate or not. If you decide to take part you are still free to withdraw at any time and without giving a reason.

There are no 'costs' involved in taking part in this study.

What are the possible benefits of taking part?

You will benefit from the research by:

- Having a free of charge report with the most effective retrofitting strategies for your house, which you can use in case you want to energy renovate it in the future
- Increasing awareness on energy efficiency that will result on greater energy savings and lower fuel bills for your household

Will what I say in this study be kept confidential?

All the information collected will be kept strictly confidential, complying with the Data Protection Act 1998 in UK and following the University's Data Protection Policy and Guidelines. Before transferring to Oxford Brookes University, data will be stored in Google Drive, for which the University has a security agreement. Data will be coded with numbers instead of names to protect your identity and pseudonyms will be used for participants in the publishing of reports.

What should I do if I want to take part?

If you want to take part to the survey, you need to contact me in the contacts details provided at the top of this information sheet within 7-10 days.

What will happen to the results of the research study?

The results of the research will be used in my thesis for the degree of Doctor of Philosophy at Oxford Brookes University. The thesis will be available to the public after obtaining the degree. However, I will send you a copy of the published research immediately after it being available.

Who is organising and funding the research?

This research is self-funded research by a research student at:
Oxford Brookes University
School of Architecture
Faculty of Technology, Design and Environment.

Who has reviewed the study?

The research has been approved by the University Research Ethics Committee, Oxford Brookes University.

Contact for Further Information

Jonida Murataj

Email: 15005185@brookes.ac.uk

Mob:

If you have concerns about the way in which the study has been conducted, you should contact the Chair of the University Research Ethics Committee on ethics@brookes.ac.uk.

Thank you in advance for taking time to read the information sheet

Jonida Murataj

Date

Oxford Brookes University
Headington Campus
Oxford
OX3 0BP
UK
Tel: +44 (0) 1865741111



CONSENT FORM

Full title of Project: INVESTIGATING THE MOST EFFECTIVE RETROFITTING STRATEGIES FOR IMPROVING COMFORT AND ENERGY USE IN RESIDENTIAL BUILDINGS IN ALBANIA

Stage 1 of the research Code:

Name, position and contact address of Researcher:

Jonida Murataj
Research student
Oxford Brookes University

Headington Campus
Oxford
OX3 0BP
UK

	Please initial box	
1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.	☐	
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.	☐	
3. I agree to take part in the above study.	☐	
	Please initial box	
	Yes	No
4. I agree to the interview being audio recorded	☐	☐
5. I agree to the use of anonymised quotes in publications	☐	☐
6. I agree to the photographs being taken. I give permission for this data to be used by the research team for research purposes	☐	☐
7. I agree to the photographs being used in presentations and publications	☐	☐
8. I agree that researcher of this project can contact me in the future for follow up visits and to share study findings	☐	☐
9. I agree to return the monitoring device at the end of monitoring period	☐	☐
10. I agree to participate in the next stage of the research	☐	☐

Name of Participant

Date

Signature

Name of Researcher

Date

Signature

Appendix 4: Lighting, appliance and walkthrough templates

Oxford Brookes University
 Headington Campus
 Oxford
 OX3 0BP
 UK
 Tel: +44 (0) 1865741111



Title of Study: Investigating the most effective retrofitting strategies for improving comfort and energy use in residential buildings in Albania

Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University

Faculty Supervisors: Prof. Rajat Gupta, Professor of Sustainable Architecture and Climate Change, Oxford Brookes University

Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

FIELD WORK: PHASE 1 - JUNE 2016

[illegible]

OXFORD
BROOKES
UNIVERSITY

FIELD WORK: PHASE 1 - JUNE 2016

[illegible]

Oxford Brookes University
 Headington Campus
 Oxford
 OX3 0BP
 UK
 Tel: +44 (0) 1865741111



Title of Study: Investigating the most effective retrofitting strategies for improving comfort and energy use in residential buildings in Albania

Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University

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 Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

