The investigation of energy efficiency measures in traditional buildings in the Oporto World Heritage Site

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The investigation of energy efficiency measures in the traditional buildings in Oporto World Heritage Site

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Abstract

Background

The improvement of energy efficiency in buildings is widely promoted as a measure to mitigate climate change through the reduction of CO_2 emissions. Thermal regulations worldwide promote it, for both new and existing buildings. Among the existing stock, traditional and historic buildings pose the additional challenge of heritage conservation. Their energy efficiency upgrade raises the risk of provoking negative impacts on their significance.

Aims and Methodology

This research used an approach based on impact assessment methodologies, defining an inital baseline scenario for both heritage and energy, from which the appropriate improvement solutions were identified and assessed. The measures were dynamically simulated and the results for energy, CO_2, cost and comfort compared with the initial scenario, and then being further assessed for their heritage impact to eventually determine the most feasible solutions. To test this method, ten case studies, representative of the identified typological variants, were selected among Oporto's traditional buildings located in the World Heritage Site.

Findings and Conclusions

The fieldwork data revealed that the energy consumption of these dwellings was below the European average. Additionally, the households expressed that their home comfort sensation was overall positive. The simulations showed that the introduction of insulation and solar thermal panels were ineffective on these cases in terms of energy, cost and comfort. At the same time, these measures pose a great risk to the buildings' heritage value. The most efficient solutions were obtained from behavioural changes and DHW retrofit. The study reinforced the idea that traditional buildings performed better than expected and can be retrofitted and updated at a low-cost and with passive solutions. The use of insulation and solar panels should be disregarded.

Key words: traditional buildings, heritage, energy efficiency upgrade, Oporto, World Heritage Site

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Preface

Personal Background

This research started from the professional and academic interest in heritage and sustainability, combined in the field of traditional and historic building refurbishment. The personal background related with this thematic started with an architecture graduation thesis that addressed the refurbishment project of the historic *Barcelos* City Hall, covering constructions from the fourteenth to twentieth centuries. The professional and academic careers have since been related with the urban and architectural refurbishment design projects.

The Master degree thesis (2000) addressed the planning and management of conservation of historic Portuguese city centres. After some years as an architecture professional, the work in the Oporto City Council Architectural Record consolidated the interest in traditional urban buildings, with focus on Oporto's historic centre.

As an academic, the practice as lecturer of 'Urban Design' and 'Sites Regeneration' in the Architecture Course of Oporto Superior Arts School (ESAP), lead to the research and interest in the sustainable city. From then, the academic objective was focused on urban and architectural conservation as strategies for achieving urban sustainability. This approach was presented in 2001, through a communication at the 6th Symposium of World Heritage Cities (Flores, 2002) and constitutes the conceptual basis of the current research.

List of Acronyms

3D - Three dimensional

ADENE - *Agência para a Energia* - Portuguese Energy Agency

AIP - *Área de Intervenção Prioritária* - Priority Intervention Area

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

BIM - Building Information Model

BPIE - Buildings Performance Institute Europe

BRE - Building Research Establishment

BREEAM - Building Research Establishment Environmental Assessment Methodology

CAD - Computer Aided Design

CCHP - Combined Cooling, Heat and Power

CFD - Computational Fluid Dynamics

CFL - Compact Fluorescent Lamps

CHP - Combined Heat and Power

CO2 - Carbon Dioxide Emissions

CRUARB - *Comissariado de Renovação Urbana da Área Ribeira-Barredo* - *Ribeira-Barredo* Urban Renewal Committee

DHW - Domestic water heating

DIY - Do-It-Yourself

DSM - Demand side management

DTM - Digital Terrain Model

EC - European Commission

EDP – *Energias de Portugal* - Portuguese Energy supplier

EEA - European Environment Agency

EH - English Heritage

EIA - Environmental Impact Assessments

EPBD - Energy Performance of Buildings Directive

EPI - Energy Performance Index

EPIMAX - Maximum allowed Energy Performance Index

ERSE – *Entidade Reguladora dos Serviços Energéticos* - Portuguese Energy Regulatory Authority

EU - European Union

EU27 - Twenty seven European Union states

GHG - Greenhouse gas

GIS - Geographic Information System

HIA - Heritage Impact Assessments

HVAC - Heating, Ventilating and Air Conditioning

ICOMOS - International Council on Monuments and Sites

IGESPAR - *Instituto de Gestão do Património Arquitectónico e Arqueológico* - Portuguese Architectural and Archaeological Heritage Institute

IPMA – *Instituto Português do Mar e da Atmosfera* - Portuguese Weather Institute (former IM - *Instituto de Meteorologia*)

IPCC - Intergovernmental Panel on Climate Change

ISO - International Standards Organization

LCA - Life Cycle Analysis

LEED - Leadership in Energy and Environmental Design

LiderA - *Liderar pelo Ambiente para a construção sustentável* – Leading for the Environment towards a sustainable construction (Portuguese sustainable buildings scoring system)

nZEBs - nearly Zero Energy Buildings

NZEB - Net Zero-Energy Buildings

OUV - Outstanding Universal Value

PCM - Phase Change Materials

PMV - Predicted Mean Vote

PPD - Predicted Percentage of Dissatisfied

POE - Post-Occupancy Evaluation

Porto Vivo SRU – *Porto Vivo Sociedade de Reabilitação Urbana* - Oporto Urban Renewal Company

RCCTE - *Regulamento das Características do Comportamento Térmico dos Edifícios* - Portuguese Buildings thermal performance regulation

RES - Renewable Energy Sources

ROI - Return Of the Investment

RUTE - *Rede Urbana de Energia Térmica* – Oporto Thermal Energy Urban Network

SCE - *Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios* – Portuguese national energy performance certification scheme

SI - International System of Units

SPAB - Society for the Protection of Ancient Buildings

TND - Traditional Neighbourhood Design

UK - United Kingdom

UNESCO - United Nations Educational, Scientific and Cultural Organization

USA - United States of America

USDOE - United States Department of Energy

WEC - World Energy Council

WHS - World Heritage Site

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Chapter One: Introduction

Chapter One: Introduction

1.1 - Background

The consequences of unsustainable development are today evident through climate change, which is emerging as the major environmental problem posed to humanity. Global warming is the most referenced consequence associated with it, leading the United Nations Intergovernmental Panel on Climate Change (IPCC) to state in its fourth assessment that, to avoid catastrophic changes, it is necessary to keep the global average temperature rise below 2°C, as compared to the year 2000 levels (IPCC *et al.*, 2007). On a political level, this target was adopted by the Ministers of the European Union, who declared it a major climate change mitigation objective to be met (EC, 2005).

In Portugal, the SIAM and SIAM II Projects have estimated major weather changes in their scenarios (Aguiar *et al.*, 2002; Santos *et al.*, 2002; Santos and Miranda, 2006). These studies forecast a significant increase in temperature until 2100, with Portuguese mainland summer temperatures rising an average of 3°C at the seaside and 7°C in the inland. Associated changes include an increase in the intensity and frequency of heat waves, number of hot days[1] and tropical nights[2], a decrease in the occurrence of cold days[3] and a reduction of the rainy season of 20% to 40%, compared to current levels, in particular during spring and autumn. The main impacts of these scenarios include predictable changes in the flood and drought regimes, a significant increase in the risk of fire hazards, air pollution levels and ecological disturbances, leading further to health problems and regional variations in agricultural productivity. A rise of erosion processes with a consequent increase in flooded areas and coastal erosion is also predicted to be severe (Ferreira *et al.*, 2008; Santos *et al.*, 2002; Santos and Miranda, 2006). The economic consequences for tourism will also be felt due to Portugal's economic dependence on that sector (CLITOP, 2007).

[1] - Defined as days with temperatures above 35°C.

[2] - Defined as nights with temperatures above 20°C.

[3] - Defined as days with temperatures under 0°C.

Greenhouse gas (GHG) emissions, from natural or anthropogenic sources, are now widely accepted as the cause for global warming (IPCC *et al.*, 2007). It is internationally recognised that the mitigation of this environmental problem must be addressed, especially in the area of man-made actions, which produce the main gases included in the GHGs. This is specifically addressed in the Kyoto Protocol, which has established international targets for the reduction of the GHGs (IPCC *et al.*, 2007; Stocker *et al.*, 2010; UN, 1998).

1.1.1 – Carbon Dioxide Emissions (CO_2)

Of all the gases contributing to the 'enhanced greenhouse effect', CO_2 is the most relevant, for 76.7% of the total composition of GHG emissions in 2005 (IPCC *et al.*, 2007). The European Environment Agency (EEA) confirms this for the European Union (EU) as well, with CO_2 accounting for 81.6% of the total emissions of the 27 member states (EU27) in 2009 (EEA, 2011a; EEA, 2011c). Accordingly, the Portuguese Environment Report of 2011 reveals that CO_2 represented 75.2% of the total national emissions in 2009 (EEA, 2011c; Vilão *et al.*, 2011). Due to the evident importance of CO_2 emissions in climate change, their reduction has become a generally accepted target, functioning both as a benchmark for environmental sustainability and as a climate change mitigation indicator.

The emissions resulting from the transformation and consumption of energy represent the highest percentage of human-generated CO_2. In 2007, it accounted for an average of 95.3% of this gas' total emissions in the 27 European Union states, equalling 3,873.6 million tonnes (EC, 2010b). These include all energy processes, namely the primary energy transformation (energy industries) and energy consumption.

1.1.2 – Buildings and Energy

In this framework, buildings play a crucial role due to their direct and indirect energy-associated emissions, with relevance to the indirect resulting from their operational use. The CO_2 produced along the entire construction process (including the manufacturing of materials) can also be accounted for under the embodied carbon of buildings. Regarding the entire life-cycle of residential buildings, some estimates reveal that the operational stage may account for 87.5% to 96.9% of the total CO_2 emissions, while the remaining percentage can be attributed to the construction phase[4] (Seongwon and Yongwoo, 2001).

The European Environment Agency developed a study to determine end-users responsibility in order to reallocate the associated emissions from energy transformation (EEA, 2011b). Taking into account all scopes, the report reveals that the residential sector reached 25% of the total EU27 energy end-use GHG emissions (figure 1). Furthermore, it is possible to identify a similar distribution of direct and indirect emissions associated with energy in the residential sector. From figure 1 it can also be concluded that the emissions associated with buildings (residential and commercial) accounted for a significant 40% share of the total. This proves the relevance of buildings' energy end-use and the potential for their reduction.

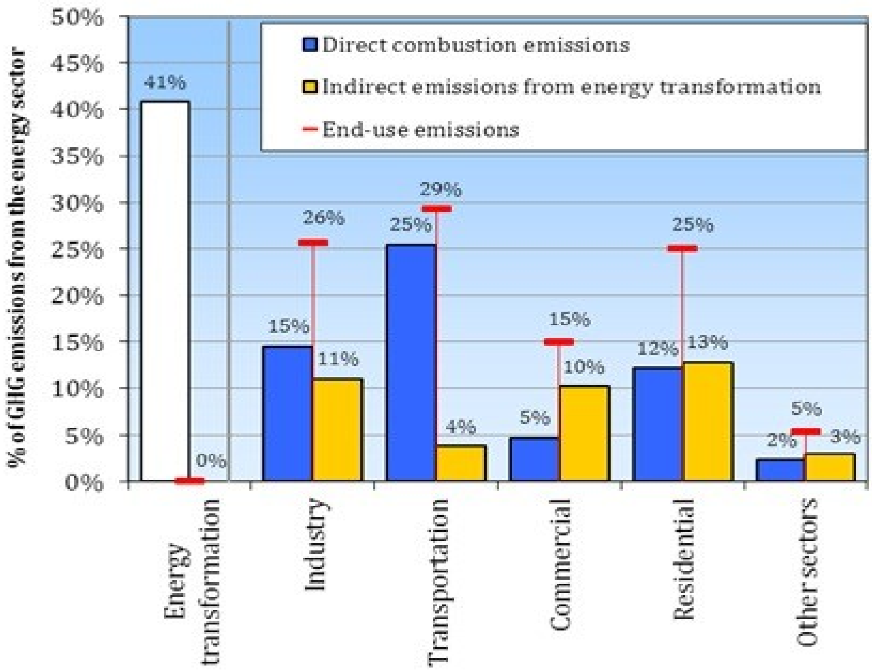

Figure 1 – 2009 end-use greenhouse gas emissions from energy use in EU27 *in* EEA (2011b, p.9)

For Portugal, the same data source reveals a slightly lower percentage of 33%, consisting of the residential (16%) and commercial (17%) sector. It also shows a lower consumption of direct energy sources and a higher dependence on energy transformation and supply than the European average.

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4 - The authors of the study considered the national average life span of buildings to be 22.4 years. Changing this will give a different ratio. Nevertheless, the operational phase will always be responsible for the larger share of emissions as stated *in* (UNEP SPCI, 2009).

It is widely accepted that buildings represent a major environmental burden when taking into account all energy involved in their complete life-cycle (construction, use, and refurbishment/demolition), and the consequent consumption of resources and CO_2 emissions. European residential buildings take predominance over non-residential ones, accounting for 75% of the total floor space per capita, ranging from 25 m^2 to 42 m^2, respectively in eastern and southern countries (BPIE, 2011). In terms of associated emissions, the European average is 54 kg of CO_2 per m^2, while the Portuguese average remains among the lowest with 40 kg of CO_2 per m^2. At the same time, European households were responsible for 68% of the total final energy use in buildings during 2009 (BPIE, 2011, p.44). This highlights the potential role of the residential buildings sector in addressing CO_2 emissions reduction by cutting on their energy consumption.

In Portugal, the energy consumption in buildings is circa 10% lower than the European average, accounting for 29.7% of the total final energy consumption in 2009. This gap could be explained by the mild Portuguese climate, which reduces the number of heating degree-days as compared to most European Countries[5] (Eurostat, 2007, p.158). However, even with an energy consumption that is below European average, Portugal still reveals a high dependency on energy imports as shown in table 1. Hence, in addition to the environmental perspective, the financial burden posed by these energy imports turns energy conservation into a strategic national issue. This is also valid at the domestic economy level, as pointed out by surveys undertaken in the residential sector, which showed that each Portuguese household averagely spent the equivalent of 3.88 minimum wages on energy (transportation and housing) per year (INE and DGEG, 2011). In the context of an economic crisis, these costs could lead to scenarios of fuel poverty.

Fuel Import Dependency in 2007 (%)				
	All fuels	**Solid fuels**	**Oil**	**Gas**
EU 27	53.1	41.2	82.6	60.3
Portugal	82.0	100	98.9	98.7

Table 1 – Energy import dependency in 2007 based *in* EC (2010b, p.30)

5 - Portuguese long-term average (1980-2004) is 1302 heating degree-days against 3386 days presented by the European Union average.

1.1.3 – Building Energy Efficiency

Consequently, buildings play a significant role in addressing climate change by reducing their energy consumption. The IPCC's *Fourth Assessment Report* identifies that GHG emissions associated with energy consumption in both new and existing buildings can be cut by an estimated 30 to 50%. In 2006, the European Commission (EC) stressed in the *Energy Efficiency Action Plan*: "Partly because of its large share of total consumption, the largest cost-effective savings potential lies in the residential (households) and commercial buildings sector (tertiary sector), where the full potential is now estimated to be around 27% and 30% of energy use, respectively" (EC, 2006, p.5).

Relevant policies to address the reduction of energy consumption in buildings were developed by the responsible authorities at international, national and local levels. These efforts focus on the reduction of CO_2 emissions both by improving the efficiency of energy transformation and distribution, as well as by introducing energy efficiency requirements in building regulations. Two main aspects for these regulations are intended to improve the fabric thermal behaviour and the efficiency of heating and cooling systems for buildings.

The European legislative framework on building energy efficiency inter-relates several parallel strategic measures to promote climate change mitigation. Accordingly, the European Union Presidency promoted the '20 20 20 strategy', which aims for a 20% reduction in GHG emissions and primary energy consumption until 2020 and a 20% increase in the use of renewable energy sources, as compared to 1990 levels (Council of the European Union, 2007). These targets reaffirmed the EU's commitment to address climate change through the improvement of the energy efficiency of buildings.

The 'Energy Performance of Buildings Directive' (EPBD) is the core of the EU building energy efficiency legislation and was mandatorily transposed into the state members' national regulations, in order to locally adapt the methodology to achieve the goals of the main text. The Directive promotes the retrofit of existing buildings as a central strategy, a pedagogic measure which has become mandatory for public buildings. It also incentivises the use of renewable energy sources and the development of district heating and cooling (EC, 2010a).

Following the EPBD, a new regulation for the thermal behaviour of buildings was released in Portugal in 2006: '*Regulamento das Características do Comportamento Térmico dos Edifícios'*

(RCCTE). This legal text focuses on residential buildings and is complemented by additional legislation directed at mechanically heated or cooled buildings. These regulations converge to the national energy performance certification scheme, '*Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios'* (RSE), which labels buildings according to their energy consumption and CO_2 emissions. This legal framework relies on a simplified calculation methodology, and focuses mainly on the construction of new buildings. In order to be able to also deal with already existing buildings, an even more simplified method of calculation was implemented in 2009, maintaining the mandatory limit values for parameters and energy consumption. Be it at a European or at a national level, the core strategy of these regulations for the residential sector resides in the global improvement of the building envelope's heat transfer and in the promotion of renewable energy sources for domestic water heating (DHW).

1.1.4 – Existing Buildings Stock

In addition to the introduction of energy-efficient solutions in the design of new buildings, the potential of adapting the existing building stock in order to improve the energy efficiency is also a growing topic of research (e.g. Balaras *et al.*, 2007; BPIE, 2011; Ecofys, 2004; Lomas, 2010; Meijer *et al.*, 2009; Nemry *et al.*, 2010; Sunikka, 2006). The current European new construction framework emphasizes the role of retrofit for existing buildings to meet the energy efficiency targets promoted by the European climate change and energy efficiency policies[6] (BPIE, 2011; EC, 2010a; EC, 2012).

Buildings built before 1960 represent a large share of the total buildings in Europe, accounting for 35%, 37% and 42%, respectively in central & east, south, and north & west European regions (BPIE, 2011). A recent study reinforces their strategic role in European energy efficiency policies by stating that "energy savings through the renovation of the existing building stock is one of the most attractive and low cost options to reduce the emissions of CO_2 and potentially improve energy security by reducing imports of fossil fuels" (Copenhagen Economics, 2012, p.4). Moreover, it emphasises the economic and social benefits from this strategy, due to its labour intensiveness when compared with the construction of new buildings. In Portugal, the refurbishment of existing buildings has also been pointed out as a

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6 - As pointed out in a European study, the use of the term 'renovation' promoted in European policy can be replaced by 'retrofit' or 'refurbishment' describing basically the same process (BPIE, 2011).

resource conservation strategy as well as promoting economic development and employment (CIP, 2010; CIP, 2011).

Despite the difficulty of comparing the performance of the heterogeneous existing building stock in Europe, as pointed out by Itard and Meijer (2008), a cross-European study promoted by the Buildings Performance Institute Europe (BPIE) revealed that the residential sector amounts for an energy saving potential of up to 71%, which corresponds to a CO_2 emissions reduction of 91.7% (2011). For the UK, a potential CO_2 emissions reduction of 60% to 80% by 2050, depending on the intensiveness of measures taken, was identified (Johnston *et al.*, 2005; Killip, 2008; Shorrock *et al.*, 2006). These scenarios integrate the macro vision of energy efficiency, accounting for the potential savings achievable by the decarbonisation of energy industries. Hence, it is possible to assume that existing residential buildings pose a major challenge and have a significant potential for energy efficiency improvement through refurbishment or retrofit.

1.1.5 – Traditional Buildings and Energy Efficiency

Traditional buildings represent the majority of the built environment in historic cities. Even if their own heritage value does not justify an individual listing, they contribute to the overall significance of any historic urban site. Consequently any disruption in their individual characteristics, which may appear to only have minor effects, could actually produce a slow change over time and hence lead to a significant disruption for the overall area. Since great care has already to be applied with any heritage grading, it has to be undoubtedly higher when dealing with World Heritage Sites.

The European thermal regulations also apply to existing buildings undergoing major renovations or upgrade processes. Such operations are defined as costing 25% or more of the building's total financial valuation. Following EPBD guidelines, the refurbishment, restoration or extension of the listed buildings or of the buildings located in historical areas, are exempt from fulfilling the requirements if they prove to be incompatible with the maintenance of the building's heritage integrity. However, incompatibility has to be proven to and accepted by the local authorities which, without clear guidance, tend to perform a rather vague and casual appreciation of such values, in particular in the case of traditional buildings without specific heritage protection. Moreover, the mandatory requirements for the energy efficiency of existing buildings are based primarily on envelope improvements in order to address heat losses. Changes to the envelope of traditional buildings are a dangerous process, raising the above expressed concerns at building and townscape levels.

A conflict between the upgrade of energy efficiency in traditional buildings and the safeguard of their heritage values can thus be identified. This configures the difficulty on conciliating the technical approach with the subtler architectural heritage conservation practice. The relevance of this problem comes both from the important role these buildings can play in the mitigation of climate change, making their adaption fundamental, and from the absolute necessity to conserve their heritage significance, which is unavoidable in order to sustain the historic environment.

1.1.6 – Traditional Buildings of Oporto

In the case of Oporto, traditional buildings are major contributors for shaping the appearance of the World Heritage Site and constitute an urban stock which must be accounted for in the future decarbonisation policies of the city. Moreover, recent trends in the construction industry and the promotion of national urban regeneration policies prove the current interest in the refurbishment strategy (Portugal, 2004; Portugal, 2009). The creation of municipal companies to deal with the urban regeneration operational tasks directed this strategy mainly for the historic areas in Portugal. The Oporto Urban Renewal Company (Porto Vivo SRU) was the first institution to be created under this legal framework and lead to a large urban renewal scheme that is mainly aimed at traditional buildings.

The gradual increase in tourist flows and urban downtown night life in Oporto (Macedo, 2011), lead to an emerging economic revitalisation and physical refurbishment processes of the historic city (INE, 2012a; INE, 2012b). The current economic constraints and the attractiveness of the historic city are evident in the increase in number of building refurbishment permits submitted to the local authority of Oporto in the first nine months of 2012 (417 representing 90% of the total), and present a continuation of the growth pattern of the previous two years[7] (Vida Imobiliária, 2013b).

7 - For the same period, refurbishment permits in Lisbon accounted for 96% of total (Vida Imobiliária, 2013a). In 2011 the refurbishment permits in Portugal reached 25% of the total (INE, 2012b, p.35).

This is also reinforced by Guedes *et al.* (2009, p.2004), stating that "(…) in terms of sustainable development the situation presently found in Portugal offers good opportunities in two critical areas: building refurbishment and the revision of the comfort criteria." The opportunity that is presented for the refurbishment of traditional buildings in Oporto's historic centre is crucial for improving their energy efficiency, while at the same time promoting a strategy inserted into the sustainable development policies.

1.1.7 – Current Research

The shortcomings of modern architecture in terms of thermal performance of buildings are pointed out by Roaf *et al.* (2009), whose research compared the performance of several buildings in Naples from different ages, and concluded that "we have much to learn from the buildings and technologies of the past, and from the lifestyles and adaptive behaviour and opportunities created by their occupants" (p.200). Furthermore, the concepts of sustainable refurbishment rely heavily on a reduction of energy consumption by decreasing mechanical environment control and by taking advantage of the passive characteristics embodied in 'regionally appropriate buildings' (Roaf *et al.*, 2009), which reveal higher levels of resilience.

Over the past 15 years a growing field of literature has been addressing the issue of thermal behaviour and energy efficiency of traditional buildings worldwide, with several examples being taken from the Mediterranean (Portugal[8], Spain[9], France[10], Italy[11], Greece[12], Turkey[13] and Cyprus[14]). This increasing interest confirms the emerging research framework. It also points to the passive characteristics of traditional architecture as a pathway to improve the thermal behaviour of contemporary buildings by for instance, the use of traditional materials or

[8] - (Afonso, 2009; Araújo and Almeida, 2006; Ferreira and Teixeira, 2010; Guedes *et al.*, 2009; Mamede, 2012; Moradias *et al.*, 2012; Silva and Ramos, 2003).

[9] - (Cañas and Martín, 2004; Gálvez *et al.*, 2012; Guerrero *et al.*, 2005; Martín *et al.*, 2010).

[10] - (Cantin *et al.*, 2010).

[11] - (Ascione *et al.*, 2011; Balocco and Grazzini, 2009; Cannarella and Piccioni, 2011; Cardinale *et al.*, 2003; Marco and Torre, 1999).

[12] - (Anna-Maria, 2009; Oikonomou and Bougiatioti, 2011; Tassiopoulou *et al.*, 1996).

[13] - (Baran *et al.*, 2011; Esin and Yüksek, 2008; Ipekoglu *et al.*, 2007; Serefhanoglu Sozen and Gedik, 2007).

[14] - (Dincyurek and Turker, 2007).

techniques (Kim and Park, 2010; Srivastav and Jones, 2009), thus following the seminal path of Hassan Fathy (1986).

A large group of research also embraces the energy efficiency of traditional building and comfort improvement by making use of their passive characteristics (Dili *et al.*, 2010a; Dili *et al.*, 2010b; Dili *et al.*, 2010c; Dili *et al.*, 2011; Fuller *et al.*, 2009; Martín *et al.*, 2010; Singh *et al.*, 2010), identifying in them some of the standards of sustainable architecture (Campagna and Frey, 2008; Jones *et al.*, 2009; Young, 2008).

In a Portuguese context, Guedes *et al.* emphasise the passive potential of vernacular architecture, pointing to the local climate as passive suitable, rendering air conditioning dispensable in the majority of situations (2009). The available statistics confirm this situation as only 22.6% of Portuguese households use cooling equipment, the majority of which are individual fans (69.5%), leaving air conditioning at a mere 7.2% of the total (INE and DGEG, 2011).

Similar research has also been conducted by several major institutions which work in the field of traditional buildings. The Building Research Establishment (BRE) in England successfully promoted the sustainable refurbishment of several Victorian and Edwardian era buildings, providing effective measures to promote energy efficiency on these types of dwellings (Cartwright *et al.*, 2011; Coad and Finbow, 1990; Ferguson, 2011; Sluce and Tong, 1991; Yates, 2006; Yates, 2010). In the past decade, English Heritage (EH) has produced practical guidance for the refurbishment of traditional and historic buildings in order to upgrade them to current energy efficiency standards, following the EPBD transposing in the United Kingdom (UK) law (Baker, 2010; Drewe and Dobie, 2008; English Heritage, 2007). The use of renewable energy sources in traditional buildings was also addressed by EH. At the same time, the impacts caused to heritage values by the introduction of these systems into an historic environment were also analysed (English Heritage, 2006; English Heritage, 2008; English Heritage, 2010a; English Heritage, 2010b; English Heritage, 2012).