FIELD WORK: PHASE 1 - JUNE 2016

Walkthrough – Building Survey			
Contact Details			
Household ID:		Address:	
Respondent ID:			
Date/Time of Interview:		Telephone Number:	
Interview Room		Email:	
Introduction			
Good morning/afternoon: My name is Jonida Murataj from Oxford Brookes University in Oxford, UK. That's my identity card. Is this [Address], isn't it? We spoke on the phone [day of telephone conversation] and agreed to meet today at [time] to conduct the interview. Do you still want to take part in this interview? Everyone so far has enjoyed the interview and please remember that there are no right or wrong answers and no special knowledge is required. [Yes/No]. [If NO, be prepared to withdraw: That's fine. Thank you for your time.] [If yes, reassure they want to monitor the house as well and explain briefly what will happen:] So, to confirm, you also accepted to monitor the temperature in your house? Is this wright? [yes] Can we go somewhere where we can seat down? OK then, I will briefly explain to you what will happen today: We will start with a walkthrough around your house to gather information regarding the house layout, construction materials, appliances and lighting present in your house and information regarding when and by whom each room is used. This information will be used to inform the computer model in order to have the actual energy performance of your house. Then the devices will be placed in your living room and bedroom. With your permission, photographs that show different aspects of your house (appliances, lighting, controls, etc) will be taken. After that, you will complete a quick questionnaire survey. The whole process should not last longer than 30-40 min. Please remember that all information you will provide today will remain anonymous. In order to begin, can you please sign this consent form [give consent form to sign]. This is only to record the consent process and your agreement to take part in this research. ☒ Consent form signed			

WALKTHROUGH TEMPLATE**About your household**

I would like to thank you for answering the quick questionnaire you had with the initial invitation letter previously.
Can we just check a few of the details?

Questions		Interviewer's Notes
Q1.	So you are the owner of this house, right?	
Q2.	And it was built in [period/year]?	
Q3.	Did you move in this house when it was built, right? [You said previously that you moved in this house in (year)]?	

[Additional comments]

General information

Questions				Interviewer's Notes
Q4.	What is the main construction material of your house?			
Q5.	Building elements composition?			
	External walls	Layers	Thickness	
	Roof			
	Floor			
Q6.	What type of heating do you have in your house?			
Q7.	What type of fuel does it use?			

Q8.	How do you control the heating temperature in your house?								
Q9.	Can you tell me, what is your main type of cooling?								
Q10.	And...what type of energy does it use?								
Q11.	How do you control the cooling temperature in your house?								
Q12.	How do you provide hot water in your household?								
Q13.	When and for how long do you usually go for holiday?								
Q14.	Can I ask how many bedrooms there are, and there are [] floors?								
Q15.	Draw a schematic plan								
Walkthrough - Room by Room									
Questions				Interviewer's Notes					
Room 1 (link with the plan)									
Room's Dimensions									
No. of windows									
Window's dimensions									
Window's type									
Q16.	Can I ask you about some information regarding the usage of this room, as well as how you heat and cool it?			(Function of the room?)					
	Days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	

	Time of day % of occupancy							
	Heating? Time?							
	Cooling? Time?							
	What time do you open the window?							
	When is the hob/oven ON and for how long?(gas or electric?)							
	How many dishwasher loads are done and when?							
	How many baths/ showers are there?							
	When and for how long is the TV/entertainment used?							
	When and for how long is the TV/entertainment used?							
	Anything unusual this week?							
Q17.	What type of heating?			What type of cooling?				
Q18.	Do you use secondary heating in this room?			Do you use secondary cooling in this room?				
Walkthrough - Room by Room								
Questions				Interviewer's Notes				
Room 2 (link with the plan)								
Room's Dimensions								
No. of windows								
Window's dimensions								
Window's type								
Q19.	Can I ask you about some information regarding the usage of this room, as well as how you heat and cool it?			(Function of the room?)				
	Days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	Time of day % of occupancy							

	Heating? Time?							
	Cooling? Time?							
	What time do you open the window?							
	When is the hob/oven ON and for how long?(gas or electric?)							
	How many dishwasher loads are done and when?							
	How many baths/ showers are there?							
	When and for how long is the TV/entertainment used?							
	When and for how long is the TV/entertainment used?							
	Anything unusual this week?							
	Q20.	What type of heating?	What type of cooling?					
	Q21.	Do you use secondary heating in this room?	Do you use secondary cooling in this room?					

Appendix 5: Occupant's survey

Oxford Brookes University
Headington Campus
Oxford
OX3 0BP
UK
Tel: +44 (0) 1865741111



Title of Study: Investigating the most effective retrofitting strategies for improving comfort and energy use in residential buildings in Albania

Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University

Faculty Supervisors: Prof. Rajat Gupta, Professor of Sustainable Architecture and Climate Change, Oxford Brookes University
Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

FIELD WORK: PHASE 1 - JUNE 2016

OCCUPANTS' SURVEY		
...OK, so now we have completed the site survey, it would be great if you could let me place the temperature monitoring devices in your living room and bedroom. They are called iButtons and are used to continuously measure and store the temperature. In this case, I have adjusted them to monitor the temperature every 30 minutes for two months. Here you've got a leaflet with detailed information on how this device operates. [Give the leaflet]. It can be attached to a piece of furniture using this kind of adhesive [show Bluetack], which can be completely removed at the end of the monitoring period and doesn't leave any mark on your furniture. [Find the appropriate spot for placing the iButton] Is it OK with you if I place it here? It will not disturb you in any way, however, if you at any point don't want to keep it anymore, please let me know and I will remove it. ...now that we finished with the walkthrough, shall we seat again and start with the interview? I want to assure you again, that the information I am collecting today and your opinions will be confidential.		
MEASURES UNDERTAKEN IN YOUR HOUSE/FLAT		
May we start with the measures you have undertaken in your house/flat or that you intend to apply in the future?		
Question		Interviewer's notes
Q1.	Have you ever undertaken any retrofitting measures to your house/flat since you moved in?	* Yes * No [If No, go to question Q12]
Q2.	Have you applied any of the measures listed below? * Efficient lighting * Energy-efficient appliances * Thermal insulation of external walls * Double glazing * Triple glazing	* Thermal insulation of hot water installations * Floor thermal insulation * Roof thermal insulation * Renewable energy * None * Other (Please, specify)
Q3.	Why did you undertake that specific measure?	
Q4.	What would be the reason that you wouldn't compromise for installing the energy-saving improvements?	

Q5.	...if I can ask you, how much did the renovation cost?	
Q6.	Do you think it was affordable for you?	
Q7.	Has the installation of energy-saving improvements in your house influenced your behaviour in any way?	[How?]
Q8.	Do you think you adapted to this change?	[If No, why?]
Q9.	Is there any aspect of the energy-saving improvements in your home that you dislike?	
Q10.	Do you like its appearance?	
Q11.	Do you think you made the right decision for installing them?	
[Additional comments]		
Question		Interviewer's notes
Q12.	You said you haven't got any energy-saving improvements to your home, is there any particular reason?	
Q13.	Are you planning to renovate your house? If No, is there any particular reason stopping you from doing so?	[If No, go to question Q21] [If economic reasons, would you renovate if the government would help you financially?]
Q14.	What measures are you planning to undertake?	
Q15.	Is there any particular reason to do this energy-saving improvement?	
Q16.	Is there any reason you can think of that could prevent you to undertake this energy-saving improvement?	
Q17.	How much could you afford to spend?	
Q18.	Would you undertake more energy-saving improvements if the government would financially help you?	
Q19.		

	What measure do you think would be the best in improving the energy performance of your house?	
Q20.	Why would you choose one measure over the other options?	
COMFORT IN WINTER/HEATING/CONTROLS		
Question		Interviewer's notes
Q21.	When do you usually start heating your house [month]?	
Q22.	When do you usually stop heating your house [month]?	
Q23.	Do you heat your house during the night?	
	How do you feel in your home in winter?	
Q26.	Do you have a sense of airflow when the windows are closed during the winter?	[Yes, No, Only when it is windy outside]
Q27.	Do you open the window or doors when the heating is on?	[If Yes, why?]
Q28.	Specify the main pieces of clothing you typically wear within your house in the winter.	
Q29.	Do you think the bills to heat your house are affordable?	
[Additional comments]		
COMFORT IN SUMMER/COOLING/CONTROLS		
Questions		Interviewer's Notes
Q30.	When do you usually start to cool down your house [month]?	
Q31.	When do you usually stop to cool down your house [month]?	
Q32.	Do you cool down your house during the night?	
	How do you feel in your home in summer?	
Q33.	How do you feel right now?	How would you prefer it to be?
	Hot	Much warmer
	Warm	A bit warmer
	Slightly warm	No change
	Neutral	A bit cooler
	Slightly cool	Much cooler
	Cool	
	Cold	
Q34.	Overall, how would you rate the comfort of your home environment during summer? Consider indoor temperature, humidity, and air quality.	
	Very uncomfortable	
	Moderately uncomfortable	