Moreover, the Society for the Protection of Ancient Buildings (SPAB) together with academics has undertaken on-site research focusing on several aspects of the thermal behaviour of traditional buildings. These case studies showed a clear gap between the calculated results and the effective measurements taken, revealing that traditional buildings have a better thermal performance than expected (Browne, 2012; May and Rye, 2012; Rye, 2011; Rye *et al.*, 2012).

From a general overview of the above literature, it can be concluded that the established perception of traditional buildings having a poor thermal performance and being inadequate to meet the current targets of energy efficiency is an erroneous preconceived idea. The passive characteristics of this type of building give them some potential to achieve higher levels of energy efficiency, as pointed out by a field study conducted in France which focused on various thermal characteristics of eleven historic dwellings (Cantin *et al.*, 2010).

1.2 - Research Objectives

The framework established in the background section allows for concluding that the promotion of energy efficiency in existing residential buildings is a widespread and fundamental policy to achieve a reduction in CO_2 emissions and therefore mitigate climate change. European Directives have made mandatory the reduction of energy consumption associated with new and existing buildings, with exemptions being made for listed historic buildings. Other heritage-valued buildings which are not listed may be casuistically evaluated according to the specific legislation of the individual member states. Traditional buildings are included in this group as they are not listed individually, but by inclusion in a conservation area.

This raises the question: **how can their energy efficiency be improved without damaging their heritage value, both in terms of the building itself and the overall townscape?**

Literature and case studies address this question from separate perspectives. Some address traditional buildings by focusing on the most effective improvements solely from an energy point of view, treating them as if they were new buildings. Others focus on specific aspects of the performance of traditional buildings, failing to take an integrated approach at the problem. Even so, some provide processes which seem to address both aspects. However, they are mainly driven by the technical side of energy efficiency, leaving the heritage aspect to be addressed purely through experienced knowledge, thus missing a clear methodological approach. Conclusively, it was identified that there is a necessity to develop a methodological framework which combines energy improvement with heritage conservation by establishing clear definitions on how to weigh and obtain the most effective solutions.

1.2.1 – Research Questions

The main aim of this research is to identify the means by which urban traditional residential buildings can be upgraded to improve their energy performance while at the same time preserving their heritage significance. Oporto’s traditional buildings, integrated in the World Heritage Site, will be used as a research object for development and testing of the methodological approach. The overall challenge will be balancing the most effective energy efficiency improvement measures to be introduced in Oporto’s traditional buildings.

The impact measurement of the measures to be proposed to improve the energy efficiency of Oporto’s traditional buildings can be achieved by a process similar to the one used by Avanti Architects in the Barbican (2005). It comprises the identification of the fundamental attributes of the buildings' design, establishing their cultural significance and identifying what is unacceptable to be changed. Then, the solutions have to be graded by their visual and fabric impact to determine what is unacceptable, conditionally acceptable and freely acceptable.

In order to address this central question other associated objectives were established to deal with it. First, it is necessary to identify how the heritage significance and the management of change in traditional buildings can be assessed. This relates to the identification of how the heritage valuing process occurs in traditional buildings and what the framework for assessing the impacts of change on these is. This is a much subtler process than the one that occurs in historic listed buildings and their establishment is fundamental to define the heritage scope in the current research. Further, it will allow establishing the heritage value of Oporto's traditional buildings and the means by which change must be managed on their energy efficiency upgrade.

In a similar process the review of traditional buildings must be addressed in order to identify their specific thermal performance factors and how to assess them. This will allow measuring the performance of traditional buildings in Oporto and the means by which they can be improved. The revision of similar research and good practice examples will complement the previous assessment, allowing the identification of the most common measures and interventions used for the improvement of the energy efficiency of traditional buildings. These must cover the technical approach and also address their compatibility with the fabric of the buildings and their impact on the heritage value.

Based on the previous framework it becomes necessary to develop a methodology to assess the improvement of the energy efficiency of traditional buildings and their acceptable heritage limit of change. From the identified background, a framework involving the current research and the advances made on the field could be recognised. Further, it was possible to identify the main gap in knowledge, which is presented by the absence of a methodological approach integrating the heritage and energy efficiency components. Besides this integration, it is also fundamental to define and measure the feasibility of the measures to achieve the proposed aims.

With the overall methodological framework defined, the second part of the research narrows the scope down to Oporto's traditional buildings in order to test and validate the approach and to clearly identify the most feasible measures. Oporto's traditional buildings provide the real data to accomplish this purpose, covering both the heritage value and the energy performance. This must address the definition of the typologies present in Oporto's historic core and the identification of their fundamental characteristics in relation to the research objectives, including the establishment of their baseline performance in terms of energy and their heritage significance. Assuming that these buildings are occupied residential units, it is also necessary to integrate the role of households into the process, which is a fundamental aspect of the current strategies to improve energy efficiency in existing buildings.

The Oporto case study will further be approached with the developed method, allowing identification of the most effective measures to improve energy efficiency without disrupting the significance of the buildings. Additionally, this final part aims to widen the methodological approach, discussing how it can be applied to traditional and historic buildings that share identical fundamental characteristics.

1.3 - Thesis Structure and Research Development

In terms of structure this thesis is divided into parts A and B. The first part (A) addresses the definition of the global framework, which shapes both components of the research: heritage valuing and energy efficiency in traditional buildings. The second part of the thesis (B) focuses on a case study of Oporto's traditional buildings in order to apply the devised methodology into the research object.

After this introduction that establishes the background for the research, the second chapter will discuss the heritage dimension, covering the valuing and management of change processes. This includes addressing both the theoretical and methodological frameworks of the subject.

The next chapter will focus on the energy efficiency of traditional buildings, and continue to cover theoretical and methodological frameworks. This will include reviewing the parameters that deal with the energy performance of buildings and the specific framework when approaching the performance of traditional buildings, which is an identified field of uncertainty.

In chapter four, similar research projects and case studies are analysed in order to identify possible solutions to address the framework outlined in the previous chapter(s). This revision encompassed both heritage conservation and technical energy efficiency improvements.

Part A concludes with chapter five, outlining an integrated methodological approach dealing with the gap identified in the current chapter's background. This methodology must adopt the theoretical and methodological frameworks revised in previous chapters.

In chapter six Oporto's traditional buildings are characterised in terms of their architectural construction systems and heritage significance.

The next chapter covers the analysis of the detailed data collected by fieldwork, aiming to obtain all necessary information to evaluate the energy performance of Oporto's traditional buildings. This includes the selection of the research area, typological identification and case studies selection.

Chapter eight then uses this information to model and simulate the case studies representative of the typological selection, allowing to obtain the performance benchmarking for the measures identified. Heritage impact assessment will be performed beforehand in order to outline the most feasible solutions under the methodological framework developed.

Chapter nine discusses the overall results, covering both the specific case of Oporto's traditional buildings and the validation of the methodological approach to traditional and historic buildings in general. This chapter will close the process of answering the research questions while addressing the global theoretical and methodological frameworks.

The final chapter concludes the research by covering the global research findings, draw recommendations and also addressing strengths and weaknesses of the overall process. Additionally, it points out future research to be developed concerning the scope of this thematic study.

Chapter Two: Valuing Heritage

Chapter Two: Valuing Heritage

2.1 - Introduction

The objective of this chapter is to review the heritage concepts associated with traditional buildings which are essential to this research. The necessity to balance energy performance improvement with heritage protection requires reviewing the concepts associated with heritage values assessment and intervention criteria, which must guide the upgrade operations of non-monumental urban traditional buildings. This will allow for addressing the objective of improving energy efficiency in Oporto's traditional buildings, leading to a result where the savings achieved in energy are not obtained at the expense of significance loss.

2.2 – Heritage

The management of change in heritage buildings has to be found in the relation between heritage values and admissible intervention (figure 2). This approach is commonly accepted in national cultural heritage legislation[15], with Portugal and Great Britain being no exception[16]. Under these procedures the initial values are assessed and compared against defined criteria, leading to the integration of the asset in a list of protected goods. The listing is made based on the relevance of the identified values, which directly leads to a level of protection and associated intervention grade, establishing their admissible change.

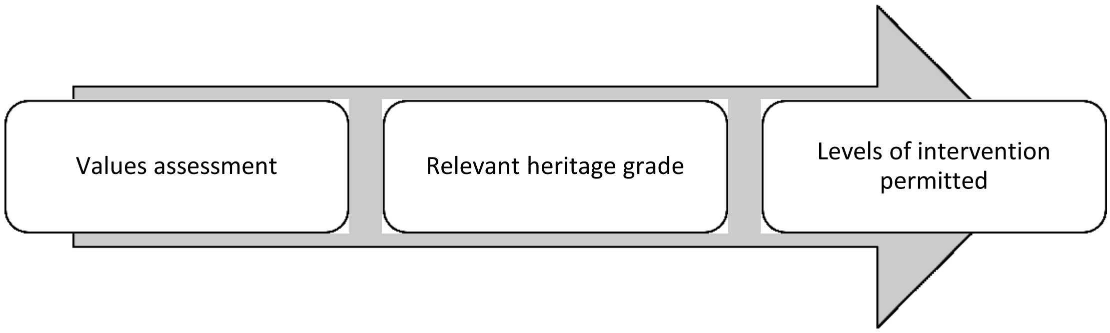

Figure 2 – Intervention process identified in heritage regulations (France, Greece, Great Britain, Italy, Portugal and Spain)

[15] - (France, 2005; Greece, 2002; Italy, 2004; Spain, 1985).

[16] - (Ancient Monuments and Archaeological Areas Act 1979. Chapter 46; National Heritage Act 2002. Chapter 14; Planning (Listed Buildings and Conservation Areas) Act 1990. Chapter 9; Portugal, 2001).

This is a proven and effective process which has been implemented in most European countries and worldwide for many years (Pickard, 2001). The major question resides in the process of defining the heritage relevance of the built objects through the identification of their associated values, allowing further the determination of their significance and respective degree of acceptable change.

2.2.1 – Heritage as a Concept

Referring to the dictionary definitions, the noun 'heritage' is both referred to as an inherited property and as a valued asset (Oxford University Press, 2008). Both cases refer to valued resources and intergenerational transmission, making it possible to identify similarities with the sustainable development concept, as defined in the *Brundtland Report* (1989). This is also pointed out in heritage literature, which frequently establishes a relation between natural and cultural heritage (English Heritage, 1997; Marco and Torre, 1999; Mason, 2002) or, in the specific economic phraseology of Throsby (2002), the notion of cultural and natural capital.

At the centre of the heritage concept is the idea of historical 'monument', as argued by Choay (1992). It is elected from a group of works for representing values that must be transmitted to future generations in order to counteract the dissolving action of time, thus perpetuating the identity and character of their specific culture, consequently leading communities to demand their preservation. This process was also what led to the inclusion of the 'intangible' under the concept of heritage.

It is possible to add the concept of 'imageability' defined by Kevin Lynch as, "(...) that quality in a physical object which gives it a high probability of evoking a strong image in any given observer" (1990, p.9). Reversely, this is the quality that causes the feeling of loss that is experienced when extensive change occurs in a familiar physical environment.

Built heritage, being the context of human activities and causing a strong impression, helps then to give form to the concept of 'collective memory'. Italian architect Aldo Rossi argued exactly this stating that cities are repositories of the collective memory of their people (1982 [1966]). This is also consistent with the contemporary concept of 'place attachment' which, as defined by Mason, "refers to the social cohesion, community identity, or other feelings of affiliation that social groups (whether very small and local, or national in scale) derive from the specific heritage and environmental characteristics of their 'home' territory" (2002, p.12).

In conclusion, it can be said that the idea of timeless heritage points to something that holds and conveys values. Focusing on the field of urban, architectural, and archaeological heritage, the term applies to a whole group of assets that by its qualities or values is part of our memory, leading to local distinctiveness, *i.e.*, characterising and distinguishing every building, place, or city.

The value of 'memory' is today weighted in the definition of heritage, leading to a 'democratic' vision by encompassing both erudite and vernacular works. At the same time, as pointed out by De la Torre (2002), this democratic framework is also extensive to the determination of what is or is not heritage, a decision that is not exclusive to conservation experts anymore, but rather extended to the general public. At the same time being dependent on people's choices, heritage values concur and sometimes conflict in the same asset. This means that the choices of a generation are not necessarily equal to the ones of the next generation and, in this way, values are also mutable. This highlights the necessity to perform reversible interventions in order to address this generational variability. In summary it can be said that heritage designates places, material objects or immaterial actions which impress people and consequently are protected and chosen to be transmitted.

2.2.2 – Architectural Heritage

In terms of architecture, the educational factor is also essential since it was always fundamental to acquire and understand models and canons of the past embodied in every built work. In architectural history, references are always present, even when they appear to be a complete break with the past, like for instance in the Modern Movement.

In the 1930's, Italian architect Gustavo Giovannoni advocated the need to protect 'urban heritage', a term first coined by him (Choay, 1992). This reveals a broader view for the safeguard of less relevant fabric, not remarkable in itself, but contributing to the harmony of the ensemble, integrating it into a general conception of urban planning. This approach was institutionalized with the publication of the *Venice Charter* in 1964, which extended the concept of heritage to vernacular architecture, *i.e.* the "(...) more modest works of the past which have acquired cultural significance with the passing of time" (ICOMOS, 1964, article 1).

This was reinforced in 1975 by the *European Charter of Architectural Heritage* and developed in a series of international documents, declarations and conventions that have multiplied over the last forty years (Jokilehto, 1999).

The introduction of the 'integrated conservation' principle in the *Amsterdam Declaration* (1975) added a social element that, confined within the physical space it interacts with, generates movements and complex relationships. Basically, this corresponds to the transition from a static view, the city-museum, to a new, dynamic view. As Lynch wrote "(…) every citizen has had long associations with some parts of his city, and his image is soaked in memories and meanings. Moving elements in a city, and in particular the people and their activities, are as important as the stationary physical parts" (Lynch, 1990, pp.1-2).

Conclusively, it is possible to say that the evolution of the architectural heritage concept leads to the inclusion of the erudite and vernacular, the monument and the site, as well as the historical centre and the territory, which came alongside with the integration of both the physical and social scopes in their conservation processes.

2.2.3 – Significance, Authenticity and Integrity

The publication of the *Burra Charter* by the Australian ICOMOS in 1979, produced the most established and disseminated national version of the *Venice Charter*. It introduces the concept of 'place', which is more comprehensive than the previously used 'monument and site'. As referred by Jokilehto, "(…) it emphasizes the less tangible aspects of cultural significance, associations and meanings that places have for people, and the need to involve people in the decision-making process" (1986, p.289). The character and values embodied in the place are also translated into the broader concept of 'cultural significance', comprising both material and immaterial components of heritage. Accordingly, with the current heritage conceptions, the cultural significance of a place is pointed out as being mutable in time, since valuation is an act which is inseparable from the times and socio-cultural contexts in which it occurs (ICOMOS Australia, 2000).

The *World Heritage Convention*, adopted in 1972, has not only broadened the scope of heritage (cultural, natural, tangible, intangible, etc.), but also introduced the valuation concepts of 'universal significance' or 'outstanding universal value' (OUV). The *Operational Guidelines for the implementation of the World Heritage Convention* (UNESCO, 2008), establish the criteria by which to assess the OUV of properties, based on characteristics which render the asset relevant to mankind. Apart from these specific criteria the cultural properties must also meet the general conditions of 'authenticity' and 'integrity'.

Based on the *Nara document*, the concept of 'authenticity' is founded on credibility and truth of all sources of information on which the values attribution is based and of the objects own attributes. In the case of buildings this ranges from form and design to context, materials, associated traditions, construction techniques, use and function (Orbaşli, 2008; UNESCO, 2008).

The concept of 'integrity' deals with the wholeness and intactness of natural and cultural heritage and of the attributes necessary to express their OUV. In the special case of the built form, this also means that the fabric and its significant elements must be in good condition and any deterioration processes should be under control (UNESCO, 2008). As pointed out by Orbaşli (2008), several aspects concur to form the overall integrity of the building, namely physical, structural, design, aesthetic, setting and context, and the professional integrity of the conservation team.

However, these concepts must be understood in the specific cultural context of the asset and not as a dogmatic approach towards conservation (Jokilehto, 2006). Management of change is another key point of the operational guidelines, ensuring the maintenance and/or enhancement of significance, authenticity and integrity of the listed properties. Today, these three concepts are the most relevant under the scope of the current research as they represent the essential characteristics that a built environment should possess to be listed as world heritage and which should be preserved in the management of change process.

2.3 – Architectural Heritage Values Assessment

As was pointed out earlier, architectural heritage values are the characteristics of a building that impress communities and consequently lead to their conservation. If the traditional conservation actors (architects, archaeologists and art historians) value objects to be essential by virtue of their embodied erudite values (artistic, historic, educational), the general public introduces a deeper complexity to the process, leading to a wider range of values as shown in table 2. However, these values are not self-contained and isolated from each other, they are usually related and concur on an object (De la Torre and Mason, 2002).

It is also possible to group and draw hierarchies for these values, as some are dependent on others. The examples of table 2 are grouped diversely by their authors: Mason (2002) clustered them under two main categories (socio-cultural and economic) while the English Heritage guidance (English Heritage, 2008) defines four main values (evidential, historical, aesthetic and communal), under which several others cross to define the heritage significance of buildings. The major questions reside on how to find values that define the status of heritage, and how to assess and establish their relative importance. In doing so, it will be possible to identify the characteristics that must be preserved in each object in order to maintain its overall cultural significance and integrity.

Reigl (1902)	Lipe (1984)	Choay (1992)	Frey (1997)	*Burra Charter* (1998)	Mason (2002)	Roders (2006)	Orbasli (2008)	English Heritage (2008)
					Sociocultural			
	Aesthetic	Artistic or aesthetic		Aesthetic	Aesthetic	Aesthetic	Artistic	**Aesthetic**
							Architectural	Design
								Artistic
							Townscape	
						Ecologic	Landscape	
Historical		Cognitive or memory		Historic	Historical	Historic	Historic	**Historical**
								Illustrative
							Local distinctiveness	
	Associative						Associative	Associative
Age		National	Prestige	National		Age	Age and rarity	**Evidential**
							Public	**Communal**
Commemorative								Commemorative
	Symbolic				Symbolic		Symbolic	Symbolic
				Social	Social	Social	Social	Social
				Spiritual	Spiritual		Spiritual	Spiritual
					Religious		Religious	
							Emotional	
				Educational			Educational	Intellectual
							Technical	Thecnological
Newness				Scientific		Scientific	Scientific	
							Research	
	Informational						Knowledge	
				Other cultural	Cultural		Cultural	
				Political		Political	Political	
					Economic			
Use			Monetary		Use (market)			
	Economic	Economic			Nonuse (nonmarket)	Economic	Economic	
			Existence		Existence			
			Option		Option			
			Bequest		Bequest			

Table 2 – Buildings heritage values in literature, partially based on (Mason, 2002) and completed with (Choay, 1992; English Heritage, 2008; Orbaşli, 2008; Roders, 2006).

2.3.1 – Architectural heritage values

In an in-depth study on the evolution of the heritage concept, Françoise Choay identified three core values, which characterise a built form and give it the status ‘historical monument’: economic, artistic or aesthetic, and cognitive or memory values (1992).

Economic value is naturally the oldest associated with the concept. It refers to the financial valuation of the building and directly recalls the idea of inheritance as an asset. Despite the difficulty to quantify the economic value of built heritage due to the ‘emotional charge’ that the property holds (*i.e.,* the other values which concur to the valuing process and are of a more subjective nature), this parameter is always present due to the ‘real estate’ nature of buildings. While this may seem absurd for estimating the value of a ‘monument’, that can be considered priceless this does not hold true when approaching heritage categorised as ‘group of buildings’ where the significance emerges from the ensemble as a whole. These buildings are inserted in a context and usually participate in contemporary life, thus making them part of the real estate market. Hence, their economic valuation plays an important role as their market value is measurable and can be inserted in the current economy (De la Torre and Mason, 2002; Mason, 2002; Throsby, 2002).

The economic vision on heritage has been growing and now plays a major role in the literature, as revealed in the studies undertaken by the Getty Conservation Institute (De la Torre, 2002; Mason, 1999). The economic sciences framework argues for allow the measurement of some values of heritage by applying the principles of economic valuation for assets (Hutter and Rizzo, 1997; Mason, 2002; Mourato and Mazzanti, 2002; Throsby, 2002).

Artistic or aesthetic value is referenced by Choay as an evidential characteristic embodied in the architectural object, which is initially perceived or attributed by scholars and over time extended to the community (1992). In this aesthetic framework it is important to distinguish between artistic and design values, as pointed out by the English Heritage guidance (2008). The first relates to the more or less spontaneous gesture of an artist or craftsman, while the second is the consequence of planned and conscious design. The discipline of architecture is tied directly with this last concept, while at the same time not excluding the artistic aspect which is present in buildings by either an erudite sculpture or painting, or by the skilled work of a craftsman.

Even if the aesthetical valuation is the result of a specific cultural context, the deeper intentions present in the architect's design are usually timeless (beauty, proportion, harmony) and can also be evoked in other cultural contexts and by other generations. It is these timeless characteristics that lead to a building being appreciated for its material evidence, impressing scholars and the community, regardless of the presence or absence of other historical or social values in it.

This aesthetic aspect is also connected with other values as the erudite design of a building always possesses an educational perspective. The timeless intentions which concur to create the overall work of art need to be found and identified in order to perform a conscious conservation, as defined in Cesari Brandi's theories (1977). Also referring to the aesthetic component of heritage, Mason presents the idea that this can be enlarged to a sensory perception, utilising all senses and not merely sight (2002). Pursuing this idea, it can be affirmed that the aesthetics of a built heritage can be interpreted on two different levels: one is related to the erudite and expert interpretation of design and artistic qualities, while the other deals with the sensory experience provoked by the objects, which can by perceived by everyone.

While traditional buildings may possess all of these values, the balance between them will probably be different. When compared with major works of architecture, their design significance might be valued less, but their artistic importance, due to their craftsmanship, communal values, or sensory experience, may play a fundamental role in their designation as heritage. The relation with physical characteristics of a specific context (*e.g.* climate and materials) must also be stressed, as they represent the bond established between man and natural resources, which is materialised in the technological value of the traditional construction systems.

Following Choay's categories, cognitive or memory values are also included in the genesis of heritage valuation. It is by the necessity of preserving the memory that protection occurs. Under this broad category most socio-cultural values can be included, as many of them are connected with specific points of collective memory (*e.g.* historical, commemorative, symbolic, illustrative or associative). This also highlights the relation with the past, as age and aesthetic were always fundamental in the heritage valuation of buildings, allowing to create a bond between past and present generations. In a wider conception of heritage, Roders proposes that all built structures that are older than twenty-five years should be considered heritage, simply as testimonials of the past, without aprioristic aesthetical or historic evaluations (2006; 2007). This vision can be inserted in the dynamic principle of preventive conservation, which should be implemented in order to avoid specific cultural or generational bias (English Heritage, 2008; Mason, 2002; Roders, 2007).

In complement, traditional buildings acquire importance because they significantly contribute to shaping historic environments. The urban image transmitted by buildings, in the sense of Kevin Lynch's 'imageability' (1990), impresses the memory of the inhabitants of historic cities and, in a subtle way, defines a sense of place which is the result of the ensemble instead of the unit. The preservation of this 'image', through a dialectic process established between the building unit and the historic city context, also preserves of the authenticity and integrity of the historic city. The fact that these units are not refined examples of design value may lead to their replacement, which in a slow and subtle way contributes to the degradation of a city's identity. Hence, the valuing process for traditional buildings has to be approached from two different perspectives: the individual unit and the overall contribution to the character of the historic site.

An analysis of the national heritage laws of England and Mediterranean countries (Portugal, Spain, France, Italy and Greece) allows the conclusion that buildings are still listed mainly by their historic and artistic values, which are transversally found in all legal texts (table 3). Most of this legislation is based on the concept of 'monument', which stems from nineteenth century laws based on the architecture and art history experts' visions. Other values were added to update the concept, but the vision of experts is still prevalent in the process of electing buildings to be protected. However, these two values have to be understood in a broader sense: 'historic' can be broken down into a series of social values (age, rarity, symbolic, commemorative, national, emotional, political, spiritual, etc.), and 'artistic' represents the values associated with the physical attributes of buildings and the impression they produce (aesthetic, design, artistic, architectural, intellectual, educational, technical, scientific, etc.).

	PORTUGAL	SPAIN	FRANCE	ITALY	GREECE	ENGLAND
Values	**Historic**	**Historic**	**Historic**	**Historic**	**Historic**	**Historic**
	Artistic	**Artistic**	**Artistic**	**Artistic**	**Artistic**	
			Aesthetic			
	Archaeological		Archaeological	Archaeological		
	Scientific	Scientific	Scientific		Scientific	
	Social	Social				
	Technical		Technical			
	Architectural					**Architectural**
	Ethnographic			Ethnographic		
				Anthropological		
	Industrial					

Table 3 – Buildings heritage values in England and Mediterranean Laws (footnotes 15 and 16).

Conclusively, it is possible to affirm that there is no definitive and absolute guidance for the valuing of buildings and for understanding their grade of significance. The *Getty Report* (De la Torre, 2002) and the *English Heritage Conservation Principles* (English Heritage, 2008), present a solid set of values identifiable in buildings, which also coincides with Choay's synthesis (1992). Most of the values in the table may also be grouped, as they are similar, with subtle denomination variations.

2.3.2 – Architectural heritage values assessment

As affirmed by Mason, the "value assessment presents a threefold challenge: identifying all the values of the heritage in question; describing them; and integrating and ranking the different, sometimes conflicting values, so that they can inform the resolution of different, often conflicting stakeholder interests" (2002, p.5). In figure 3 the overall framework in which values assessment is inserted, is systematised.

The multidisciplinary approach among experts is also fundamental to obtaining a consistent result. By using what Mason called a 'strategy of inclusiveness', this approach should result in the 'triangulation' of the diverse disciplinary methods (2002). The same author further stresses that no single method is effective to produce adequate knowledge of the heritage values. However, contextual holistic understanding (social and physical), assures a varied and robust perspective on which values to assess.