	Slightly uncomfortable	
	Acceptable	
	Slightly comfortable	
	Moderately comfortable	
	Very comfortable	
Q35.	Do you open windows in your house during summer?	
Q36.	When and how long do you usually open the windows in your house during the summer?	
Q37.	Do you open the window or doors when the cooling is on?	[If yes, why?]
Q38.	Specify the main pieces of clothing you typically wear within your house in the summer.	
Q39.	Do you think the bills to cool down your house are affordable?	
Q40.	What would you say is more necessary for your house: heating or cooling? Why?	
[Additional comments]		
LIGHTING AND APPLIANCES		
Questions		Interviewer's Notes
Q41.	Do you leave the light on in an unoccupied room?	
Q42.	Do you buy low-consumption light bulbs when you replace a bulb? [If No, why?]	[If No, why?]
Q43.	Do you usually check the energy label when purchasing a new appliance?	[If No, why?]
[Additional comments]		
ENERGY BEHAVIOUR		
Questions		Interviewer's Notes
Q44.	Do you know what is global warming/climate change?	[If Yes, could you describe what you understand by that? If No, give a brief explanation]

Q45.	*How concerned are you about global warming/climate change? **That the energy will run out in the future? ***That energy prices will increase? Why?	[why?]			
		*	**	***	
	Very concerned				
	Fairly concerned				
	Not very concerned				
	Not at all concerned				
	No opinion/not stated				
Q46.	Do you think it is important to reduce energy use in your house?	[Why?]			
Q47.	Do you feel capable of reducing energy use in your house?	[If No, why?]			
Q48.	What would help you to achieve energy reductions in your house?				
Q49.	Have you ever received any information about ways of reducing energy use in your home?	[If Yes, do you think it has changed the way you use energy?]			
Q50.	Do you think you have got enough information and knowledge to help you reduce energy use in your home?				
Q51.	How would you describe your behaviour towards energy use with one word?				
[Additional comments]					
INVOLVEMENT WITH COMMUNITY					
Questions		Interviewer's Notes			
Q52.	Do you usually financially contribute when repair work needs to be done in your community?	[Why?]			
Q53.	Are you aware of any climate change/energy-related projects in your community?	[If No, do you think there is no project going on, or do you feel you are not informed?] [If Yes, were you involved in that project? How?]			
Q54.	If it was an energy-related improvement in your community that would benefit you, would you consider financially contributing?	[If No, why? If Yes, how much?]			

[Additional comments]

Interview close	Interviewer's Notes
I think this is the end of this interview. Thank you very much for taking part. I'd like to ask you if you've got any other comments to add. [If No] Ok then, I want to reassure you that the interview will remain confidential. I will see you again after 2 months to collect the monitoring devices. I will also remind you one day before my visit. Thank you again and goodbye!	

Oxford Brookes University
 Headington Campus
 Oxford
 OX3 0BP
 UK
 Tel: +44 (0) 1865741111



Title of Study: Investigating the most effective retrofitting strategies for improving comfort and energy use in residential buildings in Albania

Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University

Faculty Supervisors: Prof. Rajat Gupta, Professor of Sustainable Architecture and Climate Change, Oxford Brookes University
 Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