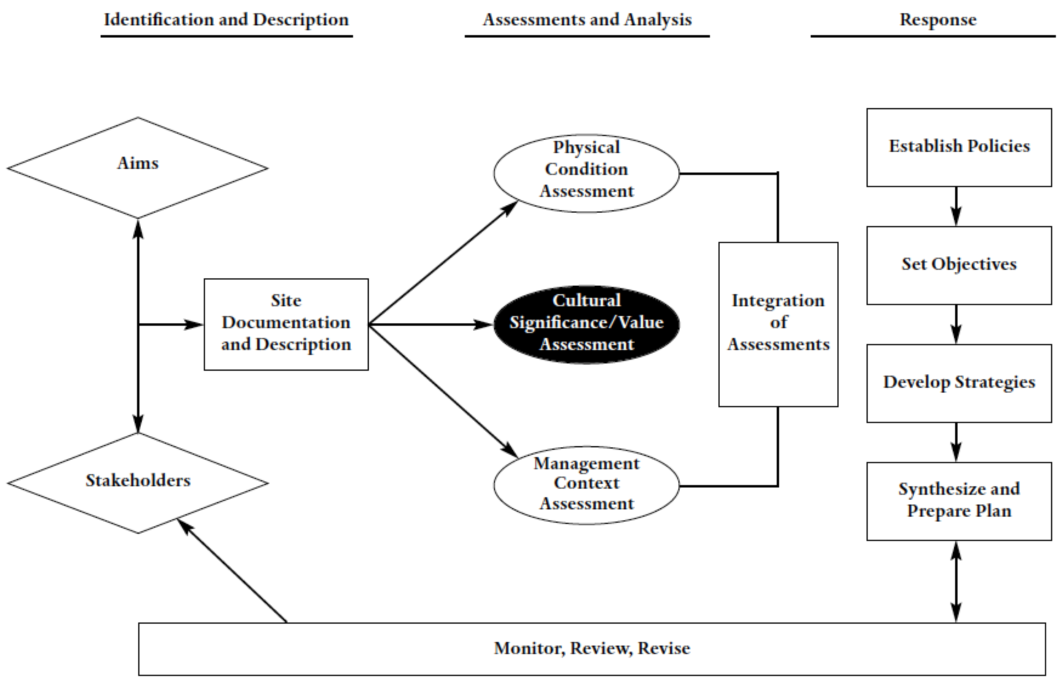

Figure 3 – The heritage management process proposed by Mason (2002, p.6) positions significance and value assessment at the centre of the process.

Nevertheless, traditional expert methodologies are still the base for identifying the values of built heritage and even when considering the most advanced conceptions, they constitute an established starting point whose scope must afterwards be extended. As affirmed by De La Torre and Mason (2002), even if the opinion of experts is one among many, their role has to be necessarily higher when dealing with buildings because of the specific technical framework of buildings, as it is evident in the heritage legislation (table 3). Accordingly, the process of assessing a building's 'heritage cultural significance' relies initially on art history research, based on documents, and archaeological and architectural surveys and analysis, referring mainly to the built object itself. This is not an impermeable process as the disciplinary approach can be crossed, turning buildings into documents for historians which also give valuable contributions for architects, with archaeologists being located in between these two fields.

As affirmed by De La Torre and Mason, environmental methodologies, in particular impact assessment tools and ethno-orientated methods, are today valuable and complementary approaches (Mason, 2002). The parallelism between heritage assessment and environmental impact assessment is also stressed by Teller and Bond (2002). Moreover, the ICOMOS's *Guidance on heritage impact assessments for Cultural World Heritage Properties* (2011), confirms how these frameworks can be effective and directly applied in the field of cultural heritage. The stages presented in table 4 can be coincident with values assessment until step eighth, which represents the ‘statement of significance’ or statement of ‘Outstanding Universal Value’, through which the identified values must be clearly described, *i.e.* defining the baseline situation.

Stages of Heritage Impact Assessment (HIA)	
1	Initial development and design
2	Early consultation
3	Identify and recruit suitable organisations to undertake works
4	Establish study area
5	Establish scope of work
6	Collect data
7	Collate data
8	**Characterise the heritage resource, especially in identifying attributes that convey OUV**
9	Model and assess impacts, direct and indirect
10	Draft mitigation - avoid, reduce, rehabilitate or compensate
11	Draft report
12	Consultation
13	Moderate the assessment results and mitigation
14	Final reporting and illustration - to inform decisions
15	Mitigation
16	Dissemination of results and knowledge gained

Table 4 – Heritage Impact Assessment Stages *in* (ICOMOS, 2011, p.13)

The process of assessing architectural heritage values is based on a mixture of methods and approaches from several disciplines (ICOMOS, 2011; Mason, 2002). Mason divides the assessment tools and methodologies into ‘suitable for cultural values’ and ‘suitable for economic values’ (table 5). Due to their objectiveness, the economic methodologies are suitable for management processes, however they pose the danger of ‘blocking’ relevant qualitative aspects of heritage (*i.e.* artistic, symbolic, spiritual, etc.) (2002). Hence, the current research aimed at traditional buildings and their cultural significance must also rely on the cultural assessment methods, as advocated by the guidance of UNESCO (2008), English Heritage (2008) and ICOMOS (2011). The economic tools are out of the scope of this study and will not be explored.

Cultural Values Assessment Methods	
Expert Analysis	Textual
	Iconographic
	Formal
	Semiology
Ethnography	Surveys
	Interviews (structured or unstructured)
	Other participatory method: field of planning/urbanism methods (public meetings, visioning, focus groups, key-informant interviews, etc.)
Mapping	Traditional data mapping or plan
	Geographical Information Systems (GIS)
	Other mapping methodologies: Interactive mapping produced by non-professionals of the sector ('mental mapping'; 'parish maps'; informal 'rock-and-dirt maps')
Primary research	Archival
	Writing historical narratives
Secondary research	Literature
Descriptive statistics	Content analysis
	Demographic analysis
Economic Values Assessment Methods	
Revealed-preference methods	Economic impact studies
	Hedonic pricing methods
	travel-cost methods
Stated-preference methods	Contingent valuation methods
	Choice modelling

Table 5 – Values assessment methods *in* (Mason, 2002, pp.19-22)

2.4 – Architectural Heritage: Management of Change

The current research focuses on the specificity of architectural heritage, leading to a building-focused approach. Architecture is a discipline with its own rules of design, to which the general concept of cultural heritage conservation can be applied, but whose refurbishment criteria also have to address disciplinary questions. The cultural significance of buildings can primarily be related to historical, symbolical, political or other social values, rather than to their aesthetical characteristics. These concurrent values can inform and be decisive in the heritage management process, but are less relevant in the specific design, thus allowing adaptive reuse.

The essential question is to identify how heritage values associated with a building can limit its refurbishment and how to establish design criteria for interventions.

Based on the EIA framework (Morris and Therivel, 2009), Mason's (2002) and ICOMOS (2011) methodological approaches are clear on the process of managing change: values must be assessed, statements of significance should synthesise the values, heritage should be graded against similar assets, and the impacts of the proposed change should then be graded taking into account the baseline expressed in the statement of significance.

2.4.1 – Architectural assessment methodologies

In the architectural field, urban and building surveys, as well as map and drawing analysis, can be used to systematise the fieldwork data obtained from the previous stages of the process. The use of geographic information system (GIS) is consensual today because it is a sophisticated and powerful tool to gather, cross and present data from several sources and disciplinary fields (ICOMOS, 2011; Mason, 2002; UNESCO, 2008). The drawing analysis made by Computer Aided Design (CAD) is common and established and allows for complex modelling and three dimensional (3D) representations of the research objects. Apart from being valuable instruments of analysis, these 3D tools are further pointed out as added-value resources for impact assessment (ICOMOS, 2011). Typological studies in architecture are also fundamental to perceive what is nuclear on buildings, allowing further comparisons between them (Fernandes, 1999). As written by Fernandez, "in 1966, Aldo Rossi in *L'archittetura della cittá* proposes new methods for the scientific study of historic cities, advocating the necessity of its morphological analysis and typological classification based in lots and built form of different ages" (1985, p.169). This typological analysis also allows for combining the built form with the context and the social behaviour, as a building's design is always the result of both physical and social factors.

These approaches need to be complemented with other traditional research methods, namely referring to archival data (documents, historic maps, and iconography), existing heritage records, secondary research (literature), and quantitative data (census and other statistics).

Conclusively, is possible to affirm that the architectural assessment methodologies, using field, primary and secondary research, will be the base for understanding heritage in traditional buildings in Oporto. These will cover archive and literature review, statistical sources analysis, traditional and GIS mapping, direct survey and drawing analysis. To complement this, the social aspects of the research will be addressed by using ethnographic assessment methodologies, consisting of conducting primary research by using ethnographic fieldwork techniques. The use of these multi-disciplinary approaches will allow obtaining several different perspectives of the research objective.

2.4.2 – Heritage Grading

The process of identifying built heritage values is directly tied with the weighting of the overall importance of the object, comparing it to others (table 6 and table 7). The 'statement of significance', which commonly summarises the values a describing text (UNESCO, 2008), constitutes the baseline from against which the impacts should be compared measured (ICOMOS, 2011).

	PORTUGAL	SPAIN	FRANCE	ITALY	GREECE	ENGLAND
Types	Monument	Monument	Historic Monuments	Cultural Heritage	Monuments	scheduled monument
	Group	Historic Group	Referenced Buildings		Historic Sites	Listed buildings
	Site	Historic Site	Sites			conservation areas
			Secteurs Sauvegardés			
			Zones de Protection du Patrimoine Architectural, Urbain et Paysager (ZPPAUP)			
Grades	National Monument	Cultural Interest (BIC)	Historic Monuments (Listed)	Cultural Interest (cultural heritage)	Ancient Monuments (until 1830)	Scheduled Monument
	Public Interest	Spanish Historic Heritage	Referenced Buildings (not listed)	Remarkable Public Interest (landscape heritage)	Recent Monuments (after 1830 with more than 100 years)	Listed Building Grade I
	Local Interest			National Monuments	Recent Monuments (after 1830 with less than 100 years)	Listed Buildings Grade II*
				Built elements and areas of archaeological interest		Listed Building Grade II

Table 6 - Buildings heritage typologies and grades in England and Mediterranean Laws (footnotes 15 and 16)

This process is conventionally used in the heritage listing performed under the diverse national regulations and international conventions. World Heritage can be considered at the top of this grading by its OUV and is normally integrated in national regulations under an autonomous grade or assuming the top grade (*e.g.* in Portugal it is automatically listed as the top grade of 'national monument'). Table 7 presents a detailed system of built heritage and historic urban landscape grading defined in the ICOMOS HIA report (2011), which adopts some of the criteria widely used in the national laws. Also transversal in the legal texts is the association between the heritage degree of significance and the relevance it has to a certain geographical area, as expressed by 'local', 'national' or 'universal' grades.

Asset value grading scale		**Built Heritage or Historic Urban Landscape**
1	**Very High**	Sites or structures of acknowledged international importance inscribed as of universal importance as WH property.
		Individual attributes that convey the OUV of the WH property.
		Other buildings or urban landscapes of recognised international importance.
2	**High**	Nationally-designated structures with standing remains.
		Other buildings that can be shown to have exceptional qualities in their fabric or historical associations not adequately reflected in the listing grade.
		Conservation Areas containing very Important buildings.
		Undesignated structures of clear national importance.
3	**Medium**	Designated buildings. Historic (unlisted) buildings that can be shown to have exceptional qualities or historical associations.
		Conservation Areas containing buildings that contribute significantly to its historic character.
		Historic townscapes or built-up areas with important historic integrity in their buildings, or built settings.
4	**Low**	"Locally Listed" buildings.
		Historic (unlisted) buildings of modest quality in their fabric or historical associations.
		Historic Townscape or built-up areas of limited historic integrity in their buildings, or built settings.
5	**Negligible**	Buildings or urban landscapes of no architectural or historical merit; buildings of an intrusive character.
6	**Unknown potential**	Buildings with some hidden (*i.e.* inaccessible) potential for historic significance.

Table 7 – Built heritage and historic urban landscape values grading *in* (ICOMOS, 2011, p.14-16)

2.4.3 – Heritage Impact Assessment

The heritage legal texts analysed are vague in defining the intervention criteria to be used in listed buildings, or on how to measure the impact of change in their heritage significance. This is usually performed in a process of building consent, which is casually evaluated by national or local heritage authorities.

The EIA framework again proves to be the most complete approach for assessing the consequences of change on heritage management. The impact prediction pointed out by Therivel and Morris (2009), stresses the necessity to cover the direct/primary, the indirect/secondary and the cumulative impacts, demonstrating that change occurring indirectly in other scales or along time by cumulative processes must also be considered in the assessment. This is of particular relevance for traditional buildings as it addresses the problem posed by the small direct impacts occurring in the single unit which can have a large significance along time for the historic site. Additionally, the authors classify the impacts accordingly with the characteristic of the effects: "positive (beneficial) or negative (adverse); short-, medium-, or long-term; reversible or irreversible; and permanent or temporary" (Therivel and Morris, 2009, p.8). Furthermore, the qualitative assessment of the impacts uses the rating of 'neutral', 'slight', 'moderate' and 'large', either 'negative' or 'positive', resulting in a system of seven grades. Due to its subjective nature, the heritage impact assessment has to be approached under a similar qualitative process.

In the London's Barbican and Golden Lane listed buildings management guidelines, Avanti Architects proposed a system of colours[17] (2005; 2007), establishing a direct relation with the requirements for the Listed Buildings Consent (LBC). Similar to traffic lights, this scheme grades the admissible types of intervention, translating the acceptable level of change of the values identified. The process determines the fundamental attributes of the building's design which convey them their cultural significance and are unacceptable to be changed. This encompasses the visual characteristics of the object, but also the intellectual value embodied on it. The guidance is applicable to diverse types of alteration: external elements, common areas, flat interiors, private terraces and balconies.

The ICOMOS report on HIA (2011) proposes a system based on the definition of a scale with five grades of impacts (table 8), which is further combined with the heritage grading, addressing separately the World Heritage (table 9) from the other categories (table 10). By

[17] - The scheme uses green, amber, red and black, referring the first to alterations which pose no problem and the last to changes where consent is unlikely to be granted.

combining the information in a matrix, the 'significance of effect' or the 'overall impact' caused to the asset can be obtained.

The tools used to measure the impact rely on the expert's consideration, but can thereafter be validated through public consultation processes (ICOMOS, 2011). More direct methodologies, like the use of architectural models or digital 3D modelling, can reinforce public participation which allows a non-expert audience to take part in the impact assessment (ICOMOS, 2011). Nonetheless, the evaluation of the impacts is always a subjective process, leading to the use of qualitative methodologies. It is also necessary to stress the necessity of promoting reversible interventions in order to comply with the current democratic and dynamic processes of heritage valuation (Orbaşli, 2008).

Impact Grading		Built Heritage or Historic Urban Landscape
1	Major	Change to key historic building elements that contribute to OUV, such that the resource is totally altered.
		Comprehensive changes to the setting.
2	Moderate	Changes to many key historic building elements, such that the resource is significantly modified.
		Changes to the setting of an historic building, such that it is significantly modified.
3	Minor	Change to key historic building elements, such that the asset is slightly different.
		Change to setting of an historic building, such that it is noticeably changed.
4	Negligible	Slight changes to historic building elements or setting that hardly affect it.
5	No Change	No change to fabric or setting.

Table 8 - Built heritage and historic urban landscape impacts grading *in* (ICOMOS, 2011, pp.16-17)

Value of heritage asset	Scale & Severity of Change/Impact				
	No Change	Negligible Change	Minor Change	Moderate Change	Major Change
For WH properties Very High - Attributes which convey OUV	Significance of Effect or Overall Impact (either adverse or beneficial)				
	Neutral	Slight	Moderate/ Large	Large/Very Large	Very Large

Table 9 – Change/Impact in World Heritage *in* (ICOMOS, 2011, p.9)

For other heritage assets or attributes	Significance of Impact (either adverse of beneficial)				
Very High	Neutral	Slight	Moderate/Large	Large/Very Large	Very Large
High	Neutral	Slight	Moderate/Slight	Moderate/Large	Large/Very Large
Medium	Neutral	Neutral/Slight	Slight	Moderate	Moderate/Large
Low	Neutral	Neutral/Slight	Neutral/Slight	Slight	Slight/Moderate
Negligible	Neutral	Neutral	Neutral/Slight	Neutral/Slight	Slight

Table 10 – Significance of impact in heritage *in* (ICOMOS, 2011, p.10)

2.5 - Conclusion

Recent literature points to the democratisation of the heritage valuing process, which displaces the conservation experts' exclusivist field to communitarian involvement. Globalisation also allows the process to be stretched from the local communities to a worldwide scale. At the same time, the cultural context, which is subject to change over time, plays a determinant role as the values of past societies are not necessarily coincident with that of present ones. Dynamic and democratic are characteristics which are today unavoidable in heritage valuing. Even so, the traditional expert's studies are still fundamental in the heritage valuing methodology. The result of such processes should be reverted into a cultural heritage '**significance statement**', which must be respected in any change management process.

In the specific case of traditional buildings inserted in an urban historic core as the ones object of the research, of modest singular significance, the assessment of values must take into consideration both, the unit and the ensemble. Moreover, when the outstanding universal value is recognised through the inscription on the world heritage list, it adds the necessity of conserving their identified authenticity and integrity. However, if integrity is object-based, authenticity is dependent on the cultural context in which the object is inserted. In general, traditional urban buildings possess in themselves a commonly recognisable set of values: design (influences from erudite architecture), artistic (presence of artistic or skilled crafts details) and technological (place based construction systems and local materials). Furthermore, their urban image is the most incisive characteristic which contributes to shape the urban historic landscape.

The next stage of the process consists of benchmarking values: they are never absolute, but relative to something to which they must be compared, measured and graded. The final stage is to assess the impact of any change which should be done against the baseline study ('statement of significance'), which summarises the asset's values. Accordingly, it is necessary to understand the changes occurring in order to evaluate and grade their impact on heritage. Consequently, it is fundamental to acknowledge the energy efficiency framework to further assess the consequences of its implementation in traditional buildings.

Chapter Three: Traditional Buildings and Energy Efficiency

Chapter Three: Traditional Buildings and Energy Efficiency

3.1 - Introduction

The objective of this chapter is to discuss the main concepts and parameters concerning traditional buildings and energy efficiency in order to further identify the framework which relates these two subjects under the scope of this research.

In order to achieve such an objective it is necessary to understand the specificity of traditional buildings, namely their definition and their clustering from the universe of buildings. Furthermore, the concept of refurbishment to be used is addressed and its integration discussed in the wider framework of urban sustainability, which is underlined in the philosophy of the current research project.

The general concept of energy efficiency and the specific approach for buildings are discussed afterwards. Additionally, the building physics and the specific parameters that influence energy efficiency in traditional constructions are analysed. The thermal performance of traditional buildings and their assessment are discussed at the end of the chapter. Overall, this chapter establishes the basis for the framework which will be explored in the next chapter in order to identify adequate solutions for this type of heritage-valued construction.

3.2 - Traditional Buildings

In this field of research it is usual to employ several terms, such as ‘vernacular’, ‘historic’, ‘traditional’ or just simply ‘old’, to define existing buildings. The use of the statistical classification of buildings by their construction age is a widely established method for clustering the existing stock (Balaras *et al.*, 2007; Neidhart and Sester, 2004; Ravetz, 2008; Tabula Project Team, 2012). This grouping is based mainly on the distinct types of construction systems identified for each time period, establishing symbolic dates which represent moments of change. Under this methodology the category of built ‘before 1919’ defines the frontier for ‘old’ buildings (UNECE, 1998). As affirmed by May and Rye, this generic classification reveals “(…) a lack of typological analysis and distinction of traditional buildings in stock modelling” (2012, p.22). The conceptual idea expressed in the *Charter on the built vernacular heritage* ties these buildings to their local or regional roots, giving form to a coherent typological responsiveness which reveals a specific cultural significance (ICOMOS, 1999). This becomes patent in the informally transmitted design and construction systems, which are effective responses to functional, social and environmental constraints. The counterpoint to the notion of globalisation is then the core of this concept, which is also related to the widespread use of standardised construction systems that occurred after the Second World War (Nicol, 2012).

The most common traditional construction system found in European historic cities from the Mediterranean comprises the use of solid stone or wood-framed walls, pitched roofs and wood as the main material for floor structures and frames. (Communities and Local Government, 2012; Eurostat, 2012).

Oporto's Traditional Buildings

Oporto's traditional urban buildings also clearly show centennial responsiveness to social and place interaction. Complementary, the influence of the architectural design of the city's historic buildings is evident in all stages of its evolution (Alves, 1988; Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992). Furthermore, the cosmopolitan influence on their design, resulting from the essence of the city as a port, is also identifiable. Overall, this resulted in a mix between traditional construction techniques and an envelope design with transnational architectural influence. This allows affirming that these buildings are both the result of place-rooted traditional vernacular processes as well as of semi-erudite design. Additionally, they are the most representative forms that shape the built environment of the Oporto World Heritage Site, both in number and typological coherence, and constitute a built stock which must inevitably be considered in the city's urban regeneration policies.

3.2.1 – Refurbishment

As referred by Kurrent, spatial architectural structures have usually a longer life than the functions for which they were conceived (1978). Hence, the intervention and transformation of existing buildings has always been a recurrent theme in the field of architecture, pursuing functional adaptation or aesthetical and cultural updates. Since the 1960's, the consciousness about traditional buildings has been growing, leading to a revisited interest in their adaptive integration into contemporary life in present times. The recognition of such a framework was affirmatively expressed by Lampugnani: "(...) the ephemeral construction in which we are forced to live never satisfied the wish of eternity that induces the work of architecture (…). We are disappointed and wishing for our modern houses the same solidity that we can find in old buildings"[18] (1992, p.II). Furthermore, Brand condensed this feeling by stating that "age plus adaptivity is what makes a building come to be loved" (1994, p.23). Resilience and 'vintage' are then the characteristics which allow traditional buildings to renew their role in the contemporary society.

The act of intervention applied to existing buildings is usually classified under a large number of terms: 'restoration', 'reconstruction', 'rehabilitation', 'refurbishment', 'retrofit', 're-architecture', 'remodelling', and 'renovation'. These terms reveal the diverse degrees of change allowed for each building based on its heritage value, ranging respectively from most conservative until least conservative. Under this principle, 'restoration' is commonly applied to historic buildings of high architectural value, as expressed in the *Venice* and *Burra Charters* (ICOMOS, 1964; ICOMOS Australia, 2000). The denomination of 'reconstruction' is also applicable to buildings of high architectural value, though in this scenario they are extremely damaged and require a more profound intervention, which consists of "returning a structure to a known earlier state by the introduction of new material into any remaining fabric" (ICOMOS Australia, 2000, p.2). The terms 'rehabilitation', 'refurbishment' and 'retrofit' apply to the greater bulk of traditional buildings, embarking varying degrees of heritage value and consequently allowing diverse levels of change. The first of these terms is currently used in Latin languages[19] and equivalently expresses the possible intervention in traditional and vernacular buildings with heritage value. The word is commonly used in English as well, but less regularly in terminology and literature addressing the intervention on existing buildings. The remaining three definitions are applied to operations which address existing buildings without heritage relevance, allowing a less conditioned process of change.

The most frequent terms currently applied in literature to describe energy efficiency upgrades in traditional buildings are 'refurbishment' and 'retrofit'. However, even if the second term is increasingly used in literature, it is more generic and originally addresses the upgrade of any object to improve its performance, which may include specific measures in a building, but also in all types of equipment and services. As pointed out in a recent report, 'refurbishment' relates to the idea of a whole-house solution, while 'retrofit' is based on particular solutions

[18] - Free translation from Italian.

[19] - French - *réhabilitation*, Italian - *riabilitazione*, Spanish - *rehabilitación* and Portuguese – *reabilitação*.

(National Refurbishment Centre, 2012). Conclusively, the most adequate term to be used in the context of this research is 'refurbishment'.

3.2.2 – Sustainability and refurbishment

The relationship between sustainability and heritage, subjacent to this research, is not an internal process of heritage conservation, as expressed by Throsby (2002), but the idea that built heritage can still play an active part in the present, while at the same time addressing the issues of urban sustainability. This concept is closer to the contemporary role advocated to vernacular architecture by several authors (Asquith and Vellinga, 2006) and complementary to the union between 'modernity' and 'tradition' as present in work of the Portuguese architect Fernando Távora (Távora and Costa, 1993).

In this sense, the refurbishment of traditional buildings has to be understood as inserted in a dynamic process of transformation, which also addresses the two parallel topics of climate change: adaptation and mitigation. In the context of the present research, the focus is on the energy efficiency upgrading, which is also understood as a sustainable strategy. Moreover, several other potential sustainability gains can be achieved with a refurbishment strategy, *e.g.* land conservation, reuse of materials, energy savings in construction and transportation, waste reduction and local economy stimulation. This is reinforced by stressing the importance of the 'embodied energy' in buildings as a driver for promoting refurbishment (Cassar, 2006; Empty Homes Agency, 2008; Heath, 2000).

Douglas emphasizes the concept of future proofing in the adaptation of buildings, arguing that this process should also consider the possibility of future uses (2006). Adaptability is further discussed at an urban level by Scoffham and Marat-Mendes, stressing that the traditional urban block offers the best shape for allowing change over time, and thus may be suitable for sustainability (2000). The environmental gains of Traditional Neighbourhood Design (TND) are also noted by Buxton (2000). Moreover, Salvador Rueda stresses the similarity between traditional urban patterns and the compact urban model, pointing out their social, economic and environmental advantages over the diffuse[20] (2000).

[20] - The diffuse model is represented by the low density suburban development which sprawled around the compact urban centres.

The future weather is also highlighted by Douglas as a factor that should be taken into account when addressing the climate change adaptation in buildings (2006). In the *Rough guide to sustainability*, Brian Edwards introduced the refurbishment of buildings as the 4th 'R' of the environmental policy (2002). A similar approach is supported by Rodwell (2007) and complemented by Carroon (2010), who introduces 'repair' between 'reduce' and 'reuse' and puts a focus on this crucial aspect of the lifecycle of existing buildings. The last author also argues for the global CO_2 emissions to be avoided by the reuse of buildings, stressing further the necessity of using low carbon materials in their refurbishment. Cassar supports this perspective, adding the physical dimension of the historic environment as the fourth pillar of sustainability, focusing "(…) on the contribution that historic buildings make towards sustainability and how historic buildings can be 'demonstration models' of sustainability for society" (2006, p.1). Additionally, several authors point out the cultural advantage of safeguarding heritage through the refurbishment policy for buildings (Cassar, 2006; English Heritage, 1997; Lewis, 1999; Rodwell, 2003).

Using the Life Cycle Analysis (LCA) for buildings, several Swedish case studies by Erlandsson and Levin concluded that refurbishment is usually more environmentally favourable than new construction (2005). Furthermore, it is stressed that this would also indirectly reduce CO_2 emissions from the transport sector, as bringing more inhabitants to the historic city centre would reduce the daily commute traffic with the suburbs. As affirmed by Roaf *et al.*: "sustainable buildings are not about fashion or style; they are about performance, resilience and adaptability" (2004, p.15).