FIELD WORK: PHASE 2 – JANUARY 2017

OCCUPANTS' SURVEY			
...I will need to place the temperature monitoring device in the same places as during the summer. Will that be Ok with you? Again, it will not disturb you in any way, however, if you at any point don't want to keep it anymore, please let me know and I will remove it. ...now, may I ask you a couple of questions thermal comfort in your home in winter? We have covered most of the questions on the last field study in summer, so, today will be very quick. I want to assure you again, that the information I am collecting today and your opinions will be confidential.			
MEASURES UNDERTAKEN IN YOUR HOUSE/FLAT			
May we start with the measures you have undertaken in your house/flat or that you intend to apply in the future?			
Question		Interviewer's notes	
Q1.	Have you ever undertaken any retrofitting measures to your house/flat since summer?	* Yes * No [If No, go to question Q2]	
COMFORT IN WINTER/HEATING/CONTROLS			
Question		Interviewer's notes	
Q2.	When do you usually start heating your house [month]?		
Q2.	When do you usually stop heating your house [month]?		
Q.	Do you heat your house during the night?		
	How do you feel in your home in winter?		
Q24.	How do you feel right now?	How would you prefer it to be?	
	Hot		Much warmer
	Warm		A bit warmer
	Slightly warm		No change

	Neutral		A bit cooler	
	Slightly cool		Much cooler	
	Cool			
	Cold			
Q25.	Overall, how would you rate the comfort of your home environment during winter? Consider indoor temperature, humidity, and air quality.			
	Very uncomfortable			
	Moderately uncomfortable			
	Slightly uncomfortable			
	Acceptable			
	Slightly comfortable			
	Moderately comfortable			
	Very comfortable			
Q26.	Do you have a sense of airflow when the windows are closed during the winter?	[Yes, No, Only when it is windy outside]		
Q27.	Do you open the window or doors when the heating is on?	[If Yes, why?]		
Q28.	Specify the main pieces of clothing you typically wear within your house in the winter.			
Q29.	Do you think the bills to heat your house are affordable?			
[Additional comments]				
Interview close		Interviewer's Notes		
I think this is the end of this interview. Thank you very much for taking part. I'd like to ask you if you've got any other comments to add. [If No] Ok then, I want to reassure you that the interview will remain confidential. I will see you again after 2 months to collect the monitoring devices. I will also remind you one day before my visit. Thank you again and goodbye!				

Appendix 6: Semi-structured interviews with homeowners

Oxford Brookes University
Headington Campus
Oxford
OX3 0BP
UK
Tel: +44 (0) 1865741111



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Principal Investigator: Jonida Murataj (Jaupi), research student, Faculty of Technology, Design and Environment, Oxford Brookes University

Faculty Supervisors: Prof. Rajat Gupta, Professor of Sustainable Architecture and Climate Change, Oxford Brookes University
Prof. Fergus Nicol, Professor Emeritus of Architecture, Oxford Brookes University

	INTERVIEW WITH HOUSEHOLDS		OXFORD BROOKES UNIVERSITY
	Code:		
INTRODUCTION			
Introduce yourself: Thank you very much for giving your time to take part in this interview today. I am a PhD student from Oxford Brookes University in Oxford, UK and I am conducting a research study that aims to find the most effective measures that can be applied to existing domestic buildings in order to improve their energy performance and improve indoor environment in housing in Albania. This is the last stage of the research, where a series of measures will be tested for their acceptance by householders and other stakeholders who have an interest in improving the performance of domestic buildings. Before we begin, can you confirm that you are the homeowner of the house you are living in? (If yes, continue the interview, if not, thank the participant and stop the interview) If yes, explain the content of the interview: The estimated time required to complete the interview will be 30-40 minutes. If you feel uncomfortable with any of the questions or you don't want to answer it, it will be skipped. The interview can be stopped at any time if you want to. However, the questions are not intended to affect you in any way. PLEASE REMEMBER TO SAY WHAT YOU REALLY THINK FOR EACH QUESTION! Also, please remember that all the information gathered during this interview will be kept strictly confidential. If you are happy with everything, can you please sign this consent form and we can begin.			
Consent form signed ☐		Audio equipment switched on ☐	
Total time for session: 5mins		Overall time: 5mins	

If the household is from the 49 households sample, go to section E

A. QUESTIONS ABOUT YOUR HOUSEHOLD		
NO	Question	Answers (Interviewer notes)
1.	Do you live in urban or rural area?	
2.	What type of building do you live (detached, semi-detached, terraced, flat) and do you know what year it was built (Before 1960, 1961-1990, after 1991)?	
3.	May I ask how many bedrooms there are? And how many floors? (If it's a flat, what floor is the flat located?)	
4.	How many people live in your household? Any of them children?	
5.	How many people are working?	
6.	May I ask, what is your average monthly income?	