The introduction of low carbon design practices added a green dimension to refurbishment, allowing existing buildings to perform at higher environmental and comfort levels. This is recognizable by the application of environmental assessment and certification schemes to traditional buildings, like LEED or BREEAM (Campagna and Frey, 2008; Ferguson, 2011; Young, 2008). Similarly, the Portuguese sustainable buildings scoring system (*LiderA*) rates the intervention in existing built structures as the most sustainable (Pinheiro, 2007). More recently, the concept of sustainable refurbishment has emerged, which stresses the role of energy efficiency as one of the most relevant objectives to be achieved (Andresen *et al.*, 2004; Anne, 2008; Douglas, 2006; Energy Saving Trust, 2010b; Mickaityte *et al.*, 2008; Zavadskas *et al.*, 2008). Keeping and Shiers based their concept of 'green refurbishment' on the downgrade of building services and on the enhancement of the passive techniques to achieve acceptable levels of comfort (1996). The authors argue that this will allow cutting down on energy and maintenance costs due to the use of low-tech equipment, which is low energy and is cheaper to repair or replace.

The theme of sustainable refurbishment applied to traditional buildings has also been widely promoted, leading to recent strategic research and practice promotion in the UK by the BRE, which established a specific sustainability scheme for traditional buildings refurbishment – *EcoHomes XBC* (National Refurbishment Centre, 2011; Yates, 2006). Conclusively, it is possible to affirm that traditional buildings emerge with a large potential for improving their environmental performance, contributing to the wider policies of climate change mitigation.

3.3 – Energy Efficiency

Energy efficiency is defined as "the ratio of useful energy output of a system, conversion process or activity to its energy input" (IPCC *et al.*, 2007, p.814). At a macro scale this includes the optimisation of energy production, distribution and consumption processes, minimising losses and consequently achieving lower levels of CO_2 emissions (Irrek *et al.*, 2008).

The EU *Energy Efficiency Plan 2011* points to the distinction between energy efficiency and energy saving. The first is defined as a narrower concept which embraces the above idea of equipment optimization, while the second encompasses "consumption reduction through behaviour change or decreased economic activity" (EC, 2011, p.2). However, this text also stresses the difficulty in practice of distinguishing between the two concepts which are used interchangeably. Under the current policy a wider concept is applied by including the local production of renewable energy and balancing the consumption in a smart grid system. As pointed out by Irrek *et al.* (2008), this last approach can be addressed from several perspectives and scales, ranging from macro-economic to end-use. In the context of the present research the focus is on the end-use energy efficiency perspective, which is achieved through technical upgrade or behavioural changes.

3.3.1 – Buildings energy efficiency concepts

The World Energy Council (WEC) report *Energy efficiency: a recipe for success* (2010) proposes two complementary action lines to achieve a reduction in energy usage: technical and non-technical or behavioural. Inserted into this overall framework, the following core concepts are directly related to buildings, covering the various possible scopes in addressing their energy efficiency.

Economic vision and fuel poverty

The WEC study explores the definition of energy efficiency framed by the economists, encompassing "(…) all changes that result in decreasing the amount of energy used to produce one unit of economic activity" (2010, p.5). However, the study stresses that savings obtained from financial constraints, resulting from high energy prices, must not be included in the scope of energy efficiency and emphasises in the report that it should not be achieved at the expense of the home thermal comfort. This context alludes to the concept of 'fuel poverty', *i.e.* when households are unable to spend 10% of their income on energy, leading to a forced reduction in energy consumption and thus the inability to fulfil the criterion of being able to keep a warm level of comfort (20˚C during all of winter) (Magalhães and Leal, 2012).

Cost-effectiveness and eco-efficiency

The economic perspective also includes the cost-effectiveness of the solutions adopted, balancing the investment in energy efficiency measures with the savings obtained in a viable time period, *i.e.* the ratio of benefits to expenses (Irrek *et al.*, 2008). This economic efficiency perspective must be complemented with the environmental perspective to avoid missing the climate change objectives. Current EU policies address both topics, adding eco-efficiency objectives to the cost optimal energy-efficiency policy (EC, 2009; EC, 2011). This relation is based on resource conservation that considers the complete life-cycle of materials and products in an integrated eco-design philosophy while avoiding the eventual use of solutions which are energy intensive in their production, thus nullifying the positive effect by increasing their embodied energy.

Technology

The technological approach is a vast field, including in buildings the areas of energy conservation, energy efficiency and local energy processes. Energy conservation relates to the capacity of improving the final energy conservation when it is used for heating and cooling in buildings. The optimization of building envelopes (opaque and glazed surfaces) through the improvement of their insulation and draught-proofing are the most relevant conservation technologies in buildings (Warren, 2003). Energy efficiency involves the optimization of the energy use in all types of building equipment, covering lighting, appliances, domestic hot water production, heating and cooling services. Local energy processes refers to the possibility of optimizing the local energy production/transformation and distribution, consequently increasing the efficiency in relation to the larger grids distribution. An example for these local processes is district heating/cooling, using combined heat and power – CHP or combined cooling, heat and power – CCHP. It can also be employed on a micro level with combined heat and power implemented at building or home levels. Their efficiency becomes apparent when comparing the transformation of primary energy in a thermal power plant with that of the local transformation of natural gas, which present respective efficiencies of 40% and 80% (AdEPorto, 2010).

Renewables

Today, the use of renewable energy sources (RES) for power or heat production is one of the most adopted strategies when dealing with energy efficiency in buildings. It can be implemented at macro level (national or international grids), at neighbourhood level (solar district heating/cooling) and at building level (micro-wind generation, biomass, air and ground source heat pumps, solar photovoltaic and solar thermal hot water) (Energy Saving Trust, 2010b).

Under the current Portuguese building thermal performance regulation (Portugal, 2006a) the installation of solar thermal collectors for domestic hot water (DHW)[21] is mandatory in new residential buildings or for major renovations, in order to take advantage of the Portuguese high solar radiation. Furthermore, the introduction of renewables in the national electric grid is also a national policy to simultaneously address climate change and fuel dependency (Portugal, 2006b; Portugal, 2008).

Behaviour

The role of human behaviour in terms of energy usage is another vector explored by energy efficiency policies. The promotion of consciousness for the optimal use of energy, in particular in the residential sector, is fundamental for achieving energy savings. The focus on the technical approach is ineffective if not complemented with optimal energy usage. As argued by

[21] - It is defined in the Portuguese thermal regulation as the potable water used for bathing, cleaning, cooking and other purposes, heated at more than 35°C on a specific equipment using conventional or renewable forms of energy (Portugal, 2006a, p.2475).

Herring and Roy, simply promoting technical innovation is unlikely to lead to a reduction of energy consumption and emissions (2007).

3.3.2 - Buildings energy efficiency framework

It is possible to affirm that the energy efficiency framework for buildings involves both the energy conservation and the energy production through renewable sources. Conservation must complementarily address technological and behavioural approaches to achieve the best results. Addressing it through a single perspective will likely not produce the expected energy consumption reductions.

Energy efficiency addresses all stages of a building's life-cycle: design, construction and operation (CIBSE, 2012). The approach shown in figure 4 is based on achieving a balance between energy consumption and production, with the goal of creating 'Net Zero-Energy Buildings' (NZEB), which is an objective of the current EPBD recast. Under this framework two phases are outlined: an improvement in building performance, including system efficiency and household behaviour, and the introduction of on-site energy generation from renewable energy sources. This principle is valid for achieving energy efficiency, both in new and existing buildings (Sartori *et al.*, 2012).

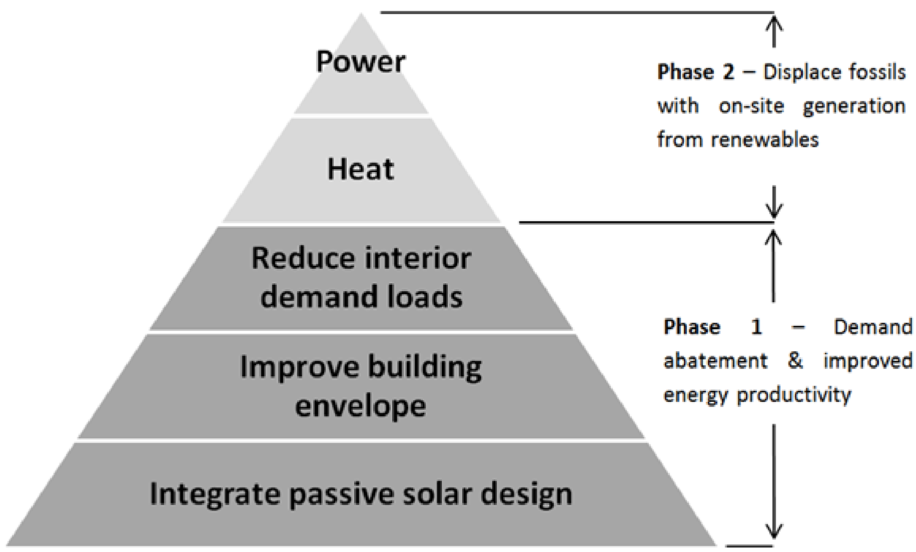

Figure 4 – Net Zero-Energy Buildings (NZEB) step approach for the existing stock *in* Ayoub (2011, p.9)

This framework can be extended to form a broader approach by integrating supplementary passive techniques, *e.g.* natural ventilation and lighting, and adding an on-site tri-generation strategy, as proposed in figure 5. This framework will be the base for approaching the energy efficiency of traditional buildings in the current research.

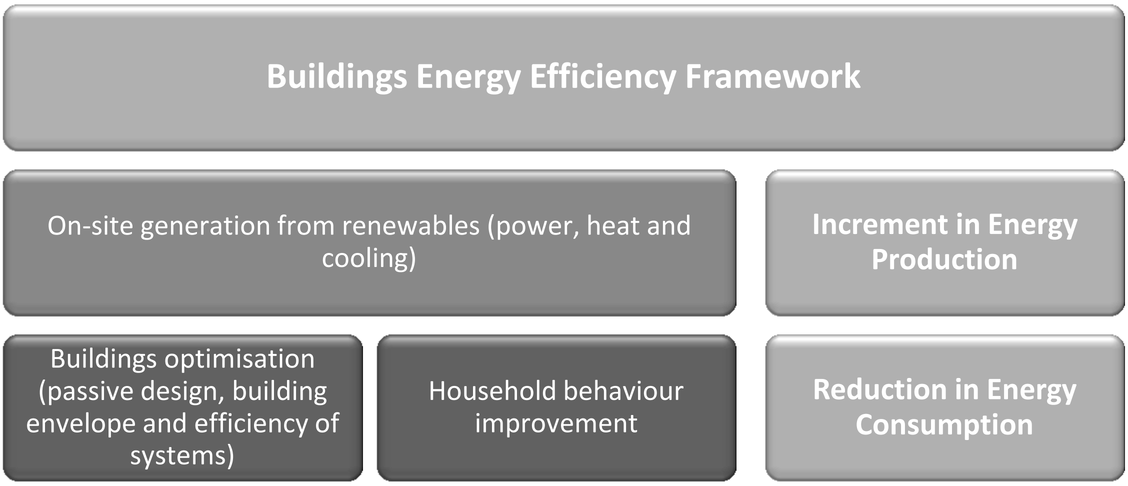

Figure 5 – Proposed buildings energy efficiency framework

Portuguese energy efficiency framework

In Portugal it is mandatory for all new buildings to meet the new requirements of the RCCTE thermal regulation, which establishes maximum annual rates for energy consumption[22]. The methodology adopted identifies a building's thermal performance by balancing heat transfer (through the envelope, thermal linear bridges and air renovation) with useful heat gains (lighting, equipment, occupants and solar gain through glazed elements). At the same time, several building parameters have to be met (envelope heat transfer coefficients, area and solar factor of the glazing elements, inner thermal inertia and roof solar protection). Additionally, any other production from RES is separately valued in the calculations, which allows for balancing possible existing energy conservation deficits.

3.4 – Factors Influencing Energy Efficiency in Traditional Buildings

An analysis of the envelopes of existing buildings in Europe shows low insulation and high air leakage levels within the oldest stock (BPIE, 2011). Furthermore, Guyot *et al.* state that the "envelope leakage can increase the heating needs by 5 to 20 kWh/m^2/year in a moderate

[22] - It determines maximum values for heating, cooling and DHW in kWh/m^2.year, which are further combined to give a global amount, that must be under the maximum admissible 'yearly global primary energy demand' (Nt - kgep/m^2.year). These values are established for the heating and cooling seasons and for the weather zones officially defined.

climate (2500 to 3000 degree-days) given today's levels of airtightness" (2010, p.7). These two factors may explain why southern European countries consume relatively high levels of energy for heating despite their lower heating needs due to milder winters (BPIE, 2011). However, the average Portuguese wall U-value decreased by 50% during the last five years as a consequence of the new thermal regulation application (BPIE, 2011).

The BPIE study draws a framework for the energy refurbishment of existing buildings and highlights the most effective measures detected:

> - Improving the thermal performance of the building fabric through insulation of walls, floors and roofs, and replacement and tightening of windows and doors.
> - Improving the energy performance of heating, ventilation, air conditioning (HVAC) and lighting systems.
> - Installation of renewable technologies such as photovoltaic panels, solar thermal collectors, biomass boilers, or heat pumps.
> - Installation of building elements to manage solar heat gains. (2011, p.100)

This approach fits into the general scheme of figure 5 and is confirmed by other studies which are supported by fieldwork and case studies analysis (Energy Saving Trust, 2010b; HFWG, 2009; Richarz *et al.*, 2007).

The level of intervention is also fundamental in refurbishment operations for existing buildings. This is addressed in the EPBD recast by crossing the cost optimal approach with several possible levels of action: building, building unit and building element (*e.g.* window, door), which are also constrained by the type of ownership. The energy efficiency upgrade of existing buildings differs from the approach for new buildings due to the major role played by the operational stage of a building's life-cycle (CIBSE, 2012). When existing buildings are redundant or inoperative, the approach has to be made mainly through an upgrade of their fabric performance (Ma *et al.*, 2012).

At the same time, the behavioural aspect of energy efficiency must complement the fabric retrofit of existing buildings. The households' feedback must be added to the physical assessment in order to provide a 'whole-house' approach (Gupta and Chandiwala, 2010). The post-occupancy evaluation (POE) is the usual technique used to understand the occupants' behaviour, as performed by the Probe project (Bordass *et al.*, 2001a; Bordass *et al.*, 2001b; Bordass *et al.*, 2001c; Cohen *et al.*, 2001; Leaman and Bordass, 2001).

3.4.1 – Building physics parameters

The thermal performance of the fabric is crucial in determining a building's energy consumption and to further identify the necessary upgrade measures. The thermal performance of buildings depends directly on the physics of materials and construction systems. Based on Fourier's Law for heat conduction, the basic principles for heat transfer in buildings are associated with two physical characteristics of materials: **thermal conductivity** (k) and **specific thermal resistance** (Rλ), expressing respectively the characteristic of materials to allow or resist heat conduction[23]. Derived from these parameters are the **overall thermal transmittance** (U) and the **total thermal resistance** (RT), which express the total values for the building's fabric elements, *i.e.* for the total materials thickness or for the sum of their diverse layers of materials (Hall and Allinson, 2010). These last two parameters are commonly named as '**U-value**' and '**R-value**'[24], and are conventionally the reference values for the thermal performance of a building's fabric under the thermal regulations and standards worldwide[25] (Portugal, 2006a; Santos and Rodrigues, 2009; Santos and Matias, 2007). They apply to the opaque and glazed elements of the building's envelopes alike and benchmark the capacity of the fabric to sustain the thermal indoor environment in order to provide comfort to the occupants with an optimal usage of energy. These parameters are also influenced by the **air permeability** ($m^3/h/m^2$) and **moisture** (percentage of water), two factors which have to be considered in the energy performance calculation.

Apart from the direct '**conduction**' of energy, heat transfer through fluid ('**convection**') and electromagnetic waves ('**radiation**') also need addressing (ASHRAE, 2009; Washington State University, 2008). Furthermore, the external environmental influence on the building's envelope is determinant to its overall performance. The way solar energy interacts with the envelope throughout the year is translated into additional parameters: external walls **light**

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[23] - The first is measured in watts per meter kelvin [W/(m·K)], while the second is inversely measured in meter kelvin per watts [(K·m)/W].

[24] - Respectively measured in watts per square meters kelvin [$W/(m^2 \cdot K)$] and in square meters kelvin per watts [$(K \cdot m^2)/W$].

[25] - In Oporto's climate zone, the maximum admissible U-values for the vertical and horizontal opaque elements, are respectively 1.6 and 1 $W/m^2.°C$ (Portugal, 2006a).

absorption coefficient (α - influenced by the colours used), **solar gain**, glazing **shading coefficient** and incident **light transmittance**.

Thermal mass is another relevant factor which influences the fabric's heat transfer. Basically, it refers to the capacity of the building fabric to store and lose heat over time (kJ/m^2K). This process is determined by the following parameters: the **specific heat capacity** (amount of heat required to change by one degree the temperature of a substance's unit mass - J/kg.K), the **mass density** (mass of the material per unit of volume - kg/m^3), the **thermal conductivity** and the **surface resistance** (m^2K/W) (The Concrete Centre, 2012).

Passive design strategies make use of the building's physical characteristics and local weather conditions, allowing for energy to be saved through a bioclimatic approach (*e.g.* natural lighting and ventilation, solar gains and thermal mass heat storage). A temperate climate like the Portuguese enhances the viability of implementing passive design strategies. Additionally, traditional buildings usually possess a high thermal mass and were designed to take advantage of passive characteristics, which enhances their potential for improving energy efficiency (Wheatley, 2008).

Conclusively, it is possible to affirm that the improvement of these building parameters is the key to upgrading the thermal performance (heat transfer) of a building's envelope. This is confirmed in literature as well, where it is pointed out that an increase in insulation is an effective way of improving the energy performance of existing buildings and reduces the typical heat losses detected in walls (35%), roofs (25%), floors (15%) and windows (10 to 15%) (Department for Communities and Local Government, 2006; Livesey *et al.*, 2013). However, while this can be accounted for at the design stage for new buildings, thermal improvement for the envelope in existing buildings is a heavyweight investment in which cost-effectiveness has to be carefully considered.

3.4.2 - Building systems

The building systems in the context of this research include all devices using energy that are necessary for the building's operation, namely, all the equipment used for heating (space conditioning and water), cooling (space conditioning and food refrigeration), cooking, entertainment (media) and lighting. The intensity of usage and the equipment efficiency are the main drivers of energy optimisation in building systems, which crosses technological improvement with behavioural enhancement.

The energy labelling and eco-efficiency policies mainly address the technological framework, while smart-metering promotes behavioural change by improving the conscientiousness of the real energy consumption. From this perspective, the occupants' behaviour is determinant for improving energy efficient practices. Additionally, the upgrade of the equipment efficiency must be cost-effective in order to make its implementation feasible.

3.4.3 – Occupants' Behaviour

The framework of the behavioural approach can be divided into choice and pattern of use. The first relates to the selection of the most efficient equipment and building services, accordingly with the global policies of energy labelling in appliances, lighting, heating and cooling equipment (EURECO, 2002). The second deals with the efficient and conscientious use of said equipment, with special relevance in the residential sector to the stand-by mode reduction, the lighting operation, the thermal environment control (including equipment, openings and shading devices) and the efficient use of appliances (*e.g.* use in off-peak hours). This second line is complemented by the recent smart-metering policy, leading to potential energy savings by promoting the 'demand side management (DSM)' (EC, 2006). An ongoing smart-metering field study revealed that it was possible to reduce energy consumption by 20% per house over one year in the Spanish pilot project (Gas Natural Fenosa, 2012).

In the UK the average yearly standby and off-mode consumption varies between 343 kWh and 591 kWh (Energy Saving Trust and DEFRA, 2012). In Portugal, studies undertaken by *Quercus* revealed an average yearly consumption of 194 kWh per dwelling, corresponding to 4.8% of the inhabitants' annual energy bill (Ferreira *et al.*, 2008; Ferreira *et al.*, 2011; Quercus, 2008). The *Selina Project,* which studied this specific subject at European Union level, stresses that addressing this through policies (energy labelling), funding and promoting household consciousness, will be expected "to achieve very large cost-effective savings of electricity (80 TWh projected by 2020) and carbon emissions (30 MTons of CO_2 by 2020)" (SELINA, 2011, p.10).

Overall, it is estimated that a household's potential for energy savings in the EU27 by 2020 (with 2004 as the base year) may vary between 7.2% and 28.9%, for low and high-optimistic scenarios (Fraunhofer-Institute for Systems and Innovation Research *et al.*, 2009). Moreover, Almeida *et al.* stress that the combination of behavioural and technological approaches can be more effective, leading to potential electricity savings in the European residential sector of up to 48% (2011).

Fuel poverty

Today, the relation between energy consumption and poverty is a developing line of research (Bouzarovski *et al.*, 2012). In recent studies, it was revealed that Portugal is one of the most vulnerable countries in context of the European Union (Thomson and Snell, 2013; WHO, 2012). This was also confirmed in previous research by pointing to the high rate of deaths occurring in winter, mainly among the elderly population, that were caused by fuel poverty (Bouzarovski, 2011; Healy, 2004). Another study estimates that 50% of the Portuguese mainland households are living under fuel poverty conditions (Magalhães and Leal, 2012). Further, it points out that these rates calculation accounted for the social prices of energy still available, rising to 92% if they are ignored in the estimating model. Even if these perspectives are based mainly on statistical analysis and simplified comfort models, they reveal a scenario which is probably less severe than the reality, but still troubling. Accounting for a future liberalization of the energy market and the economic distress, this will probably aggravate. Additionally, the projection for the Portuguese population reveals an accentuated ageing process, forecasting three elderly for each young in 2060, being predictable a greater exposition to the risk of fuel poverty (INE, 2009; INE, 2010). This is relevant in the context of Oporto's historic centre since the majority of these households are elderly people with low income (Azevedo and Baptista, 2010; INE, 2011).

3.4.4 - Indoor thermal comfort

The level of indoor thermal comfort is another factor that influences the use of energy in buildings and is directly associated with the occupants. Thermal comfort refers to the achievement of a level of "satisfaction with the thermal environment and is assessed by subjective evaluation" (ASHRAE, 2010, p.2). It depends on several factors, which are condensed in the ASHRAE thermal comfort standard under two categories: environmental (temperature, thermal radiation, humidity, and air speed) and personal (level of activity and clothing[26]) (ASHRAE, 2010). The combination of these parameters provides a temperature

[26] - With an associated system of measurement: 'met' units for human metabolic rate and 'clo' units for measurement of clothing insulation.

range, in which the sensation of human comfort lies. However, this assessment is very complex and dependent on climate, culture and individual sensorial factors (both psychological and physiological), rendering it subjective.

The models and methods developed by Olgyay (1963), Givoni (1969), Fanger (1972) and Dear *et al.* (1997) represent a wide variety of approaches for the determination of the thermal comfort zone. The major distinction between them resides in the static or adaptive perspective undertaken. The first approach is based on a fixed comfort temperature set for all year round and for all occupants, disregarding local specificities. The method developed by Fanger establishes the 'Predicted Mean Vote' (PMV) and the 'Predicted Percentage of Dissatisfied' (PPD), which are based on a person's direct vote on a seven point thermal sensation scale in a climatic chamber. This static method (PMV/PPD) is based on the statistics of these people's sensations, taking into account six environmental and personal parameters, but disregarding the human capacity to adapt to the local environmental conditions. The 2010 ASHRAE indoor thermal comfort standard also uses this method but poses certain conditions (metabolic, clothing and air speed) which must be met in order to determine the comfort zone (2010). It also introduces the 'elevated air speed method', allowing an increase of the comfort zone by incrementing the air flow, assuming that the occupants are able to control it.

Further research introduced the 'adaptive model' (Brager and Dear, 2001; Dear *et al.*, 1997; Dear and Brager, 2002) which was also integrated into the ASHRAE's standard and is accessible online to perform calculations (Tyler *et al.*, 2012). This model adds outdoor weather parameters, which influence human thermal comfort perception, rendering it climate responsive and variable throughout the year by relying on the human capacity to tolerate and adapt to different thermal conditions. This model is mainly suitable for naturally conditioned spaces, which "are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of windows" (ASHRAE, 2010, p.9). Traditional buildings were conceived to function under these passive characteristics and still usually depend on their use for performing the control of indoor thermal comfort.

The European EN 15251 standard (CEN, 2007) incorporates the revision of the adaptive model for Europe, following the results of the SCART's project (McCartney and Nicol, 2002). It extended the scope of indoor comfort by incorporating thermal, air quality, visual and acoustic dimensions. Comparisons between these two adaptive approaches were discussed in several research projects (Guedes *et al.*, 2009a; Halawa and van Hoof, 2012; Olesen, 2012; Roetzel *et* *al.*, 2011). The main differences pointed out reside in the calculation of the outdoor temperature (mean monthly outdoor temperature in ASHRAE 55 and outdoor running mean temperature in EN 15251) and in the comfort acceptability grades: PMV 80% and 90% in the ASHRAE 55 and categories I to IV in the EN 15251. 'Category III' is pointed out in the European standard as being the most suitable for complying with the thermal expectations of occupants of existing buildings.

Even if the fieldwork dissimilarities detected are not significant, the results show that both standards' comfort limits are exceeded in the Mediterranean area (Guedes *et al.*, 2009a; Roetzel *et al.*, 2011). Nicol and Mike (2011) performed a critical overview of the European standard, pointing out that the comfort perceived by occupants differs from the standard, leading them to conclude for the necessity of revising these limits, which should also be done in the ASHARE method. Based on previous research in free-running buildings (*i.e.* naturally ventilated), Roetzel *et al.* (2011) argued that the standard's inability to conform with the human comfort acceptability detected may be explained by the occupants' adaptive resilience. These authors also concluded that in the Mediterranean climate of Athens it is very difficult to fulfil the criteria of both adaptive comfort standards, which could lead to the inadequate use of mechanical heating and cooling. Conclusively, it is possible to assume that in temperate climates the use of passive techniques to control the indoor environment can be a successful strategy. This was also affirmed by Guedes *et al.* (2009b) who concluded that Portuguese traditional architecture depends on high thermal mass and other passive techniques to achieve the best possible indoor comfort.

Despite the incertitude of the adaptive models, due to the complexity of the human response to the environment, they are conceptually the best approach to determine the indoor comfort in existing buildings. As stated by Nicol and Humphreys (2009), this methodology relies on the interaction between building, occupant and environment, avoiding a closed building approach based on the use of heating, ventilating and air conditioning (HVAC) equipment. This approach has become part of the mainstream and can play an important role in the design strategy for low-energy buildings (Nicol, 2011). Thus, the adaptive comfort is naturally the approach to consider in traditional buildings, which have always relied on natural ventilation, passive technologies and human capacity to adapt. The challenge is to promote an acceptable thermal comfort range in their indoor spaces.