	- Up to €300 €300-€500 - More than €500?	
7	In terms of energy use in your house, may I ask how much you pay monthly for electricity, gas, other?	
Additional comments:		
Total time for session: 5mins		Overall time: 10mins

B. QUESTION ABOUT SPACE HEATING		
NO	Question	Answers (Interviewer notes)
8	Do you heat your house during the winter? <i>(if not, can you give me the reason/reasons for not doing that?)</i>	
9	What type of fuel do you use for heating? (electricity, gas, wood)	
10	What type of heating do you have in your house? (AC inverter split, stove, fireplace, electric heater, central heating in the building, separate central heating in the dwelling, other?) a. When it was installed? b. Which rooms in the house are heated by this type of heating?	
11	Do you use any additional heating type? a. Which rooms in the house are heated by this type of heating? b. How often do you use it?	
12	When do you heat the house? a. Times during the day? b. Times during the night? c. What months?	
13	Does the room ever overheat when heating is on? <i>If yes, what action do you take?</i>	
14	May I ask you how do you find temperatures in your house in winter? Hot Warm Slightly warm Neutral Slightly cool Cool cold <i>(is this in the whole house, or only living room? What about the other rooms?)</i>	
Additional comments:		
Total time for session: 5mins		Overall time: 15mins
C. QUESTION ABOUT SPACE COOLING		
NO	Question	Answers (Interviewer notes)
15	Do you cool your house during the summer? <i>(if not, can you give me the reason/reasons for not doing that?)</i>	
16	What type of cooling system do you have in your house? (AC split, electric cooler, Chiller-Fan coil, other?) c. When it was installed? d. Which rooms in the house are cooled by this type of cooler?	
17	Do you use any additional cooling type? c. Which rooms in the house are cooled by this type of cooler?	

	d. How often do you use it?	
18	When do you cool the house/flat? d. Times during the day? e. Times during the night? f. What months?	
19	What do you do when the room is overheated? (What about when you have turned the cooling on and is still overheated?)	
20	May I ask you how do you find temperatures in your house in summer? Hot Warm Slightly warm Neutral Slightly cool Cool cold (again, is this in the whole house, or only living room? What about the other rooms?)	
Additional comments:		
Total time for session: 5mins		Overall time: 20mins

D. QUESTION ABOUT WINDOW OPERATION		
NO	Question	Answers (Interviewer notes)
21	When and for how long do you open the windows in winter? a. Where are these windows located – bedroom, living room etc? b. May I ask whether do you open them when heating is on? c. Do you open all windows, or just the room's you spend most of the time?	
22	When and for how long do you open the windows in summer? a. And, do you open them when cooling is on? b. Again, do you open all windows? c. Do you open windows during the night? (if not, what is the reason?)	
Additional comments:		
Total time for session: 3mins		Overall time: 23mins
E. QUESTION ABOUT HOME IMPROVEMENTS		
NO	Question	Answers (Interviewer notes)
23	Have you ever renovated your house, since you moved in? (if not, skip questions ---- to -----) If yes continue with the questions:	
24	What measures have you applied? When they were installed? What was the main reason that you installed them? Where did you hear about that measures? How much did the renovation cost approximately?	
25	Have you seen any improvement in your house by installing this/those energy improvement measurements? a. In terms of energy savings b. In terms of comfort c. In terms of energy behaviour? (if not, why do you think this has happened?) If yes, ask the questions: a. What changes have you noticed?	