In Portugal, the buildings' thermal performance regulation establishes a fixed reference temperatures of 20°C for the heating season[27] and 25°C in conjunction with a relative humidity of 50% for the cooling season[28] (Portugal, 2006a). The local application of the adaptive method for the indoor comfort of buildings was approached in several Portuguese fieldwork studies (Guedes *et al.*, 2009a; Matias, 2010; Silva *et al.*, 2010). They concluded the inadequacy of the fixed model required in the regulation, and argued for the necessity of further fieldwork to confirm a local adaptive model. This is particularly stressed for the residential sector due to the insufficiency of fieldwork in this area, which is normally limited to offices.

3.4.5 – Cost-Efficiency

The economic dimension of the implementation of energy efficiency measures is a crucial aspect to determine their feasibility. The cost optimal energy-efficiency concept is not completely clarified in terms of their methodological application (EC, 2009; EC, 2011), despite the discussion promoted by recent studies (Atanasiu and Kouloumpi, 2013). The idea of cost-efficiency is mainly centred on the time needed to recover the initial investment, based on the financial results obtained from the energy savings. This is usually used in energy efficiency upgrade operations to determine the 'pay-back' or 'return of investment' (ROI) periods (Changeworks, 2008; Energy Saving Trust, 2010a; Yates, 2006). Like this, the assessment of the cost-efficiency is established, allowing for benchmarking the solutions to be implemented.

3.4.6 - Traditional Buildings thermal performance assessment

The analysis of the literature revealed a diverse perspective from the usual depreciation of traditional buildings in terms of their thermal performance. Moreover, and despite the specificity of their geographical location, it is transversal in traditional buildings to have a common responsiveness towards climate in order to achieve the desired comfort, which indicates a potential for their improvement.

This was confirmed in 1999 by the United States General Services Administration, which found that the historic buildings under their supervision used 7% less energy than other buildings (Wolf *et al.*, 1999). Similar results were found in Canada for commercial buildings (NRTEE-

[27] - Conventionally from October to May.

[28] - Conventionally from June to September.

TRNEE, 2009), and in the UK for court buildings (Wallsgrove, 2008). This last case stressed that pre-1900 buildings performed better than all others (197 kWh/m^2)[29]. Moreover, the study refers that the older buildings were continuously upgraded and no significant differences can be found between them and the remaining age bands in terms of equipment and systems (2008). The American report explains this performance based on the thick, solid walls of these buildings, resulting in greater thermal mass which normally improves insulation, thus requiring less energy for heating and cooling (Wolf *et al.*, 1999). Additionally, the use of natural lighting is also stressed, as these buildings were designed before the widespread use of electric lights and function based on large windows and high ceilings. Even if these results are too scarce to be generalized, they are a statement that these buildings can function based mainly on passive solutions.

Concurrently, traditional buildings with solid walls have a high thermal mass, whose enhancement is also seen as a passive design strategy to explore in the temperate climates (Araújo and Almeida, 2006; Kosny *et al.*, 2012; Richarz *et al.*, 2007; The Concrete Centre, 2012). The BRE case studies proved that the initial poor performance of traditional buildings is surmountable through the introduction of energy efficiency measure on their refurbishment process, allowing cuts exceeding 60% in energy and CO_2. This reveals the large potential residing in the improvement of these buildings.

English Heritage and Historic Scotland have also actively promoted research to evaluate the performance of traditional buildings. A good example is the work of Baker, that concluded that traditional wood sash windows can perform as well as modern ones without compromising the image of the historic environment (2010). The tests undertaken combined the windows draught-proofing with other measures to improve their performance (introduction of curtains, blinds, shutters and double glazing). The results revealed that adding double glazing and using the traditional inner shutters were the most effective and achieved heat loss reductions of 63% and 51% respectively. In the best scenario, it was possible to reduce the initial U-value of 4.5 W/m^{2}K to less than 2.0 W/m^{2}K. Hence, the crucial role of inner shutters in the overall performance of windows must be emphasised and reinforced due to their usual use in traditional constructions. It must also be underlined that the sash windows and inner shutters

[29] - They consume less 24% than 1900-1939 buildings, less 45% than 1940-1959 buildings, less 36% than 1960's buildings, less 21% than 1970's and 1980's buildings and less 8% than 1990's and 2000's buildings (Wallsgrove, 2008).

studied are similar to the ones used in Oporto's traditional buildings. In addition, as pointed out by Changeworks (2008), these single glazed windows represent a large area of the total envelope of traditional buildings, with high heat losses which must be addressed in the upgrade projects.

Comparing the performance of traditional and new buildings, Drewe and Dobie point out that the main differences resides in the need of the traditional fabric to 'breathe' and in the necessity of controlling their moisture, factors that should be taken into account in designing retrofit projects (2008). This is seconded by Richarz *et al.*, which applied these principles to the design of several solutions to address the energy efficiency upgrade in existing buildings (2007). The findings of the EU-funded project SUSREF, also point to the importance of moisture control when refurbishing solid stone walls and confirmed the influence of moisture content in their thermal behaviour (Häkkinen, 2012; Peuhkuri *et al.*, 2012). This became evident in a field study conducted by Rye et al., where the analysed traditional buildings revealed a direct coherence of the moisture in the walls and the U-values ; if connected to the ground, the walls presented a higher level of moisture until a height of 1.00/1.2m above the finished floor, directly leading to higher U-values (Rye and Hubbard, 2012). The Drewsteignton case study, with solid granite walls like the ones used in Oporto, revealed a U-value differential of 0.26 W/m^2K between lower and higher sections.

Moreover, this research project highlights how 'orthodox' calculation methodologies, directed mainly towards new buildings and current construction systems, fail to predict the real performance of traditional buildings. The thermal parameters used in the construction systems databases are mainly based on contemporary materials, which do not always deal correctly with the complexity of the traditional systems. In the seven case studies undertaken, the *in situ* readings were up to 69% off from the ones estimated by the calculation standard (Rye and Hubbard, 2011). This confirms previous research which pointed out the recurrent discrepancy between the calculated U-values for traditional buildings and the ones measured *in situ* (Baker, 2011; Changeworks, 2008; Rye, 2010).

The data on table 11 illustrates this gap by comparing the measured and the calculated U-values of four case studies before and after the refurbishment (Rye *et al.*, 2012). Taking the example of the Drewsteignton solid granite wall, it is possible to verify the significant deviation between the values predicted (2.45 W/m^2K) and the ones measured (1.24 W/m^2K), which fades in the post-refurbishment stage. In this case, an impressive heat loss reduction of 87% was obtained after the internal insulation of the exterior walls.

Location	2011 Measured un-insulated W/m^2K	2012 Measured insulated W/m^2K	2011 Calculated un-insulated W/m^2K	2012 Calculated un-insulated W/m^2K
Shrewsbury South wall	1.48	0.48	1.52	0.59
Shrewsbury West wall	2.06	0.63	1.71	0.62
Drewsteignton	1.24	0.16	2.45	0.19
Riddlecombe	0.76	0.72	0.93	0.60

Table 11 – Measured and calculated U-values before and after refurbishment *in* Rye *et al.* (2012, p.6)

3.5 – Conclusions

The cultural advantage of preserving the heritage value of traditional buildings is widely argued to be a fundamental act of sustainable development. This chapter argued for the inclusion of reusing traditional buildings and energy efficiency upgrades under the urban sustainability strategies, addressing environmental, economic and social dimensions.

Energy efficiency is a wide field which addresses the optimisation of energy production and use and must be addressed on technical and behavioural scopes in buildings. Further, the role of RES and passive techniques are relevant in order to obtain the most optimised and cost-optimal scenarios.

A building's energy efficiency parameters influence all heat transfer processes occurring on the envelopes (opaque and glazed). The measurement of energy consumption and associated CO_2 emissions before and after improvements is another well-established method in the field. Results on comfort improvement and cost effectiveness of the solutions are additional parameters for benchmarking the energy efficiency of the operations.

From the general overview of literature it is also possible to conclude the evident inaccuracy of ‘orthodox’ calculation methodologies to provide reliable data for the simulation of traditional buildings. It is thus necessary to develop further research and case studies to support improvement projects of such buildings (May and Rye, 2012).

The social approach has to be safeguarded in these operations by promoting the appropriate levels of comfort, while at the same time avoiding false energy efficiency due to fuel poverty. This aspect is most relevant in the social framework context of the traditional quarters in Portuguese historic centres affected by the depression. Additionally, the approach of using diverse levels of intervention is appropriate to address the refurbishment of occupied traditional buildings by adding additional feasibility to the operations.

Based on this context, it is necessary to identify the most feasible and effective measures to address the energy improvement of traditional buildings by crossing the cultural heritage issues with the technical and the behavioural approaches of the energy efficiency framework.

Chapter Four: Energy Efficiency Improvement in Traditional Buildings

Chapter Four: Energy Efficiency Improvement in Traditional Buildings

4.1 - Introduction

This chapter aims to identify the measures and solutions which have been developed to specifically address the energy efficiency upgrading of traditional buildings, namely the constraints posed by their heritage value. This was performed through the analysis and revision of the literature and available case studies addressing specifically the energy efficiency improvement in traditional buildings.

The framework of energy efficiency improvement for traditional buildings and the specific measures to address it are discussed, with special focus being put on the constraints posed by this type of building. This includes connecting several aspects of this field of research, namely the economic and social framework involving these typologies, the thermal performance of traditional buildings, their construction systems, the consequences for the heritage after introducing these measures and the current developments in technical research dealing with the energy efficiency of buildings, which can further be applied to Oporto's traditional buildings.

4.2 - Energy Efficiency in Traditional Buildings

The approach to improve the energy efficiency of existing buildings through refurbishment is similar to the general buildings' framework explored in the previous chapter. The main differences reside in the pre-existing physical conditions, which are unchangeable (site location and building orientation), and the necessity of dealing with the occupants' behaviour, which is usually accounted for in the design of new buildings. In being part of the existing stock, traditional buildings share this approach. Additionally, their specificity leads to the necessity of considering further factors: the cultural heritage values and the performance of traditional construction systems.

4.2.1 – Existing Buildings Energy Efficiency Approach

The framework proposed by Erlandsson and Levin comprises the sub-systems 'physical building' and 'housing', which can be compared to the 'hardware' and 'software' concepts of information technologies (2005). The first relates to the building itself and all its components, while the second refers to a building's services and occupants' behaviour. A similar approach is proposed by Richarz *et al.* dividing energy efficiency upgrades in two complementary lines: constructions and installations (2007).

Addressing the building simulation, Hensen and Lamberts (2011) presented a division in sub-systems, which dynamically interact and influence energy efficiency in buildings (figure 6). This adds the actions of the occupants and the environmental conditions of the building site to previous approaches. It is worth mentioning that the division proposed in the building services, separates the equipment (lighting, appliances) from the HVAC system. This division is not consensual, being also usual to find these sub-systems under the building installations or services. This separation is not crucial, as these systems are dependent on the occupants' control and on their level of efficiency. However, this separation makes sense when dealing with existing buildings due to the variable costs involved in the upgrade of the equipment (soft measures) and of the HVAC systems (hard measures).

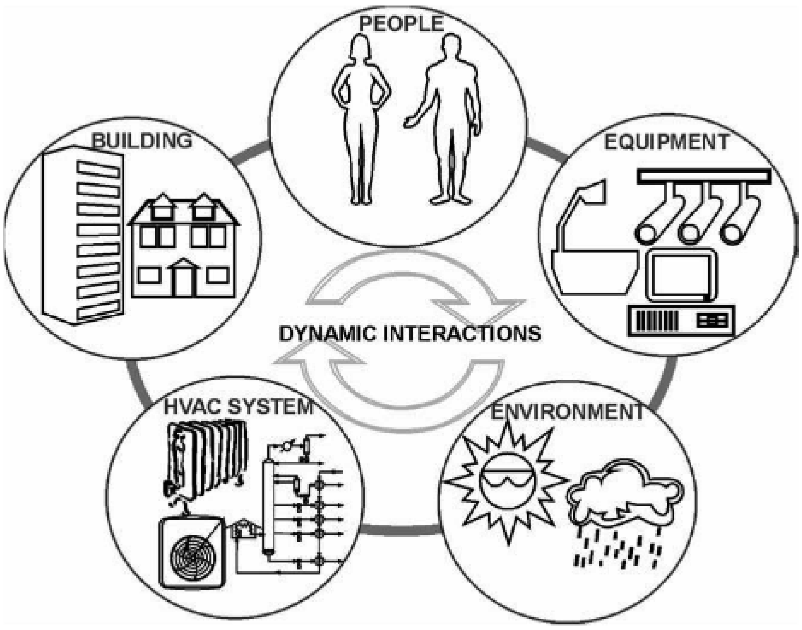

Figure 6 – Dynamic interactions of sub-systems in buildings *in* Hensen and Lamberts (2011, p.2)

The building framework described by Brand, divides building and services systems into layers (figure 7), relating them to their possible timescales of change and simultaneously stressing the adaptive capacity of traditional buildings. The building is disaggregated into structure, skin and space plan, while facilities are divided into services and stuff. All these layers are described according to their usual cycle of replacement: structure - 30 to 300 years; skin - 20 years; services - 7 to 15 years; space plan - 30 years; stuff - widely variable. Accordingly, services and stuff are the most feasible layers to be upgraded, followed by skin, which corresponds to the building envelope. Under the management of change it is also possible to affirm that these layers are widely accepted as the major targets for the energy efficient retrofit of buildings.

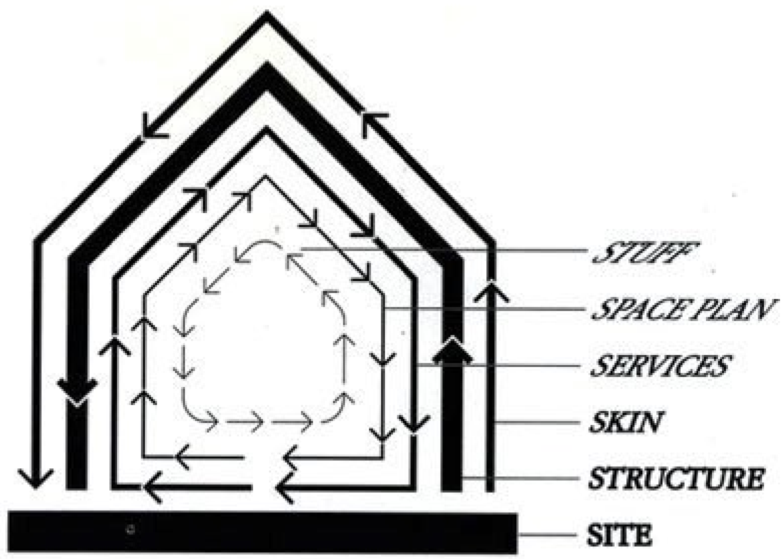

Figure 7 - Building layers of change *in* Brand (1994, p.13)

Richarz specifically addressed the energy efficiency upgrade in existing buildings, concluding that renewing the installations can be the most effective way of achieving it (2007). Insulation is also pointed out as a highly effective solution. The same author argues for the use of passive measures in order “to activate or re-activate natural, self-regulatory processes in the building” (2007, p.21). It is also stressed that these measures work well in temperate climates, as they focus on natural ventilation and lighting, and take advantage or improve the existing thermal mass.

The Recast Directive (EC, 2010) proposes several scales to address energy efficiency: technical building system, building, building envelope, building unit (house) and building element. These are complemented with local renewable energy production at superior scales, like the neighbourhood or the district.

Table 12 presents a synthesis of the energy efficiency approaches identified in the literature, showing both the building framework approach and the possible scales of intervention. This allows for pointing out the necessity of addressing energy efficiency upgrade in traditional buildings through these scales, based on the feasibility of their execution (affordability and ownership) crossed with their effectiveness in achieving energy savings (return of investment and carbon cuts). Furthermore, the comparison between the measures applicable at individual unit (home) and at building scale (*e.g.* insulation and renewables) should be taken into account to evaluate the improvements and obtain an overall scenario of potential cuts in energy and CO_2 emissions.

In terms of the implementation of the solutions, it is also important to consider a 'fabric-first approach', which means that "renewable energy sources should always come second to insulating a building and making it airtight. Without these measures, occupiers won't receive the benefits from their renewable energy and micro-generation installations" (National Refurbishment Centre, 2012, p.10). The Building Research Establishment advocates the same in the refurbishment of their Victorian terrace case study, establishing a three steps approach: fabric first, then heating and hot water and finally renewables (BRE, 2012).

Conclusively, it is possible to affirm that the approach for an energy efficiency upgrade in traditional buildings has to be directed towards the improvement of their envelope performance, technical systems efficiency and the occupants' behaviour, and must be complemented with the introduction of RES. Furthermore, it should be approached from various levels of intervention, in order to make it affordable for the households. The four components are interrelated and inextricably linked; however, for traditional buildings the envelope upgrade is the most sensible aspect, because it is subject to major heritage constraints. At the same time, its performance is crucial for the overall performance of the building, thus also posing the greatest technical challenges in its improvement. Similarly, the introduction of renewables has to be considered in respect of the visual consequences it causes to the building and to the historic city image.

Erlandsson and Levin, 2005	**Richarz *et al.*, 2007**	**Hensen and Lamberts, 2011**	**Brand, 1994**	**Energy Efficiency Directive Recast, 2010**	**AdEPorto, 2010**	**Restart Project, 1996**
		Environment	Site	District		
Physical Building	Construction	Building	Structure	Building		
			Skin	Building Envelope	Roof	Roof
					Main facade	Main facade
					Gable facade	Gable facade
					Exterior windows and doors	Exterior windows and doors
						Skylight
			Space Plan	Building Unit	Party wall	Floor
						Partition wall
				Building Element		
Housing	Installations	HVAC System	Services	Technical building system	Solar thermal	Central HVAC system
		Equipment	Stuff			
		People				Temperature space control

Table 12 – Compared building approach framework

4.3 – Improvement of Traditional Buildings Energy Efficiency

Using the defined framework it is possible to draw up an approach for the energy efficiency improvement of traditional buildings based on three complementary levels: the building's physical elements, the housing (services, equipment and occupants) and the energy production (renewables). They can further be divided into systems and sub-systems, providing the possibility of addressing independent improvement measures (table 13).

Framework			**Solutions Implementation**	
Level	**System**	**Sub-system**	**building level**	**home level**
Physical Building	Building	Common area	o	
	Building Envelope	Roof and Loft	o	
		Main facade	o	
		Gable facade	o	
		Party wall	o	o
		Glazing (exterior windows and doors)	o	o
		Skylight	o	
	Interior space	Floor/ceiling	o	o
		Partition wall		o
		Interior doors and windows		o
Housing	Building services	DWH, Heating, Cooling and ventilation	o	o
	Equipment	Lighting		o
		Appliances		o
	Occupants	Behaviour		o
		Control		o
Energy production	Renewables		o	o

Table 13 – Traditional buildings improvement framework proposed

Moreover, the elements to be improved are addressed by two scales of possible implementation: building and home. These levels are based both on the cost and on the consent procedures necessary to implement the solutions, which are aggravated in Portugal by the complex legal tenancy framework. A similar situation is identifiable for the improvement of the communal areas of the Scottish Georgian tenements, where any work must have the consent of all tenants (Changeworks, 2008). Hence, the focus must be set on the measures addressing the building unit or the building elements, which allow a direct action without the necessity of engaging all tenants or the building owners. Moreover, these measures are usually more affordable, consequently increasing their feasibility.

At the same time, it is necessary to consider the possibilities posed by the local energy production. The heritage constraints posed by the historic cityscape limit their application. However, the district systems can be used to overcome such a situation, by concentrating the energy production and consequently minimising the impact. An example of this is the future RUTE (Thermal Energy Urban Network), which envisages the use of tri-generation from natural gas in Oporto's urban core to provide combined cooling, heat and power to large consumers, while simultaenously reducing the losses in energy distribution by 30% (Cardoso, 2011; Fernandes, 2009). If this was applied to domestic consumers as well, it could help reducing the environmental footprint of Oporto's traditional buildings with a reduced risks for heritage damaging. However, district scale is not in the scope of this research, so the subject will not be developed here.

4.3.1- Solutions for Traditional Buildings

The English Heritage developed a toolkit which identifies gradual stages of measures based on the cost and easiness of their implementation in the traditional buildings residential sector (2011). These stages range from easy savings ('soft measures') to long term planning ('hard measures') as shown in table 14. The first type is based mainly on lifestyle enhancements, both by improving the household's behaviour and by using more efficient equipment. In what can be considered a second level, it proposes the general draught-proofing and 'easy insulation' of some building elements, which should be considered before carrying out 'hard measures'. The maintenance and improvement of traditional windows and doors is further encouraged in order to maintain the character and appearance of traditional buildings. It consists either of draught-proofing the frame or in the installation of secondary glazing. 'Easy insulation' addresses the building systems and the elements which are reachable by the interior and whose insulation poses no negative visual consequences. Inversely, the long term measures can be both costly and difficult to implement, as they involve construction work. They can be planned in advance and may be considered if in-depth refurbishment is to be undertaken.

This framework of solutions seems consensual in the literature and summarises the research promoted by BRE, English Heritage, Historic Scotland and SPAB, based on UK case studies from the pre-1919 built stock, covering Georgian, Victorian and Edwardian houses (Cartwright *et al.*, 2011; Changeworks, 2008; Drewe and Dobie, 2008; Ferguson, 2011; Pickles *et al.*, 2012; Rye *et al.*, 2012; Yates, 2006)[30]. This literature is crucial, because it represents the most solid corpus of research, developed along a consistent period (since the 1990's until now) and is based both on scientific experiments and case studies. At the same time, the type of buildings in question reveals a certain formal similarity with Oporto's traditional buildings (with Georgian design influence), which is further discussed in Chapter Six.

level	category	Measures
easy savings ('soft measures')	lifestyle enhancements	appliances standby nulling
		lights turned off
		lower heating temperature
	home appliances upgrade and better use	higher efficiency
		lower temperatures in clothes washing
		less water boiling
	heating controls and energy metering	introduction of controls for radiators and boiler
		use of intelligent thermostats
		smart energy metering
	improved lighting	use of low-energy lamps
		motion detectors for external lighting
	energy efficient heating	boiler maintenance
		introduction of fuel efficient boiler
		use of biomass heating
	general draught-proofing of doors and windows	shutters
		portieres
		heavy curtains
		'sausage dogs'
		frame draught-proofing
		installation of secondary glazing
	easy insulation of some building elements	floors and chimneys
		roof and loft (by the interior)
		systems (hot water tank and piping system)
long term planning ('hard measures')	insulation of the building envelope	roofs and walls
	insulation of floors	suspended or solid
	Introduction of renewables	solar thermal
		photovoltaic
		micro-wind
		hydro power
		air or ground heat pump

Table 14 – Residential traditional buildings energy efficiency toolkit *in* (English Heritage, 2011)

30 - See table 16.

Framework			Solutions									
Level	**System**	**Sub-system**	**English Heritage, 2011 (´soft measures')**	**English Heritage, 2011 (´hard measures')**	**Drewe and Dobie, 2008**	**Changeworks, 2008**	**Yates, 2006**	**Richarz *et al.*, 2007**	**Rye *et al.*, 2012**	**AdEPorto, 2010**	**Restart Project, 1996**	**Cartwright *et al.*, 2011 and Ferguson, 2011**
Physical Building	Building	**Common area**				Draughtproofing entrance door Draught lobby	draught sealing of front doors insulated porch					
	Building Envelope	**Roof and Loft**	Interior insulation (roof and loft)	Re-roofing incorporating insulation	Top floor insulation	Roof insulation Loft insulation	Roof insulation Loft insulation	Roof insulation from inside Roof insulation from outside Loft insulation		Roof insulation	Roof insulation	Roof insulation
		Main facade				Dry lining insulation	Interior insulation (exterior wall dry lining insulation)	Dry lining insulation	Dry lining insulation	Main facade insulation	Interior insulation of main facades	Main facade dry lining insulation
		Gable facade	Draught-proofing chimneys	Adding wall insulation	Wall insulation	Exterior insulation	External insulating render	Composite external insulation External insulation with ventilation cavity	External insulating render	Gable facade insulation		Other facades external insulation
		Party wall				General draught-proofing including chimneys				Party wall insulation		
		Glazing (exterior windows and doors)	Draught-proofing doors and windows Secondary glazing Keeping traditional windows, doors and shutters		Draught-proofing doors and windows Draught-stripping on windows. Maintaining traditional shutters	Draught-proofing windows Double glazing or secondary glazing Maintaining traditional shutters	Double or secondary glazing	Weatherstripping of windows and doors Introduce double glazing in existing frames Maintenance or introduction of inner shutters		Glazed element improvement	Set a maximum of free-cooling rate Double glazing in wood frame	Draught-stripping and seal on windows. Double or triple glazing
		Skylight				Secondary glazing in skylight Double or triple glazing in skylight				Skylight improvement	High light transmission, low solar gains, low reflectance glass in skylight	
	Interior space	**Floor/ceiling**	Draught-proofing floors	Adding insulation to floors	Ground floor insulation	Draught-proofing floors Floors insulation	Ground floor insulation Suspended floors insulation	Ground floor insulation Floor insulation (confining with unheated spaces)	Ground floor insulation		Floor insulation (confining with unheated spaces)	Floors insulation
		Partition wall	Low-cost draught-proofing (heavy curtains, portiere, shutters, sausage dogs)				Partition wall insulation		General draught-proofing		Partition wall insulation	
		Interior doors and windows										
Housing	Building services	**DWH, Heating, Cooling and ventilation**	Energy efficient heating Easy insulation (tank and pipes)			Energy efficient heating Heat recovery	Gas central heating with condensing boiler Mechanical ventilation with heat recovery Controlled ventilation system	LPG-fired condensing boiler (hot water and space heating) Mechanical ventilation with heat recovery Natural cross ventilation			Central HVAC system Natural ventilation	Central biomass pellet boiler air-to-air and air-to-water source heat pumps Condensing combination boiler with a mechanical heat save device
	Equipment	**Lighting**	Efficient lighting			Efficient lighting	Low energy lamps				Natural lighting	
		Appliances	Home appliances			Efficient appliances	A-rated energy efficiency appliances					
	Occupants	**Behaviour**	Lifestyle (nulling stanby, turning off lights, turning down the thermostat)			Room thermostats					temperature space control	
		Control	Heating controls & energy metering			Smart metering	programmer, room thermostat and thermostatic radiator valves					
Energy production	Renewables			Micro-generation (wind, photovoltaic, solar thermal, hydro power and heat pumps ground and air)			Solar thermal	Solar thermal		Solar thermal		Solar thermal

Table 15 – Solutions framework

		Yates 2006					Cartwright *et al.*, 2011 and Ferguson, 2011	Richarz *et al.*, 2007		Rye *et al.* 2012		Changeworks, 2008	Restart, 2000	Energy Saving Trust, 2010
			Pilot	Case study 1	Case study 2	Case study 3	Case Study and demonstration project		Case study	Light refurbishment case study	Test wall	Georgian Tenement in World Heritage Edinburgh (test in a stair of 9 flats - 1820)		
		usual energy efficient measures in solid wall houses	**Four-storey tenement in Greenock, Scotland (1996)**	**Nelson Housing Market Regeneration Scheme (2006)**	**The Flagship Home Project, Beaufort Gardens, London**	**The Nottingham Ecohome (2000)**	**BRE Victorian Terrace - Watford (2007)**	**Recommended solutions**	**Rectory, Ampermoching (1724; 2001-2002)**	**The Firs, Riddlecombe, Devon (2012)**	**Mill House, Drewsteignton, Devon (2012)**	**Lister Housing Co-operative, Lauriston Place, Edinburgh (2007-2008)**	**CRUARB Office, Rua da Fonte Taurina, Oporto (1996)**	**Sheffield EcoTerrace (2009)**
Building Envelope	**Roof and loft**	loft insulation	150 mm mineral wool loft insulation between joists, 50 mm laid over joists	re-laying the roofs and the insulating of the roof spaces	Addition of a floor with high insulated roof	Roof insulation above the ceiling: 400 mm of Warmcell recycled newspaper insulation above and between the ceiling joists	mineral wood and sheep's wool insulation	Roof insulation from inside: waterproofing covering natural or mineral fibers between the rafters, vapour barrier, second layer of insulation and finish						
						Roof insulation along slope of rafters: 300 mm of blown Warmcell insulation in a plywood web	heat phase-change materials in ceiling tiles	Roof insulation from outside when re-roofing: waterproofing covering, insulataion layer, second natural or mineral fibers between the rafters, vapour barrier and finish	Natural cross ventilation of unheated roof space					
						Additional work: Re-roofed re-using most of old slates; Installed breathable underlay to protect insulation; Extended verge overhang for future external insulation		Top most floor insulation: filling void space between joists with natural or mineral fibers or loose fill material (cellulose flakes), vapour barrier (plastic sheeting or building paper), second layer of insulation if necessary and floorboard	loft insulation between the joists with mineral wool, vapour barrier			Loft insulation - 300mm of insulation		
	Exterior walls	insulated dry lining to external walls	Plaster removed. External wall – 50 mm expanded polystyrene insulation – plasterboard		dry lining	Internal insulation: 2 × 50 mm zero odp phenolic foam laminate boards (This was applied to the front elevation so that the external appearance could be maintained)	Main facade internal insulation: aerogel, polyurethane foam and polyisocyanurate insulation (PIR)	Internal insulation with upgrade of existing single glazing: insulation material place in the wall (rigidPS foam, mineral wool, mineral foam, rigid PUR foam, calcium silicate sheets), vapour barrier, finish. Points necessity to insulate internal partition 500mm when joining the external wall, and insulation of timber joists floors support in external walls (PUR spray foam). Secondary bouble galzing added			Internal insulation in granite external wall: gypsum skim (3mm), plasterboard (12.5mm), air gap (25mm), PIR (polyisocyanurate) board (100mm) + existing wall			
		external insulating render		use of traditional materials and original design features for the chimney stacks which are in keeping with the period of the houses		External insulation: 140 mm expanded polystyrene board and a Sto render system. The thermal performance of the walls has been improved by 860%	North facade external insulation: Expanded Polystyrene (EPS)	External insulation (in conjugation with new double glazing window): composite system (insulation board with rendering system)	External insulation composite system (60-140mm)	External insulation lime render 40mm				
								External insulation with ventilation cavity (conjugated with new double glazing window): create double framework of rails to support cladding; two levels of insulation between rails, possible covering of system withn boards, cladding material						
	Glazing	secondary glazing	Replacement timber windows with double glazing (22 mm air gap) and draught sealing	fitting traditional double glazed sash windows to improve energy efficiency	double glazed windows in the rear elevation	The house would originally have had single glazing – double glazed u-PVC windows were inherited and no secondary glazing. Two north facing sets of French windows were triple glazed, krypton filled with two low e coats	Double and triple glazed framing	New double glazing windows	New double glazed windows	Existing wood double glazed windows		Secondary glazing (slim line) reducing U value to 2.0		
					secondary glazing in the front elevation			Secondary double glazing	Introduction of folden wooden shutters internally			Shutters refurbishment		
								Weatherstripping of windows and doors: self-adhesive strip (DIY but limited durability), grooves in frame and standard sealing profiles				Draughtproofing - reducing air changes per hour from 2.5-3 (usual in sash windows) to 0.4		
								Introduce double glazing in existing frames						
Internal Construction Improvements	**Floors**	ground floor insulation				Solid ground floor: Excavated down and laid damp proof membrane horizontally and vertically to above ground level; 150 mm polystyrene with 50 mm edge upstands; 100 mm concrete slab		Insulation of floors to unheated space	Suspended ground floor insulation: mineral wool, vapour barrier	Ground floor insulation				
						Suspended ground floor: 100 mm of sheep's wool between the joists and 60 mm ofinsulating wood fibre board (Gutex) beneath the joists. A breather membrane over the Gutex						Floor insulation (21mm of insulating material and 9mm of particle board - u value of 0.25)		
						Second floor: Existing floorboards taken up and the joists strengthened; Loose Rockwool placed between joists for sound insulation (should have used sheep's wool but not readily available at the time); 3 mm Regupol sheet made of recycled rubber and cork over joists for impact noise reduction; Existing boards replaced and supplemented with additional reclaimed boards to enlarged the floor area				General draught-proofing				
	Internal partition and doors	partition wall	Composite board comprising 12.5 mm wallboard and 19 mm extruded polystyrene fitted internally											
			draught sealing of front doors of flats	replacement of front doors and rainwater goods		Replacement of some of the existing u-PVC doors with fsc timber								
Buildings Systems	**Systems**	gas central heating with condensing boiler	Gas fires, gas fired central heating from back boiler, programmer, room thermostat and thermostatic radiator valves		Two condensing boilers were installed to provide communal heating to all the units but with each tenant having radiators and programmable controls		Central biomass pellet boiler		LPG-fired condensing boiler (hot water and space heating)			New 'A' rated condensing boilers		
							Air source heat pump							
							air-to-air and air-to-water source heat pumps							
							Condensing combination boiler with a mechanical heat save device							
		factory insulated hot water cylinder	Back boiler, 135 litre hot water tank with 80 mm factory applied insulation		Solar panels were installed on the roof to supply part of the building's hot water with a heat recovery ventilation system	4 m^2 flat plate solar panel contributes 50% to annual hot water; wood-fired boiler for central heating and hot water top-up; 1100 litre accumulator stores and distributes hot water to the radiators and domestic use; It was planned to install one or two 1 metre diameter wind turbines (this is no longer the case as it would not generate viable amounts in this area; Renewable energy and low energy construction has saved £800 to £1000 a year	Solar thermal		Solar thermal					
	Ventilation	controlled ventilation system	kitchen and bathroom extract fans		Mechanical ventilation with heat recovery unit per floor	Both bathrooms and both kitchens have heat recovery fans which save up to 80% of airborne heat. Whole house heat recovery mechanical ventilation	Mechanical ventilation with heat recovery		Mechanical ventilation with heat recovery					
	Lighting and appliances				All low energy lamps and A-rated energy efficiency appliances							Low energy lighting (CFL's 23W); smart metering; energy advice		
Future improvements				district heating system based on a biomass boiler		install a new front door and create an insulated porch								
				The potential environmental impact could be further reduced by combining the use of carbon neutral technology with a planned re-use of construction materials supplemented by low environmental impact traditional materials such as lime mortars, insulation made from sheep's wool or newspaper, and timber.		Over time, the u-PVC windows will be replaced as the glazing units fail (double glazed or secondary glazing)								
Savings					energy cut by 67%/year and CO_2 emissions cut by 63%/year	The overall energy savings are 75% in terms of costs and 85% in terms of tonnes of CO_2 emitted				4% improvement in U-value of external wall	87% improvement in U-value of external wall	The annual energy cost of each flat were reduced by na average of £175 (some cases up to £400); The annual CO_2 emissions of each flat were reduced by na average of 1 tonne (some cases up to 2.4 tonnes)	Simulated: (20% savings in heating, 20% savings in cooling, 40% saving in lighting	less 76% of CO_2 emissions; less electricity consumption of 60% and less gas of 81%
					after the work was completed the houses national home energy rating (NHER) increased from approximately 3.0 to 9.0.							The annual energy consumption of each flat were reduced by na average of 5000kWh (some cases up to 12000kWh); The annual CO_2 emissions of each flat were reduced by na average of 1 tonne (some cases up to 2.4 tonnes)	Simulated: (7 MWh heating, 13 MWh cooling, 20 MWh lighting against similar non refurbished 13 MWh heating, 19 MWh cooling, 32 MWh lighting)	Less 67% in running costs

Table 16 – Traditional buildings energy efficiency case studies in the United Kingdom

By crossing the framework for the improvement of traditional buildings presented in table 13, with the specific solutions identified in the literature reviewed, it was possible to produce a table that confirms the solutions framework presented above, and details it with the effective measures taken in diverse case studies (table 15). From these solutions it is possible to highlight the envelope insulation, the glazing upgrade and the introduction of renewables as the most effective for improving the energy efficiency of traditional buildings. As such, these measures will be further addressed below. Furthermore, the upgrade of the communal spaces and the cost-effectiveness of the solutions, which are subjects that need to be evaluated in the energy efficiency upgrade of Oporto's traditional buildings, are also reviewed.

Insulation

The use of external insulation is acknowledged to be the most effective, as it takes advantage of the high thermal mass that is usual with traditional buildings (Ferguson, 2011; Richarz *et al.*, 2007). However, its use in the building envelope is considered the major challenge for improvements to traditional buildings, for both the technical and the heritage constraints posed, as pointed out in several of the reviewed case studies (table 16). The BRE research conducted on several Victorian examples, supports this by pointing out the problems posed by the insulation of solid walls (Yates, 2006). The improvements tested were made by addressing the envelope's insulation at several scales (roof, walls and glazing) and by paying careful attention to the consequences this had for the buildings' authenticity. This 'case-by-case' basis is the most commonly applied approach for assessing the visual impact of the solutions and to verify the heritage disruption caused.

The use of natural insulation, such as mineral and natural fibres or hemp batts, is pointed out to be more adequate for traditional buildings. It is normally more expensive than petro-chemical materials, but it absorbs and lets out moisture and allows the traditional construction to continue breathing (Changeworks, 2008; Curtis, 2008; Drewe and Dobie, 2008; English Heritage, 2011; Yates, 2012). Richarz *et al.* underline the difference between the measures executed from the interior or from the exterior of the building, putting emphasis on the use of scaffolding which represents a substantial increase in the total cost (2007).

Moreover, the same authors reviewed the type of insulation available for each approach, stating that flexible materials (*e.g.* mineral or natural fibres), are more suitable for inner insulation than rigid boards, as they can easily be inserted into the construction voids. These factors confirm that natural and flexible insulation solutions are the most viable for the energy efficiency upgrade of traditional buildings.

In the specific case of Oporto it is important to stress the dimensional problem posed to the feasibility of insulation due to the reduced interior dimensions of spaces and/or by the limited thickness available on the main facades due to the granite stone carving whose plan should not be surpassed. Consequently, the insulation thickness reveals to be an important parameter to consider in the implementation of the solutions. The local climate allows the use of reduced insulation thicknesses when compared to North European countries, but even so the available space is still constricted[31]. The use of dry lining insulation is additionally limited by the usually existing relation of the wall with the ceiling stucco, which must be preserved. The use of slim insulation materials may be considered to overcome the visual and dimensional effects of the intervention. Hence, it is possible to consider the use of two recent materials: aerogel insulation and phase change materials (PCM), *i.e.* materials which store or release heat when changing their phase (solid to liquid and vice versa). However, as pointed out by Cartwright et al., the use of less conventional materials poses two major restrictions: their high initial cost and the lack of knowledge in their application, which leads to longer times of execution and consequent higher costs (2011).

The incorporation of microencapsulated PCM in plaster was studied in Portugal by Silva *et al.* (2008) and Monteiro *et al.* (2005), both pointing out its potential for energy efficiency. In these experiments 25% of PCM[32] was incorporated in the final layer of plaster covering the inner face of exterior walls. The results revealed that the room maximum temperature was reduced by 28% and the room minimum temperature was increased by 6%, without using any heating or cooling equipment (Monteiro *et al.*, 2005). This 1 mm thick PCM layer improved the wall thermal mass significantly and, with an additional cost of 1€ per square meter of the total render cost, it seems to be a high potential solution to be used in the upgrade of the thermal performance of traditional buildings[33]. The analogous research undertaken by Lucas measured

[31] - The AdEPorto *et al.* study (2010), addressing the energy efficiency improvement of Oporto's traditional buildings, admits the possibility of using the minimal insulation thickness of 50mm in external walls, which may be increased until 100mm for obtaining the best results. Similarly, the roof insulation may use thicknesses varying from 70mm until 160mm.

[32] - This ratio proved to be the best in terms of balancing the mechanical stability of the plaster with their thermal improvement.

[33] - The BRE Victorian terrace experimental project also incorporated PCM insulation into the ceiling tiles of the presentation room, with no results available yet (BASF, 2010).

a variation of 4 to 5°C between a wall with PCM plaster and a reference wall. The author highlights that it enabled achieving the thermal comfort temperatures with a reduced use of energy (2011). Additionally, the work undertaken by Zamalloa *et al.* in Spain during the summer of 2008, showed that the use of the PCM insulation increased the thermal inertia of a wall, thus reducing the cooling demand up to 30% (2009). These results confirm how PCM insulation can play a relevant role in the passive cooling of buildings, increasing of comfort and saving energy.

The approach towards roof insulation is also consensual in literature, and is considered in conjunction with the loft space (Changeworks, 2008; Drewe and Dobie, 2008; English Heritage, 2011; Richarz *et al.*, 2007; Yates, 2006). If the space under the roof is not inhabited the insulation is placed on the floor which permits cross ventilation of this space (cold roof). If it is used for living, the insulation is then placed directly in the roof, either by re-roofing and placing insulation on the exterior, or by incorporating it between the rafters (warm roof).

Glazing

The upgrade of the traditional external windows and doors also needs to be carefully considered in order to avoid the disruption of the overall building character. The approaches that have proven to be the most successful are based on upgrading the glass (by the insertion of double glazing if the frame design allows it) or by the introduction of secondary glazing, which is usually a more viable measure with several successful examples among the reviewed literature (Changeworks, 2008; Curtis, 2008; Yates, 2006). From these examples, the *Slimline* secondary glazing applied in a Scottish pilot study deserves a special mention for its reversibility (Changeworks, 2008). The authors argue that the secondary glazing is usually less intrusive, but it must be conjugated with the original windows design.

Furthermore, the literature stresses that the use of 'low-cost' measures (draught-proofing, curtains and inner shutters) allows enhancing the performance of the glazing systems (Changeworks, 2007; Drewe and Dobie, 2008; English Heritage, 2011). Addressing this objective, Richarz *et al.* introduced internal folding wooden shutters in upgrading a German traditional building with the aim of improving its thermal efficiency (2007).

Associated both with the roof and the glazed elements of the buildings, updating skylights is also addressed in the case studies. Their improvement is similar to the approach used in windows and focuses on the replacement of single by double glazing, the introduction of secondary glazing (Changeworks, 2008), and the upgrading of glass for high light transmission, low solar gains and low reflectance (Restart Project, 2000).

Communal spaces

Like in the Georgian tenements of Scotland, the skylights in Oporto are inserted on the top of the building's communal space where the staircases are located. This raises the problem of the upgrade of such spaces, which was addressed in the Changeworks report (2008). Known in the Scottish tenements as the 'stairwell' or 'close', it allows for heat to escape. The proposed improvement of these spaces is based on three complementary measures: insulation, lighting and recycling of heat (Changeworks, 2008). The insulation consists mainly of draught-proofing the flats and building entrance doors. The building's main entrance can benefit from the installation of a second door creating a 'draught lobby', which allows the retention of heat. The similarity between Oporto's traditional buildings makes this a possible measure to be taken into account when addressing their comprehensive upgrade. At the same time, the use of low energy lighting and the installation of a mechanical pump and piping system to recover heat from the roof space into the communal areas, which can then benefit from this 'free' heat, are advocated. However, as it is also stressed in the report that this is only viable when integrated in major refurbishment works (Changeworks, 2008). The same applies to any measure addressing the retrofit of the building's exterior, due to the high cost involved in such construction work, which is escalated by the necessity of using scaffolding.

Cost-effectiveness

The data compiled by Changeworks (2008) clearly shows how measures which are construction intensive have a high payback period and are hardly likely to be undertaken by tenants or owners with lower incomes (table 17). From the table it is possible to confirm that small house improvements are more effective, with the additional advantage of having the possibility of being executed on a Do-It-Yourself (DIY) basis, reducing the costs and the payback period.

Inner space measures, such as the insulation of suspended timber floors and lofts or the building's general draught-proofing, are also widely pointed out in literature as effective for energy efficiency upgrading of traditional buildings (table 15). This is confirmed by their payback time, in particular if they are executed without using a contractor. The retrofit of the building systems and the improvement of the occupants' behaviour, are similar to the ones previously discussed and usually do not present negative consequences for the traditional buildings' fabric, which allows to classify them as 'heritage friendly'. The upgrade of equipment and systems is highly variable, depending on the initial investment made, which can cover just a simple upgrade (insulation on the water tank or piping) up to the complete renovation.

Measure	Cost (£)	Annual savings (£)	Payback period
Hot water tank insulation (800mm jacket)	12	20	c. 6 months
Hot water pipework insulation	10	10	1 year
Suspended timber floor insulation	90 (DIY)	45	2 years
Loft insulation (270mm)	250 (DIY)	110	c. 2 years
	500 (contractor)		4 to 5 years
Cavity wall insulation	500	90	c. 5 years
Draught-proofing	90 (DIY)	20	c. 5 years
	200 (contractor)		c. 10 years
Solid wall insulation (50mm plasterboard laminates, or battens, insulation and plasterboard)	From 42/m^2	300	Depend on property size
Double glazing (seal units)	3,000	90	20+ years

Table 17 – Payback periods from typical energy efficiency measures *in* (Changeworks, 2008, p.26)

This framework of low and hard cost measures is also supported by Portuguese research. The study undertaken by Afonso identified that a period of 13 years is necessary in order to achieve the payback of the investment made for the building's energy efficiency improvement (2009). Further, it points out that if this upgrade is inserted in the building's total refurbishment, it requires only an additional investment of 10%. Similar results were obtained by Veiga, who identified a payback period of 12 years and confirmed the additional cost of 10% for improving the building's thermal performance under an overall refurbishment process (2011).

Renewables

The introduction of renewables is widely pointed out as a positive measure to compensate the energy consumption of buildings. Their use is proposed in some of the case studies identified, with precedence being given to the solar thermal systems (table 15 and table 16). However, their use in the historic environment is not consensual, as it has been revealed to be disturbing for the site character. English Heritage promoted research on this subject and analysed the introduction of micro-generation from renewable sources, covering wind, solar thermal, photovoltaic, and biomass energy, in traditional buildings (English Heritage, 2006; English Heritage, 2008c; English Heritage, 2010a; English Heritage, 2010b; English Heritage, 2012). A similar but more detailed perspective is given by Changeworks for Scottish traditional buildings (2009). The major conclusion provided by this source stresses that renewables can be introduced but safeguarding a building's significance must always be met and the visual consequences of the 'intrusion' must be carefully considered in each individual case.

4.3.2 - Traditional buildings energy efficiency upgrade in Portugal

In Portugal, the energy efficiency of traditional buildings has often been addressed in research, but concrete case studies are scarce. Further, the approach is mainly technical, driven by the attempt to comply with the thermal regulation for buildings.

Driven by this objective, the Portuguese Energy Agency (ADENE) promoted research addressing the retrofit of existing residential buildings, focusing basically on dwellings built in the past five decades (Anselmo *et al.*, 2004). Therefore, with the exception of pitched roofs, this research does not cover traditional buildings and their construction systems. Nonetheless, referring to the example of Oporto it points out that addressing the roof insulation is more effective in terms of cost-benefit analysis than insulating exterior walls.

The larger bulk of research addressing this subject in Portugal was developed by the universities' engineering departments, which may justify the focus on the technical approach undertaken (Afonso, 2009; Craveiro, 2008; Cupido, 2000; Jardim, 2009; Rocha, 2008). Based on the dynamic thermal simulation of a traditional building, Afonso concluded that to achieve the desired level of comfort, the top floor and the attic require the major thermal loads, while the middle floors present a very similar performance (2009). Additional research also points out the discrepancy between the thermal loads calculated, when using the static method inserted in the thermal regulation, and the dynamic modelling made by software, which presented lower values (Veiga, 2011).

Some of this scholarly research addressed very detailed aspects of the construction systems of traditional buildings and their thermal performance improvement. Santos's research addressed traditional pitched roofs, identifying mineral wool as the most effective insulation solution for the majority of the cases (2009). The reversibility of the solutions in order to avoid damaging the heritage value of buildings is also stressed by this research.

The 1996's Restart project was a pioneer study in addressing the energy efficiency of Oporto's traditional buildings (Resetnet, 2010). The Oporto RESTART Project - '*Porto - Rehabilitation Process in the Historical Centre*' - was integrated in the urban regeneration process taking place in the World Heritage area of the Historic Centre. This experimental project addressed the adaptive reuse of a building to host the Oporto Municipal technical body for the historic centre - CRUARB's (Restart Project, 2000). The central strategy was based on the use of natural lighting, taking advantage of the central skylight and upgrading its glass characteristics. The building insulation was also central in the intervention, addressing the roof, partition walls and floors in non-heated zones. External walls were insulated from the interior to avoid conflicting with the building's character. The project also promoted natural ventilation, but the thermal comfort was, however, mainly provided by a central HVAC system.

The guidance promoted by AdEPorto *et al.* presents a holistic and very experience-based approach to the energy efficiency improvement of Oporto's traditional buildings (2010). The study was also monitored by the Portuguese Heritage Institute (IGESPAR) in order to assess the solutions from the heritage conservation perspective. Methodologically, this work applies the most proven solutions to Oporto's traditional buildings to achieve the thermal performance levels required by the regulation. The occupants' behaviour or the appliances' efficiency are disregarded in the study, which addresses mainly the fabric and the systems. The approach focussed on the improvement of the overall building envelope, divided into exterior wall, glazed elements and roof (AdEPorto *et al.*, 2010). The report stresses the particularity of the facades of Oporto's traditional buildings, where the glazed area is usually superior to the opaque, which adds a high relevance to the retrofit of windows and French doors. Aligning with the previously reviewed literature, the exterior walls were divided into main and gable facades and grouped with the according possible insulation approaches. These are respectively dry lining and exterior insulation with independent cladding and air cavity. The proposed roof insulation is similar to the one presented by Richarz *et al.* (2007), consisting of the insertion of flexible materials between the rafters and of a vapour barrier layer to avoid condensation. When possible, it is recommended to upgrade the glazed elements (double glazing or introduction of secondary glazing, including in the skylight). It is also recommended to use traditional inner wood shutters, as advised in the reviewed best practice case studies. The introduction of solar thermal panels is also promoted in order to reduce the energy demand

and comply with the regulations. Aiming to minimise their visual impact, the design guidance stipulates that the panels should cover less than 10% of the total roof area, be mounted directly on the slope and parallel to the ridge. However, even if this reduces their impact, it is important to point out that the visual contrast between the black panels and the red roofs tiles is likely to disturb the image and character of the Historic Centre if applied on a large scale. This situation is aggravated by the sloping topography of the city, which allows seeing the historic centre roofscapes from above at several points, as shown in figure 8.

Figure 8 – Oporto historic centre roofscapes as seen from the Cathedral hill

4.4 – Heritage in Energy Efficiency Improvement of Traditional Buildings

In the past ten years the UK's heritage bodies have promoted several studies in the field of refurbishment of traditional and historic buildings in order to meet current day standards. The most recent concern is directed at climate change and sustainability in general (Cassar, 2005; English Heritage, 2008a; English Heritage, 2008b), and energy efficiency in particular, following the EPBD translation into the UK national regulation (Changeworks, 2008; Drewe and Dobie, 2008; English Heritage, 2007; GHEU, 2007; Pickles *et al.*, 2011; Wood and Oreszczyn, 2004). Further, these studies reinforce the necessity of minimising the disturbance to the existing fabric and of promoting reversible solutions when upgrading for energy efficiency in traditional buildings (Drewe and Dobie, 2008).

The concern posed by the application of the European thermal regulations in the historic environment, drove ICOMOS France to publish an official declaration (2008) and to organise a conference to discuss this subject with Euromed Heritage (2010). The results specifically stress the necessity to preserve the authenticity of traditional buildings, which are less protected and subjected to suffer damaging change during the renovation processes to achieve the regulation standards. Once more, the emphasis is put on the external insulation of buildings as the major challenge and risk for traditional buildings, as proven by the results presented by the Graz case study[34] (2010).

Overall, it is possible to affirm that the concern posed by the traditional buildings upgrade to address energy efficiency seems consensual among the conservation community. This concern can be summarised into the need of applying compatible technical systems to traditional buildings, which perform differently from modern ones, preserving at the same time their authenticity. However, a methodological approach balancing the weight of heritage with energy efficiency was not identified. Yates advocates the necessity of establishing a 'conservation limit' and developed a methodology for dealing with it (2006; 2011). The method proposed is mainly based on the intervention criteria established in the international heritage charters and on the professional's practice. Special emphasis is put on avoiding changes to the fabric and aesthetic appearance of the properties, but no specific method for achieving this is provided. The research promoted by the English Heritage and Historic Scotland bases its assessment on the conservation principles, but without clearly defining the assessment methodology (Baker, 2010; Changeworks, 2008; Curtis, 2008; Drewe and Dobie, 2008; English Heritage, 2011; Historic Scotland, 2012). May and Rye stress the necessity of developing a "systemic approach (…) regarding the assessment and retrofit of traditional buildings" (2012, p.7). They recommend the investigation of further methods and propose guidance for the management of change, implementing the usual three colours system (green, amber, red) for grading the impact of the solutions (2012). Even if the process of impact assessment was not straightforwardly defined, this study effectively presents the most comprehensive approach identified. The Oporto research and guidance are focused mainly on the technical aspects

[34] - The Federal Office for Historic Monuments in Vienna uses a colour system for grading the energy upgrade intervention. It is based in the three traffic lights in a very similar way to the previously reviewed in Chapter two.

(Cupido, 2000), merely addressing the heritage aspect on a common sense approach as avoiding to damage the appearance of buildings (AdEPorto *et al.*, 2010; Restart Project, 2000). From this framework it is possible to conclude that an integrated method for addressing heritage in energy efficiency improvement processes is still needed.