26	Why is it that you have never installed any energy saving measures? (wait for answer and then, ask: What would make you consider installing any of them?	
27	Will you be willing to install other energy saving measures? <i>If not, why?</i>	
Additional comments:		
Total time for session: 10mins		Overall time: 33mins
F. QUESTION ABOUT HOME IMPROVEMENTS MEASURES AND PACKAGES PROPOSED IN THIS STUDY		
NO	Question	Answers (Interviewer notes)
28	You said that you intent to improve the energy performance of your home, what is your motivation for doing so? • Cost • Energy reduction • Comfort improvement • Health benefits • Aesthetics • Etc?	
29	You said that you intend to apply some energy saving measures, would you do single measures (ex. Wall insulation, roof insulation, floor insulation, change of windows, change the heating/ cooling split device to a better efficiency, or would you consider applying package of measures? <i>(Leave question open)</i>	
30	Why would you choose that measure/package? <i>(Leave question open)</i>	
31	What is the reason for choosing single measures, instead of packages (or via verse)? <i>(Leave question open)</i> <i>What would you make change your mind?</i>	
32	What is the main reason that would make you install energy saving measures? <i>(Leave question open)</i>	
33	Is there any reason that would make you not choose any of the above measures? <i>(Leave question open)</i>	
34	You are saying that the reason is to reduce energy consumption, then, based on the results of this study, which of the measures would you chose focusing in only energy reduction for heating and cooling? a. 5cm external wall insulation Possible energy reduction up to 40% based on the archetype b. 10cm external wall insulation Possible energy reduction up to 52% c. Window replacement with double glazed Possible energy reduction up to 33% d. 12cm roof insulation Possible energy reduction up to 30% e. 5cm floor insulation Possible energy reduction up to 21% f. Upgrade of split system Possible energy reduction up to 35% g. 5cm external wall insulation and double glazing windows Possible energy reduction up to 68% h. 5cm wall insulation, floor and roof insulation, double glazing and better efficiency split system Possible energy reduction up to 80%	

	<i>All these measures would improve significantly the indoor temperatures in winter with mean temperature above 18°C and in Summer below 28°C.</i>	
35	You said that cost is the main reason for not undertaking any of the measures/ packages. Have you got any information what would be the cost for installing the above measures? <i>(Leave question open)</i>	
36	What if I give you an approximate investment costs that are needed per measure by unit area that include also labour costs and VAT? Would you consider any of the installations? a. 5cm external wall insulation Average cost is 14EUR/m² b. 10cm external wall insulation Average cost is 18EUR/m² c. Window replacement with double glazed Average cost is 20EUR/m² floor area d. 12cm roof insulation Average cost is 18.50EUR/m² e. 5cm floor insulation Average cost is 11.50EUR/m² f. Upgrade of split system Average cost is 42EUR/m² g. 5cm external wall insulation and double-glazing windows Average cost is 25-30EUR/m² h. 5cm wall insulation, floor and roof insulation, double glazing and better efficiency split system Average cost is 80-100EUR/m² For example, for a 70m² house the average investment cost would be: a. 5cm external wall insulation Average cost is 2,000EUR b. 10cm external wall insulation Average cost is 2,700EUR c. Window replacement with double glazed Average cost is 1,400EUR d. 12cm roof insulation Average cost is 1,300EUR e. 5cm floor insulation Average cost is 800EUR f. Upgrade of split system Average cost is 800EUR/UNIT g. 5cm external wall insulation and double-glazing windows Average cost is 3,400EUR/m² h. 5cm wall insulation, floor and roof insulation, double glazing and better efficiency split system Average cost is 6,500EUR The cost of measures and packages in the case of flats would be considerably less, due to the less external walls and having to insulate only one roof and floor area.	
37	You are saying that you cannot afford the investment costs. How much would you be able to pay?	
38	Because you live in a flat, undertaking these measures will require the association of all households in the apartment block. Do you think this will be achievable? What would be the main barrier in this case?	
Additional comments:		
Total time for session: 15mins		Overall time: 48mins

A. CLOSING THE INTERVIEW		
NO	Question	Answers (Interviewer notes)
39	Just wanted to ask if you have anything to add, that was not questioned in this interview, which you think would be relevant?	
Thank you very much. I appreciate your participation, and I wanted to reaffirm that everything said in this interview will be confidential. Thank you very much again and have a good day!		
Total time for session: 5mins		Overall time: 53mins