Framework			Solutions Implementation			Heritage Consequences			
Level	System	Sub-system	Solutions	building level	home level	Compatible	Neutral	Intrusive	Disruptive
Physical Building	Building	Common area	Dry lining insulation	o			o		
			exterior insulation	o				o	
			General draughtproofing	o		o			
			Create insulated porch	o			o		
	Building Envelope	Roof and Loft	exterior insulation	o			o		
			Inner insulation	o	o	o			
		Main facade	Dry lining insulation	o	o		o		
			exterior insulation	o				o	o
		Gable facade	Dry lining insulation	o	o		o		
			exterior insulation	o			o		
		Party wall	Dry lining insulation	o	o		o		
		Glazing (exterior windows and doors)	draughproofing		o	o			
			Inner shutters		o	o			
			Double glazing		o		o		
			Secondary glazing		o		o		
		Skylight	draughproofing	o		o			
			Double glazing	o			o		
			Low emissivity glass	o			o		
	Interior space	Floor/ceiling	draughproofing	o	o	o			
			Insulation	o	o	o			
		Partition wall	Insulation		o		o		
		Interior doors and windows	draughproofing		o	o			
			Double glazing		o		o		
Housing	Building services	DWH, Heating, Cooling and ventilation	Improve efficiency		o	o			
			Piping insulation		o	o			
			Tank insulation		o	o			
			Thermostats		o		o		
			Natural ventilation	o	o	o			
	Equipment	Lighting	Low energy lamps		o	o			
			Natural lighting		o	o			
		Appliances	Improve efficiency		o	o			
	Occupants	Behaviour	Stand-by nulling		o	o			
			Decrease heating temp.		o	o			
		Control	Smart metering		o	o			
			Temperature control		o	o			
Energy production	Renewables		Solar thermal	o				o	o
			Solar photovoltaic	o				o	o
			Micro-wind	o				o	o
			Biomass	o	o		o		
			Heat pumps	o			o		

Table 18 – Energy efficiency improvements and their heritage consequences in traditional buildings

Based on the framework of solutions previously approached and on the levels of intervention identified, it was possible to categorise these solutions accordingly to the consequences they pose to the cultural significance of traditional buildings. This can be defined in the same way ICOMOS proposed the heritage impact assessment discussed in chapter two (2005; 2011). A similar code of colours was applied to assess an initial impact of the measures identified. The blue colour represents the neutral solutions, while green stands for the compatible solutions which pose no special consequences in their implementation. The solutions under the yellow group are most likely to be compatible, but this must be confirmed in detail. The intrusive solutions, which are disruptive and must be avoided, are represented under the red colour. The scheme in table 18 presents this framework which is provisionally fulfilled. This proposal will be further analysed in chapters six and seven, where it will be applied to the specific characteristics of Oporto's traditional buildings.

4.5 - Conclusions

The approach to upgrade the energy efficiency of traditional buildings is consensually based on two major areas which can be called 'hardware' (the buildings fabric and all the physical related elements) and 'software' (building services, equipment and household behaviour). Also stressed is the priority given to the improvement of the energy conservation of the envelope, which further enhances any behavioural or equipment upgrade that otherwise may turn out to be ineffective. The introduction of renewables must come afterwards and be handled carefully in order to avoid damaging the historic city's significance.

Also consensual is the approach for traditional buildings energy efficiency improvement found in the literature, with special focus on the consistent research produced in the United Kingdom covering Georgian, Victorian and Edwardian architecture. This framework is also organised under several upgrade levels, according to the easiness and the feasibility of the implementation of the diverse solutions, which are crucial to take into account when dealing with rented buildings.

It was also verified that the different approaches covering the integral building refurbishment or performed at home level, highly influenced by the economic feasibility of the solutions. Regarding the ownership framework of Oporto's traditional buildings and the economic constrains of the households, the focus must likely be set on the solutions that address the home level and may be executed by the tenants themselves and thus have a high potential of feasibility.

The most usual and effective measure to improve energy efficiency in buildings, is widely pointed out in literature to be the insulation of the envelope. At the same time, the envelope is also the most vulnerable element of traditional buildings, as heritage constraints limit the changes it can be subject to, both at building and site scale.

The specific measures identified to deal with the energy efficiency refurbishment of traditional buildings can be summarised as follows:

- Use of ‘low cost’ solutions (draught-proofing, curtains and inner shutters);
- Improvements in the insulation and draught-proofing of the building envelope (roof, walls, floor, windows and doors);
- Taking advantage of high thermal mass and increased use of passive solutions (natural lighting, solar gains, natural ventilation);
- Promotion of local energy production from renewables (solar thermal, solar PV, micro-wind, biomass boilers and heat pumps);
- Promotion of efficient district transformation of energy (co-generation);
- Using the most efficient possible heating, ventilation, air conditioning (HVAC) and lighting systems;
- Increasing the households’ awareness of efficient and optimised use of energy in dwellings (smart-metering);

The solutions identified were further crossed with the consequences they posed to the significance of traditional buildings and coded into a four colours scheme. This must be confirmed in chapter six and seven, when addressing specifically Oporto’s traditional buildings. Moreover, this overall scheme will be the base for performing the building simulations in chapter eight.

Chapter 5: Methodology

Chapter 5: Methodology

5.1 - Introduction

The purpose of this chapter is to describe the framework of the research process in detail and discuss the methodology. Previous chapters reviewed the two main components that comprise this research: the valuing of heritage and the energy efficiency improvement of traditional buildings. Additionally, the most effective measures were identified through reviewing the literature and case studies analysis. Further, it will be necessary to cross these two distinct fields of research to obtain specific solutions to try out on Oporto's traditional buildings.

The first section covers the general framework dealing with the main objectives and the methodological base. The next section details the methodological approaches used for the assessment of heritage and energy performance of buildings. This section relates to the framework that was worked out in chapter two, where methods to value heritage were discussed, and chapter three, addressing the energy performance of buildings. The final section explains the adopted methodology for improving the energy efficiency in traditional buildings without disrupting their heritage value. It was developed from chapter four, which reviewed solutions that had been developed in a number of case studies and in the literature that focuses on performance and heritage. The following sections detail the methodological approach devised to be applied to Oporto’s traditional buildings.

5.1.1 – Methodological Framework

From the analysis of the frameworks found in the literature and case studies, a sequential approach, that will address energy efficiency improvement and management of change in traditional buildings in a structured way, can be proposed. The literature addresses these two fields separately, dealing either with heritage values and impact assessment or with energy efficiency improvement. The exceptions were case studies in which the energy efficiency improvement of traditional buildings was analysed in the regards to the impact of the proposed measures on heritage. However, this approach is only outlined in research and no explicit methodology was expressed to merge these two fields.

It was consequently necessary to devise a methodological approach that could deal with the aims and objectives mentioned above. From the analysed set of methodologies it can be concluded that the most adequate frameworks rely on 'environmental impact assessment' methodologies (Morris and Therivel, 2009) or on their adaptation to the specific field of 'heritage impact assessment' (ICOMOS, 2011; Therivel, 2009). Basically, the common approach resides on establishing a baseline situation, identifying and characterising changes to be implemented and finally measuring their impact against the baseline and in doing so identifying negative and/or positive consequences. Then, a strategy to deal with the consequences and to monitor the changes to be implemented can be derived from this process. The wide approach process proposed by Therivel and Morris (2009) in conjunction with the heritage-focused approach proposed by ICOMOS (2011) were the base for establishing the methodological approach of the current research.

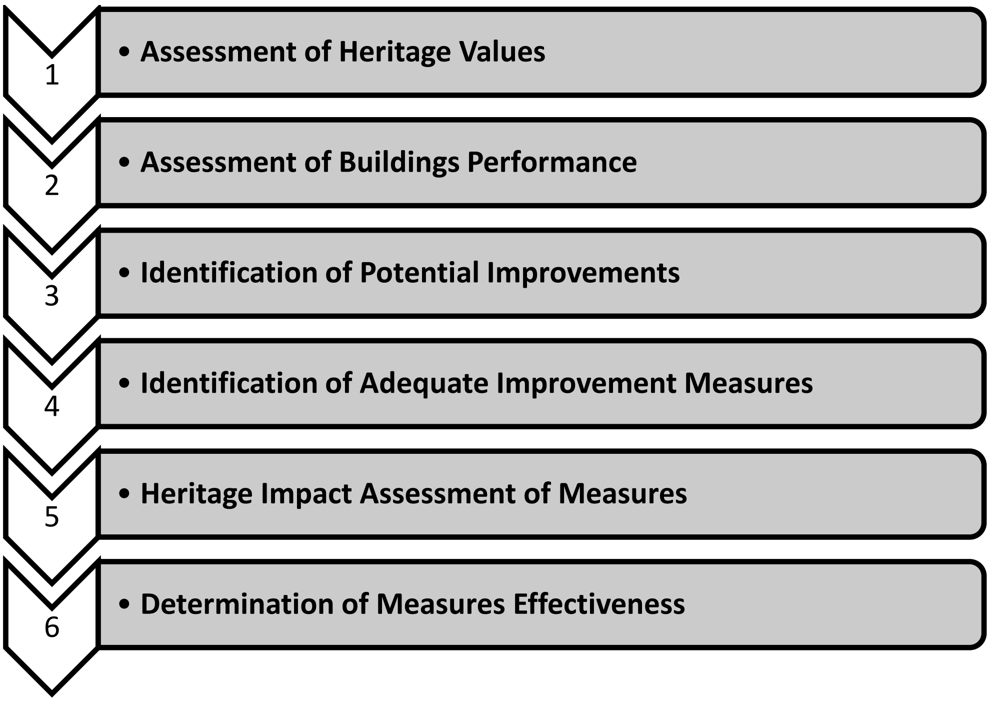

Figure 9 – Proposed sequential approach for energy efficiency improvement and management of change in traditional buildings

The adaptation derived from the cited frameworks uses the same core philosophy, detailing the three-stage process (baseline assessment, measures identification and impact assessment) into six steps, which address the specificities of the research objectives (figure 9). The first three stages detail the baseline assessment stage, covering both heritage values and building performance and include the identification of potential improvement areas. The fourth stage identifies weaknesses in the energy performance and measures which can adequately mitigate them. The following stage performs the heritage impact assessment of these measures, grading their consequences in comparison to the baseline, thus allowing to determine which changes may be considered, leading to what Therivel and Morris (2009) called the ‘preferred option’. The final stage addresses the main objective of the research by identifying the overall effectiveness of the measures by taking into consideration the parameters defined for this purpose: energy, CO_2, cost effectiveness, comfort and heritage. This includes the simulation of the proposed measures in order to assess their performance against the baseline and to obtain the most effective measures by crossing these parameters. In the following sections this process will be detailed in terms of its methodology of application.

5.1.2 – Data Types and Tools

The research is based both on quantitative and qualitative data collection methods, as is usual in research processes (Walliman, 2001). These two types of research strategies also echo the energy efficiency and heritage subjects, which are related respectively to quantitative and qualitative data. The quantitative methods were used in the fieldwork data acquisition and in the statistical and comparative analyses. This was complemented by qualitative and quantitative data gathering and analysis, obtained through a case studies survey and households questionnaires.

PART A	Data		Tools/Sources
	Data type	**Collection method**	
Chapter 2 - Valuing Heritage	secondary	literature review	internet, library
Chapter 3 - Energy Efficiency in Buildings	secondary	literature review	internet, library
Chapter 4 - Improving Energy Efficiency in Traditional Buildings	secondary	literature review	internet, library
PART B			
Chapter 6 - Traditional Buildings in Oporto	secondary	literature review	internet, library, statistics
	primary	archival analysis	archive, CAD analysis
	primary	visual survey	CAD analysis, fieldwork, GIS analysis
Chapter 7 - Case Studies Baseline	primary	physical survey	measurement, CAD analysis
	primary	interview	questionnaire
	primary	monitoring	sensors
Chapter 8 - Case Studies Modelling	primary	previously collected	software modelling

Table 19 – Data types and tools framework

Table 19 summarises the structure of the thesis in relation to the data gathered and tools used. Chapters one to four addresses the literature review aimed at identifying the research background, gap in knowledge, definitions, terminology, global framework and parameters to be used. This review was based mainly on secondary sources (books, journal articles, reports and papers) (Walliman, 2001). The second part of the thesis mainly uses primary sources obtained through archive analysis, fieldwork (research area and case studies surveys), sensors monitoring and interviews.

5.2 – Baseline Assessment

A proper definition of the methods to be used in assessing the heritage significance and energy performance of Oporto's traditional buildings is fundamental to this research. These separate fields must be used to define the baseline with which the process of change to improve energy efficiency then must be compared.

5.2.1 – Heritage

The identification of values, which need to be gathered in order to define the significance of traditional buildings, is the first step in the process of heritage assessment. Secondly, these values must be graded by means of assessing the impact any change to them would have, thus identifying to what extent it will affect the character and significance of the building. As identified in chapter two, this is based not only on the use of traditional architectural analysis and history of art studies, but also on environmental impact assessment as advocated by ICOMOS (2011). Focusing on historic buildings and sites, Therivel identifies three main sources of judgment: archaeology, architecture and architectural history (2009). In the current case, it is possible to affirm that the assessment of buildings must be based mainly on the architectural disciplines. The ICOMOS experts' evaluation of the Oporto World Heritage Site pointed to the homogeneity of the townscape, shaped by its urban fabric and historic buildings, confirming the centrality of this disciplinary perspective (UNESCO, 2006).

Of the identified value assessment methods, mainly the architectural methodologies will be used. The study edited by De la Torre showed a broad approach, covering a diversified range of heritage typologies, identifiable from several perspectives (2002). The combined methodological approach devised by Mason for cultural value assessment is the most comprehensive and was adapted for this reason in the current research (2002). The six categories presented by Mason are used and combined in order to obtain a wide spanning approach, which can specifically cover the assessment of traditional buildings. The methods and tools, based on an adaptation of Mason's scheme that will be used in the research to perform the heritage assessment are graphically expressed in figure 10.

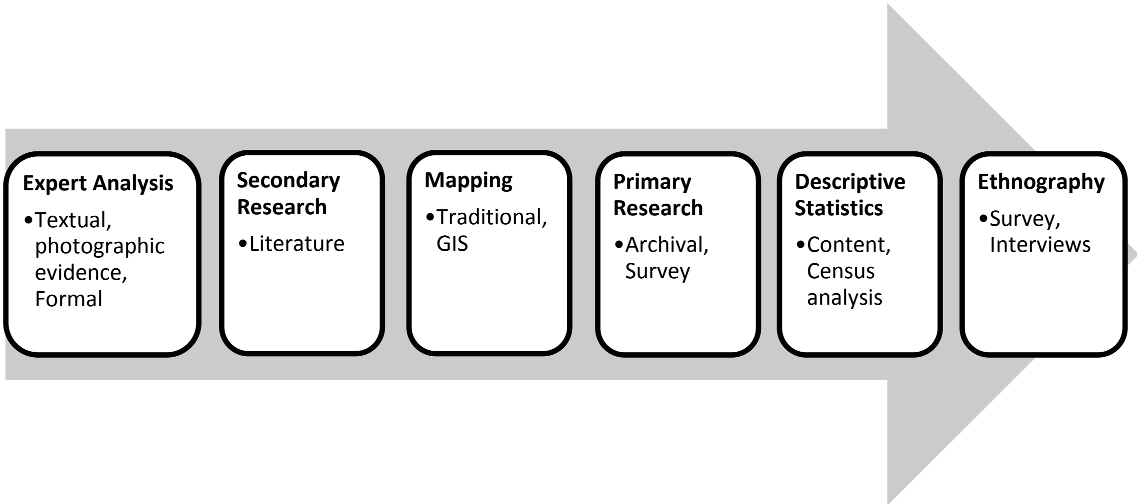

Figure 10 - Heritage assessment methodologies used in the research

Expert Analysis

The use of expert analysis can be divided into two different levels: the use of expertise in the analysis of data and the recourse to the opinion of a selected group of experts. Both approaches are valid and can be used in conjunction. In the specific case of Oporto, a large number of elaborate reports by experts have been published or are available in archives. Of these, the research produced under the World Heritage listing process (Loza, 2001; Loza *et al.*, 1993; Loza *et al.*, 1998; UNESCO, 1996; UNESCO, 2006) and the heritage debate arising from it (Campos, 1997; Campos, 1999; Campos, 2002) deserve a separate mentioning. Furthermore, the scientific research produced by recognised experts focusing on the historic city of Oporto and its architecture is extensive. This permits an integrated approach, encompassing diverse scientific areas (architecture, history, archaeology, art history, sociology, economy and demography). At the same time, direct sources analysis, namely of archive drawings, images and historic maps, was conducted. Based on the extensive research produced for the World Heritage Site (WHS) inscription process, and on the availability of primary and secondary data sources, a further peer assessment of the significance of the historic buildings in Oporto was not deemed necessary. Personal expertise, through the visual analysis of the buildings performed during the survey and further comparing them with the literature, was also used.

Secondary Research

The process of reviewing the literature was performed under the usual terms of similar research. The importance of 'desk study' in the development of the baseline is pointed out by Therivel and Morris (2009). Besides the usual library consultation, the research was also done by referring to electronic resources, namely online databases, journals, recognised institutions' websites and university repositories. The analysed case studies came from several reliable research institutions (*e.g.* European Union, English Heritage, Building Research Establishment, Historic Scotland, Energy Saving Trust and SPAB).

Mapping

In chapter two, the analysis of traditional mapping and the use of geographical information systems were identified as valuable tools for dealing with urban, architectural and social data. The use of historic maps found in the archives and the experts' literature proved to be resourceful in understanding the historic city background. The use of CAD maps and aerial imagery allowed gathering information that served as a base for the first geometric and typological analysis and for preparing the fieldwork surveys. The GIS tool was used for gathering information of maps and databases, allowing for further analysis and conclusions. The buildings' typological analysis and identification were based primarily on the GIS capabilities, which permitted cross referencing the available and the surveyed data.

Primary Research

The use of primary sources in the research was approached from two separate action lines. Firstly, the research in archives (mainly the Oporto Historic Archive) gave access to historic images and maps, refurbishment projects and previous surveys, which were valuable for the research. The second line resides in the fieldwork and conducted surveys, focusing on the object of the research itself, which is the most direct source available.

Descriptive Statistics

The use of the Portuguese Census data was the main source for statistical analysis, which was also integrated into the GIS process. This data was compared with the one available from international statistical organisations (*e.g.* Eurostat, OECD), putting it into a larger perspective. The data was mainly related to the social conditions, complementing the architectural perspective. Apart from this, environmental and energy related statistics were also analysed and compared at local, national and international levels.

Ethnography

Ethnographic methodologies were used for the interviews in the selected case studies, aiming to retrieve information about dwellings occupancy and energy-related behaviour. Further, it was also aimed at understanding the heritage valuation the householders attributed to their home and their relation with the traditional dwellings and the historic city.

5.2.2 – Buildings Performance

The building performance assessment deals with two main factors: the definition of how to benchmark the energy performance of buildings and the methodology to be used in their measurement. As pointed out by Pérez-Lombard *et al.*, "the primary aim is saving final energy or any related parameter (primary energy, CO_2 emissions or energy costs) without compromising comfort or productivity" (2009, p.273). The benchmark of such processes is widely recognised through national certification schemes, which establish an energy-rating system based on the relation between calculated yearly energy consumption and the standard value for this building type. The European Standard EN 15217 defines the method to perform this relation, stating an overall energy performance index (EPI)[35] and a maximum value which limits it (EPIMAX) (CEN, 2007). The ratio between these two indicators is further assessed against a range of levels (from A to G), corresponding to the usual energy labelling systems. The maximum value of the EPI is usually conditioned by the climate zone and/or the building type. For enlarging the comparison, the final results of the parameters are usually converted from useful energy into final energy[36]. This system can be classified as absolute because it rates buildings in a broad system, making it possible for a 'consumer' to perceive the position of the 'product'. The assessment process proposed by Pérez-Lombard *et al.* confirms this, by starting with a stage for gathering information about the building types, which is followed by the determination of the baseline limits, against whom the actual performance and results from the improvements of the specific cases are then compared (2009). This allows establishing a relation with the impact assessment process: definition of a baseline, impact assessment and mitigation. Thus, it is possible to conclude that it is viable to use an adapted

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[35] - The EPI is expressed through the energy consumed per unit of conditioned area in a year (e.g. kWh/m^2/year) allowing comparing the building's performance.

[36] - Portuguese thermal regulation states the conversion factors (F_{pu}) of 0.290 kgep/kWh for electricity and 0.086 kgep/kWh for any solid, liquid or gaseous fuel (Portugal, 2006).

methodological process for the assessment and comparison of the energy efficiency upgrade of Oporto's traditional buildings. The initial stage can be substituted by the identification of the building typologies and/or variants, which must be assessed for defining their baseline (the actual building performance) and to identify their potential improvements (figure 11). For the purpose of the current research aims, this must further be compared with the proposed measures for identifying the resulting energy variation.

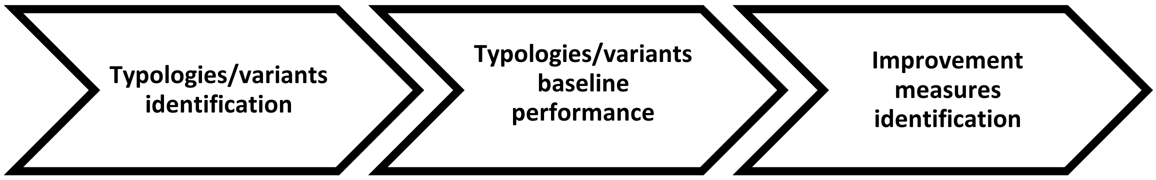

Figure 11 – Oporto's traditional buildings energy assessment process

The assessment of the factors influencing the energy efficiency of buildings can be sub-divided into two parallel lines, one addressing the building's fabric and one addressing the occupants' equipment and behaviour. These types of approaches are concurrent, aiming to create a final baseline model which allows understanding the building's overall performance. The methods used for collecting information are similar (sometimes concurrent) to the ones used in the heritage assessment, and cover: literature review, drawing analysis, mapping, energy statistics analysis, surveys and direct interviews. The established parameters for energy performance include the energy consumption (kWh), carbon emissions (kg CO_2) and cost (€). These are also suitable for energy efficiency comparisons, allowing for a direct comparison between baseline model and simulations, and with other buildings. Cost can be an effective parameter for transmitting the results to the householders and to the general public. Besides the energy-related parameters, thermal comfort is also widely established as a factor which energy efficiency must not compromise, thus becoming an internal benchmark for the upgrade process. In chapter three several comfort models, in particular the static (PMV/PPD) against the adaptive, were discussed. Even if the adaptive model could represent human behaviour in free-running buildings more accurately, there is no extensive field experience on its use in Portugal. Hence, the 'Predicted Percentage of Dissatisfied' (PPD) indicator was used due to its widely established application. In conjunction, these four indicators (energy, CO_2, cost and comfort) were used for comparing the efficiency between actual values and the ones obtained from the simulated design scenarios. At the same time, being the most widely used indicators, they also permit extending the comparison beyond this research (Energy Saving Trust, 2010; IES, 2009; Rye *et al.*, 2012; Yates, 2006).

Under the current research, the costs were directly calculated from the energy consumption obtained for the two fuel sources that have been identified for Oporto's dwellings (LPG and electricity) and all values were reported in Euro[37] (AdEPorto *et al.*, 2008; AdEPorto and UCP, 2011). The thermal comfort indicator was crossed with the energy consumption to identify eventual fuel poverty bias. The heating and cooling set points used in simulation were set in accordance with the values established in Portuguese thermal regulation at 20°C and 25°C respectively.

As explained in chapter three, the heat transfer pattern associated with the building fabric is the most relevant factor identified. Thus, the assessment of a building's energy performance is essentially associated with its envelope. The thermal conductivity of materials and construction systems is the parameter which acts as the major benchmark for their performance. Accordingly, regulations on the energy efficiency of buildings widely use maximum admissible values for the construction elements. At the same time, air tightness is also an additional parameter which allows to assess the envelope performance in terms of energy. This especially relates to the performance of windows and doors, but can also be extended to other light construction systems which are normally present in the traditional constructions (suspended ceilings, lofts, roofs).

The assessment of the thermal performance of buildings is then directly related to the acquisition of information about the behaviour of their construction systems, with relevance to masonry and glazed envelope elements. This question will be addressed in chapter six, through a literature review of the traditional Portuguese construction systems in order to identify in detail the usual fabric present in Oporto’s traditional buildings and the physical parameters associated with it. During the fieldwork in the research area, the construction systems and materials present were visually surveyed and recorded, in order to typify the most common ones. The case studies survey allowed a detailed record of these systems, which were

37 - All prices relate to 2013 and are inclusive of VAT (23%). Electricity prices were retrieved from EDP (0.1728/kWh) and exclude all fixed taxes which are independent from consumption. The butane gas prices were obtained from GALP company and were calculated through the disaggregation of a 13Kg bottle price per kg (0.8€). The cylinder price was not included because it is only paid once at first time acquisition. All values are in Euros (€) and when it became necessary to convert from British Pounds (£) 1.169 was used as a conversion factor.

compared with the reviewed literature and with the one identified in previous fieldwork, aiming to validate the information and to fulfil any existing gap. This data was used to obtain the baseline performance situation of the case studies.

The thermal performance of materials in traditional buildings was identified in chapter four as presenting a certain degree of uncertainty (Baker, 2011; Rye, 2011a; Rye, 2011b; Rye *et al.*, 2012). This raises doubts about the use of typical values, which are primarily verified for contemporary construction types. Ideally, the process should be performed through in-situ measurements to reduce uncertainty. However, the necessary equipment and expertise to execute such measurements were not available, making it impossible to be incorporated into the research. A specific study has already addressed the particularity of the thermal performance of traditional Portuguese construction systems (Santos and Rodrigues, 2009). However, the results were not based on direct measurements, but rather on the use of typical U-values for the calculation of traditional construction systems. This gap was closed by crossing the information provided with several sources in an attempt to identify consensual values and thus reducing the eventual lack of accuracy (AdEPorto *et al.*, 2010; ASHRAE, 2009; CIBSE, 2006; Mendonça, 2005; Quercus, 2004; Santos and Matias, 2007).

Apart from the envelope's heat transfer rate, the air permeability of its components is another parameter which influences the overall thermal performance of a building. Therefore, measuring it becomes necessary to complement the data used to determine the baseline performance, both for energy and household comfort. Like U-values, draught rating should be measured in-situ to obtain real data and higher accuracy. Unfortunately, measuring this parameter also requires specialised equipment, expertise and long periods of monitoring, which made its use impractical for this research. To obtain alternative information, the standard values in the literature were reviewed. Additionally, the existing cracks around the frames were measured[38], during the case studies survey, which allowed inserting the correspondent data in the simulation software and calculating the air permeability.

In the literature review, an improvement of the occupants' behaviour towards energy consumption was identified as having a significant reduction potential. Hence, it became fundamental to assess the behaviour of the households of the selected case studies in order to

[38] - This parameter is required by the simulation software.

achieve data which could be used both for thermal modelling and equipment modelling. The approach for this aspect was discussed in chapter four, covering the systems (heating, cooling and DHW), equipment (appliances, cooking and entertainment), lighting and human behaviour (occupancy pattern and control). The necessary data was obtained directly through the case studies survey and household interviews following the model implemented by Gupta and Chandiwala to perform similar questionnaires (2010). They were devised to collect information about the various pieces of equipment used by the households, covering information about their location, type, power rating and average usage hours. The information was collected during the survey, both by the direct observation of the equipment and by interviews with the occupants.

Baseline Performance Modelling

To obtain conclusions from this stage it is necessary to perform calculations to define the baseline model. Two possible methodologies were identified to develop such a model, differing in the use of steady or dynamic models of calculation. Both methodologies can be performed under the same thermal calculation standards and focus mainly on the thermal performance of the building's fabric and on the energy spent to satisfy the established level of thermal comfort. The main difference resides in the use of a simplified model based on an abstract type of use as opposed to a model which aims to simulate the real performance based on actual data. The first methodology is applied in thermal regulations to determinate the energy efficiency grading of new buildings or major refurbishments, targeting a typical use in the absence of real data. The dynamic model, on the other hand, allows for integrating real data information, including all sources of energy consumption, human behaviour, equipment, environmental conditions control and typical weather data, simulating the yearly variation. Even if this model can always only be a simplified version of reality, it is the most suitable for simulating the performance of occupied dwellings. Consequently, it becomes clear that the dynamic model represents the most effective and flexible approach to deal with occupied traditional residential buildings, from which actual data was collected. This is confirmed by the reviewed literature, where this method was predominant in determining the performance of traditional buildings.

Modelling Software

The complexity of the dynamic models can only be accurately handled with the use of computers and specific software. Thermal modelling software for buildings permits conjugating complex data in a simplified model in order to establish the baseline performance and simulate improvement scenarios. The selection of the software for modelling traditional buildings must use the available data, covering all the factors involved as described by Hensen and Lamberts (2011). The *Building Energy Software Tools Directory*, maintained by the United States Department of Energy (USDOE) provides a large spectrum for an initial selection based on the first criterion defined (US DOE, 2011a). Several possibilities from the specific retrofit software section were analysed. The software from Integrated Environmental Solutions (IES) - Virtual Environment PRO (IESVE PRO) - was selected based on the review of the literature and on the licensing scheme and support available in the Oxford Brookes University. It was concluded in the undertaken review that this tool was used by several academic and research institutions (Hensen, 2011; University of Cambridge, 2012). An Anglo-American study extensively revised a large amount of energy modelling software, confirming IESVE PRO as a powerful dynamic simulation tool with capabilities of integrating all the necessary variables for the current research (Crawley *et al.*, 2005; Crawley *et al.*, 2008). The software permits a "detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use" (Crawley *et al.*, 2008, p.665). The interoperability of the software, namely with Building Information Model (BIM) and CAD formats, is pointed out by Kumar (2008) and Kensek and Kumar (2008). Furthermore, the software was used in a similar research to model traditional buildings, establishing the baseline performance and the improvement options based on several design scenarios, and thus confirming their feasibility of use (IES, 2009). This study was commissioned to the IES by Historic Scotland, which allowed confronting the software developer with the difficulties posed by the simulation of traditional buildings. The software suite offers several modules integrating a wide range of possible analysis, namely energy, carbon, thermal (including comfort) and solar[39]. In terms of the standards compliance, the IES Virtual Environment meets the calculation procedures of both the International Standards Organization (ISO) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (US DOE, 2011b).

39 - The complete suite includes further the daylight, light, Computer Fluid Dynamics (CFD), bulk airflow, HVAC, climate, egress, ingress, value, cost, and low carbon/renewable strategies modules. In order to obtain expertise to perform the simulations in the IES-VE software, several web training sessions were performed in the following modules: 'Model-IT' (geometry data modelling, weather and location), 'SunCast' (solar shading simulations and calculations), 'MacroFlo' (wind and natural ventilation), 'ApacheSim' (construction and thermal data to perform dynamic thermal simulations) and 'Vista' (thermal results analysis).

The analysis of the results output by the software, allows establishing the baseline performance of Oporto's traditional buildings and identifying their potential improvements. This corresponds to the third stage of the general methodological framework, while also synthesising the first two previously described assessment stages. The baseline study encompasses both the energy performance and the heritage significance, performed in two parallel approaches. From this stage, the building's performance deficiencies are also identifiable, which allows defining the adequate measures to address them.

5.3 – Energy Efficiency Improvement and Management of Change

In chapter four, the framework for the energy efficiency improvement of traditional buildings and identifying the measures used in the case studies reported in the literature, were reviewed. One of the major points emerging from this framework, that must be addressed methodologically, is the assessment of how the upgrade measures affect the heritage in traditional buildings. The interaction of this component with the technical aspect of energy efficiency improvement is outlined in the analysed case studies, even if it was not explicitly expressed in terms of methodology. Most of the studies were undertaken by experts in both fields and/or promoted by institutions whose primary objective is heritage conservation (*e.g.* English Heritage, Historic Scotland or SPAB). A common approach towards heritage is identifiable in the diverse cases in the selection of the measures based on the criterion of retaining the visual integrity of the traditional buildings. Some of the cases also follow the guidance of the heritage charters and regulations. Accordingly, the usual envelope improvement is performed with solutions which are visually nonintrusive. The introduction of renewable energy sources is also part of this concern, posing similar questions regarding visual changes to the external envelope. Hence, it is possible to conclude that the visual assessment of the impact on the architectural elements which contribute to the significance of buildings and site is the main aspect to be considered.

The process for traditional buildings has to be approached on two different levels: individual building and the overall historic urban landscape. This is justified because the individual change has to be considered for its wider consequences to the site. This can be approached by the ‘direct’ and ‘indirect’ impacts identified in the EIA classification. Moreover, the concept of ‘cumulative impacts’ can also be applied, because the accruing of low, direct impacts along time can provoke highly damaging indirect impacts. This gains greater relevance in cases like

Oporto, where the conservation of the authenticity and integrity of traditional buildings is imperative for the protection of a World Heritage asset. Referring to the ICOMOS ‘grading scale’ discussed in chapter two, it is possible to state that Oporto's traditional buildings are classified under the ‘very high’ category due to their significant contribution to the attributes that convey the OUV of the World Heritage area, as recognised by the UNESCO (1996).

5.3.1 - Measures Identification

Stage four of the methodological approach deals with the identification of adequate measures to mitigate the previously measured energy performance weaknesses. This is always an open stage based on the gathering of the most up-to-date technology to meet the identified problems. At the same time, the solutions to be considered must also be adequate to traditional buildings, *i.e.* they must be compatible with the constructions systems of traditional buildings, namely allowing for maintaining their ‘breathability’. In the current research this stage was addressed through the revision of the scientific and technical literature and analysis of similar case studies discussed in chapter four.

5.3.2 - Heritage Impact Assessment

As pointed out in chapter two, the heritage impact measurement relies mainly on experts' consideration, but can also be validated in public consultation, depending on the scope and extension of the change process. In the current research the OUV of Oporto’s traditional buildings relates directly to the maintenance of the integrity of their architectural image, which shapes the character of the overall urban site. It is necessary to use a methodology which assesses the consequences of the proposed design scenarios in this image. The method described by Knight for the visual impact assessment was identified as being suitable for this process (2009). The application of the method was made in reference to the visual analysis of the consequences resulting from similar, already applied measures in Oporto’s traditional buildings and identified in the fieldwork. Furthermore, the simulation through photomontage was also used as proposed by Knight (2009).

The consequences are later compared against the significance baseline using a grading scale, as discussed in chapter two. The grading attribution is directly related to the degree of impact on the values identified during the design process. The ICOMOS methodology proposes an impact scale of five grades which are further translated into the significance of the impact. The type of impact scale usually used in EIA, covers seven grades, varying from major positive to major negative, which can be translated into a numerical scale ranging from +3 (major positive) to -3 (major negative) (Morris and Therivel, 2009). To assess the impact of the design solutions in more detail, this last scale was used, in order to obtain the overall impact of the solutions. These levels relate to the previously identified specificities of traditional buildings: the direct impact on the building's fabric (compatibility), the maintenance of the visual integrity of the building, and the consequences of the measures to the site (accounting for the cumulative impacts). In table 20 this method is synthesised by cross referencing the terminology used by ICOMOS (2011), the EIA impact scale (Therivel and Morris, 2009) and the usual colour scheme, with the diverse levels to be assessed. As stressed in chapter two, impact grading is essentially a subjective process and will be performed using professional researcher and academic expertise.

Scale & severity of change/impact	Significance of effect or overall impact	EIA impact scale	Impact on fabric	Impact on visual integrity	Impact on site	Overall impact
Major positive impact	Very large	3				
Moderate positive impact	Large	2				
Negligible positive impact	Slight	1				
No change	Neutral	0				
Negligible negative impact	Slight	-1				
Moderate negative impact	Large	-2				
Major negative impact	Very large	-3				

Table 20 – Building dynamic simulation design scenarios heritage impact assessment

This results in a process which is driven by a maximum admissible limit of change, to which the other indicators have to be weighted to achieve the global feasibility of the solutions. The determination of the 'limit of change' is then a critical process that must be based on the preservation of the fundamental elements identified, giving significance both for the buildings and for the entire World Heritage Site. In this sense and independently of their type or geographical location, the traditional buildings must be evaluated in what can be called a 'Group Impact Significance'. For the simulated scenarios the limits of change were identified based in the characteristics identified in chapters six and seven. The 'professional judgement' approach used was coincident with the city regulations for the WHS management, which focus on the preservation of visual integrity of the urban historic city (PORTO VIVO, 2008; WHO, 2012). However, none of the city's regulations specifically detail how to perform such preservation, forwarding the responsibility of evaluating the consent to the technicians of the local authorities.

5.3.3 - Measures Effectiveness

The final stage addresses the evaluation of the effectiveness of the proposed measures. The major question emerging at this point concerns the assessment of the effectiveness, which must be performed to obtain conclusions from the results. This stage directly compares the results from the design scenarios with the initial baseline model, following the usual method identified in the literature (IES, 2009). The comparison of the results was based on the four indicators previously described. They report quantitatively the improvements achieved in energy savings, CO2 reduction and comfort level. However, the measurement of their effectiveness must be assessed by using additional indicators that address the economic dimension, which will allow verifying the effectiveness of the investment made. The use of 'return of the investment' (ROI) or pay-back is a proven method to measure this cost-effectiveness by calculating the number of years necessary to regain the initial investment. The measurement of the effectiveness based on the cost was selected because it relates to the feasibility of the measures' implementation, which is relevant in the context of low-income households in rented homes. To accomplish this calculation, the costs involved in the implementation of the measures were estimated, including both the upgrade of the building fabric[40] and the equipment[41].

It is necessary to stress that at the end of this proposed process the effectiveness of the measures is determined by the total process and not only by the final stage as it incorporates all previous assessments made in terms of heritage, energy performance and comfort. This means that effectiveness is based on several components and is measured by weighting the following: heritage (impact of measure), energy and CO_2 (measured improvements), cost-effectiveness (pay-back measurement) and comfort (acceptable PPD). This is also a hierarchical process, with heritage impact assessment at the top, *i.e.* if a measure is revealed to be undoubtedly damaging for the building's significance it will be disregarded, even if it proves to be highly efficient in the remaining parameters.

40 - The values involved in the measures implementation were retrieved from the construction estimating costs database available in the internet (Cype Ingenieros, 2011).

41 - The costs involved in upgrading the efficiency of the equipment were retrieved from the European Union funded internet database (Quercus, 2012).

5.4 – Research Process

Following the methodological conceptualisation explained in the previous section, the most relevant aspects of their application are now further explained. The main aspects to be addressed deal with the fieldwork surveys undertaken and with the development of the virtual models performed in the thermal simulation software, which contain detailed technicalities that must be explained.

5.4.1 – Research Area Selection

Due to the relative extensiveness of the area covered with traditional buildings in Oporto and their apparent homogeneity, the selection of the research area was made through 'cluster sampling', which is a feasible method to achieve representativeness of the building stock (Trochim, 2006; Walliman, 2001). The research area was chosen under the aspect of achieving the closest possible similarity with the overall traditional buildings stock and so that previous surveys and studies could be employed. The sample comprises a unique area coincident with official administrative boundaries, inside which all buildings were initially considered.

5.4.2 – Fieldwork

The conducted survey corresponds to the usual 'bottom-up' information processing strategy, where detailed information from the basis (individual building observation) is gathered in order to identify the common characteristics of the sample. Reviewing the possible approaches, Swan and Ugursal state that the "high level of detail is a strength of bottom-up modelling and gives it the ability to model technological options" (2009, p.1822). This methodological strategy was also extensively applied in the EU-funded project Tabula, which was conducted in fourteen countries and aimed at performing an energy assessment of the existing built stock through a typological approach (Dascalaki *et al.*, 2011; Tabula Project Team, 2010; Tabula Project Team, 2012). In the context of this study, "the term 'building typology' refers to a systematic description of the criteria for the definition of typical buildings as well as to a set of exemplary buildings representing the building types" (Tabula Project Team, 2012, p.7). This approach can be inserted in a 'multi-stage sampling' methodology (Trochim, 2006), by first identifying the typologies and afterwards the exemplary types, which represent the ones that can be used as case studies for posterior generalisation of the results. As also pointed out by Swan and Ugursal, this approach needs to be extrapolated to represent the universe, which is accomplished by weighting the typologies according to their representativeness (2009). This was also the general methodology taken for this stage of the research project.

The Geographic Information System (GIS)[42] and the Computer Aided Design (CAD)[43] analyses were made to prepare the background information for each building prior to the fieldwork. These analyses were based on digital maps and aerial imagery from Oporto City Council, which were complemented with more recent imagery from Google and Bing Maps to clarify very specific mapping doubts. The use of GIS is a valuable method to manage information in heritage surveying as clearly pointed out by Mason (2002). The same is pointed out by Swan and Ugursal (2009) for addressing the identification of the building 'archetypes' in a bottom-up model.

A database was drawn and directly filled in the field for each building[44]. It included information about all the aspects and materials of the building envelope, urban insertion, function, age, conservation and heritage[45]. The approach implemented was based on the identification of the main typologies driven by the parameters that influence energy performance, focusing mainly on the envelope and the urban insertion (the relation with other buildings). These are coincident with the main factors influencing the building's energy performance, identified in the previous chapters and literature (Tabula Project Team, 2012). The GIS allowed gathering all the information, linking the records and photos from the survey with other sources of information, namely Census, SRU, CRUARB and Oporto City Council data, allowing their cross analysis.

5.4.3 – Typological Variants Identification

The first stage consisted of the identification of all buildings meeting the criteria of being mainly residential and built before 1919. Exceptional buildings were excluded, based on both

[42] - ESRI ArcGIS educational software version 9.3 was used; later it was updated to version 10.1.

[43] - Autodesk Autocad Map 3D 2011 educational software was used.

[44] - The protocol is included in the appendix A.

[45] - The personal experience obtained in the professional experience in the Oporto City Council Architectural Record, which include the Oporto heritage recording fieldwork, was a valuable background to fulfil this stage of the research. This experience included the development of record protocols, both used in the field and in the databases.

their function and built form. The functional survey allowed identifying the buildings where the residential function was dominant, *i.e.* occupying more than 50% of the building's area. The visual survey, literature review and historic mapping helped identifying the pre-1919 buildings. In this group the buildings whose built form allowed them to be identified as traditional, even if a major refurbishment had changed their aspect partially, were included. Based on the literature, the stratification of the age of traditional buildings comprises: 'before eighteenth century', 'eighteenth century' and 'nineteenth century', which also included the buildings until 1919 (Fernandes, 1999; Ferrão, 1985). Furthermore, the selection was made through data crossing in the GIS software.

5.4.4 – Case Studies Selection

The case studies were selected by representing each building variant and the householders were approached personally by the researcher and/or with the support of some local institutions. The case studies selection was casuistic and their numbering followed the chronological order of acquisition.

5.4.5 – Case Studies Survey

The data achieved from the initial fieldwork was complemented with the architectural projects obtained in the local archives and then analysed before the case studies survey in order to anticipate the geometric measurements to be done. The analysis also aimed to determinate all information needed to perform the thermal modelling for the buildings by identifying it beforehand. This information covered the identification of materials and geometrical parameters directly related to the thermal performance variables identified in chapter three.

Data collection was obtained by direct observation and measurement, through information provided by the households or by instrumentation (table 21). Official weather data was acquired from the Portuguese meteorological institute (*Instituto Português do Mar e da Atmosfera* - IPMA) with the objective of establishing the reference weather to be compared with the fieldwork data. The energy consumption data was obtained from the electricity provider (*Energias de Portugal - EDP*), after seeking the respective household's consent.

Equipment	Measurement unit	Brand	Model
Digital Light meter	light (lux)	Extech	LT300
Digital sound level meter	noise (db)	Extech	407730
Thermo-Hygrometer	temperature (°C) and humidity (%)	Oregon Scientific	THGR228N
Sensor (External Data Logger)	temperature (°C), humidity (%) and light (lux)	Onset	HOBO U12 - 012
Sensor (Temperature data logger)	temperature (°C)	I-Buttons	DS 1920

Table 21 – List of the equipment used in the survey

5.4.6 – Household Questionnaire

The methodology and design of the questionnaire were based on the Post Occupancy Evaluation (POE) strategy of the Probe research project (Bordass *et al.*, 2001a; Bordass *et al.*, 2001b; Bordass *et al.*, 2001c; Cohen *et al.*, 2001; Leaman and Bordass, 2001) and on similar research performed by Gupta and Chandiwala (2010). Even if the aim was not to perform a POE, it is partially similar as it also addresses existing, occupied buildings. Furthermore, the information gathered by the POE questionnaire corresponded in parts with the thermal comfort evaluation.

The questionnaire is designed in a structured format and composed of various types of information divided into three sections: occupancy, comfort and equipment, allowing the users' profiles to be defined. Methodologically, the comfort section was designed based on a structured scale assessing the way occupants feel and their preferences ((Gupta and Chandiwala, 2010). The seven point thermal sensation scale was the base for the questionnaire 'feel' grading (ASHRAE, 2010; International Organization for Standardization, 2005), while a short five point version was used for the 'preferable' measurement. Additional data was collected to perform a later check on the given answers. This included measurements with equipment (table 21**Erro! A origem da referência não foi encontrada.**), the activity level of the occupants during the last 15 minutes[46] and their clothes[47]. This section further contains semi-structured questions about the house environment control, which provided data to be inserted in the modelling profiles.

[46] - The scale used allows a later conversion into 'Metabolic Rate' units (International Organization for Standardization, 2005).

[47] - The scale used allows a later conversion to 'Clothing' units (International Organization for Standardization, 2005).

As pointed out by Schwarz and Oyserman, the gap between research questions and the way they are understood by respondents leads to a data bias which is difficult to avoid (2001). This subjectivity bias when collecting data for performance modelling of buildings is also pointed out by Swan and Ugursal (2009). However, the main objective was to represent the occupants' behaviour towards energy consumption in order to enable the implementation of a dynamic simulation, in the most accurate way possible. The survey undertaken, besides its limitations, allowed for a detailed recording of behavioural patterns and collection of valuable quantitative data which enabled performing dynamic modelling with real conditions.

5.4.7 – Units and Variables

In accordance with Portuguese standards, the units used in the research are the ones specified in the 'International System of Units' (SI) (Bureau International des Poids et Mesures, 2006). These are also commonly used in the scientific literature and use the metric system as it is also used in Portugal. This system covers both the 'SI base units' as the 'coherent derived units' and their decimal multiples and submultiples. Additionally, other 'Non-SI units accepted for use with the International System of Units' were used (Bureau International des Poids et Mesures, 2006). Overall, these are used in the European (EN) and International (ISO) standards related to the energy performance calculation for buildings (Dijk and Khalil, 2009; International Organization for Standardization, 2012), on which the correspondent European Directives and Portuguese thermal regulations are based (EC, 2010; Portugal, 2006; Santos and Rodrigues, 2009; Santos and Matias, 2007). Furthermore, the ISO Standards were the base of the calculations performed in this research both for the thermal modelling and the U-value calculation.

The energy power was expressed in watt (W) or kilowatt (kW) and the energy consumption in the usual kilowatt per hour (kWh). As the large majority of the equipment in question was powered by electricity, no conversion was needed. The only exception was the use of standard 13Kg butane gas cylinders. This poses the necessity of converting the number of cylinders used per month, based on information provided by the households, into kilowatt units. Based on the consulted sources, it is possible to verify that the conversion is not entirely consensual, ranging approximately from 12.2 to 14 kWh per kg of butane gas (Calor, 2012; Casa Certificada, 2009; Climate Change Levy, 2008; Euroheat, 2003). The conversion factor of 13.62 kWh per kg of butane gas was chosen because it was the most commonly found one.

5.4.8 - Terminology

The determination of the terminology to be used in the research was fundamental for the initial literature review. The dual language (Portuguese-English) posed difficulties in specific traditional building construction systems terminology, which is a very narrow field of research, without specific translations available. In order to avoid misunderstandings in the translation process, the strategy was based on the use of English architecture visual dictionaries to mediate the technical terminology conversion (Ching, 1995; Davies and Jokiniemi, 2008; Dorling Kindersley, 1992; Merrian-Webster, 2012). During the literature review process, other terms, that were deemed suitable, based on detailed images of materials of traditional buildings and construction systems, were added to this initial base. (Brunskill, 1992; Costa, 1955; Leitão, 1896; Mascarenhas, 2012; Mateus, 2002; Pinho, 2000; Segurado, n.d.-a; Segurado, n.d.-b; Teixeira and Póvoas, 2012).

5.5 - Conclusion

This chapter outlined the methodological framework and described some detailed aspects of its application. The method is a consequence of the reviews made in the previous chapters and its definition closes part A of the thesis. The next chapters will apply this framework to Oporto's traditional buildings, aiming to achieve the validation of the method and to answer the research questions that were initially posed.

In chapter six, survey fieldwork and analysis of a detailed characterisation of Oporto's traditional buildings is achieved through data collection, which allows identifying their typological matrix. A detailed survey is further undertaken on selected case studies, allowing the acknowledgement of their performance in real situations, the results being explained in chapter seven. The next chapter reports on the modelling of these cases and on the simulation of the previously identified solutions. The discussion in chapter nine allows identifying the most effective and feasible solutions, crossing environmental gains, cost effectiveness, feasibility of application and cultural significance consequences. From these results, conclusions are drawn in order to establish the method of sensitive refurbishment practices that do not unduly damage the heritage value of these buildings and that may be further replicated. The final chapter concludes the research and identifies further research to be undertaken.

Chapter Six: Traditional Buildings in Oporto

Chapter Six: Traditional Buildings in Oporto

6.1 - Introduction

The objective of this chapter is to identify Oporto traditional building typologies, in order to determine their main geometric, spatial, and construction characteristics. In parallel, are also addressed the associated parameters influencing the buildings energy performance. The sections of this chapter cover the buildings analysis based on the surveys and research undertaken. The identification of the heritage values is also discussed, as the admissible change to be respected in any refurbishment operation.

6.2 – Research Area Background

The settlement in the granitic bank of the River Douro, near its mouth in the Atlantic coast, determined the mercantile character of the city. During the Middle Ages are established commercial relations with the Northern Europe, with special focus on the port cities of England, France and The Netherlands. Those natural and cultural conditions established the history of the city and shaped its urban form and traditional architecture.

6.2.1 – Oporto's Natural and Climatic Context

Location

Oporto is located in the geographic coordinates of 41˚ 08’ 27’’ N Latitude and -8° 36’ 52’’ W Longitude, taking the *Ribeira* Square in the historical centre as the reference mark. The city developed in the north bank of the river Douro, circa 4.4 Km from its mouth and is today inserted in the metropolitan area, to whom it is the core and the main historic reference.

Geomorphology

The topography of the city spreads from the river until an elevation of 163 meters, forming a hill with several valleys fitting it perpendicularly to Douro. On those, several rivers and streams run until reaching the confluence with Douro, where some of the first human settlements developed. On the top of the hill was established a fortified settlement facing the south and controlling the river activity. The development of the city was shaped in the relation established between those two levels.

Geologically, the city is settled in granite rock which is significantly known as the 'Oporto granite' (Costa and Teixeira, 1957; Oliveira, 1973), which was largely used in the construction of buildings, leading Oporto to be denominated as the 'granite city'.

Climate

The Oporto climatic sub-type presents a dry or temperate summer, with an "average temperature in the hottest month below or equal to 22°C, and with four months or more with average temperatures above 10°C" (AEMET and IM-I.P., 2011, p.17). The Atlantic influence is determinant for the Oporto's climate pattern avoiding extreme thermal amplitudes (AEMET and IM-I.P., 2011; Monteiro, 1997; Oliveira, 1973). The bioclimatic comfort index for the period between 1941 and 2000, reveals also that July is classified as ´hot´, while January is 'fresh' (IGP, 2005).

Temperature

The Oporto Climate data (Instituto de Metereologia, 2012) show that the average maximum temperature reaches 25°C, while the average minimum is of 5°C. The number of days with maximum temperature above 30°C or minimum temperature under 0°C is not significant. In the summer period, the number of days with maximum temperature above 25°C is more expressive, ranging from 25% in June to 40% in August.

Relative Humidity

The location by the riverside and the proximity to the sea naturally influences this parameter for Oporto. From the analysis of a 75 year data set, Oliveira concluded that Oporto's average humidity was 79.0%, classifying it as 'strong humidity' (1973).

Precipitation

The precipitation pattern is regular for the Portuguese northwest mainland, revealing the analysis of a 78 year data set that the yearly average precipitation was of 1210.8mm (Oliveira, 1973). As expressed by Monteiro the driest month is July, which is consistent with the usual maritime influence (1997).

Wind

Once again the sea proximity and the location in the Douro valley, which forms a direct channel, are fundamental factors settling the wind direction patterns (Oliveira, 1973). From

April until September the dominant winds in Oporto come from the northwest, while in January and February the south winds are predominant and reveal the stronger yearly average speed (Monteiro, 1997). From the analysis of monthly wind patterns, Oliveira concluded that the yearly average wind speed was of 18.5 Km/h (1973). Regarding wind speed, Oliveira states that the strongest winds were from the northwest to the southwest, with an average speed of 20.8 Km/h and a maximum average speed of 24.0 Km/h registered in the northwest quadrant.

Insolation

Portugal's location is very favourable in terms of insolation, reaching the yearly sun average hours of 2200 to 3100. Oporto achieves circa 2600 hours per year, which leads to a monthly average of 216.7 hours. The monthly distribution data shows July as the sunniest month, with an average above the 300 hours. Regarding irradiation it is naturally achieved the same distribution pattern, reaching Oporto a yearly sum of global irradiation between 1500 and 1600 kWh/m^2. The optimal average yearly angle for solar panels is of 34 degrees in Oporto.

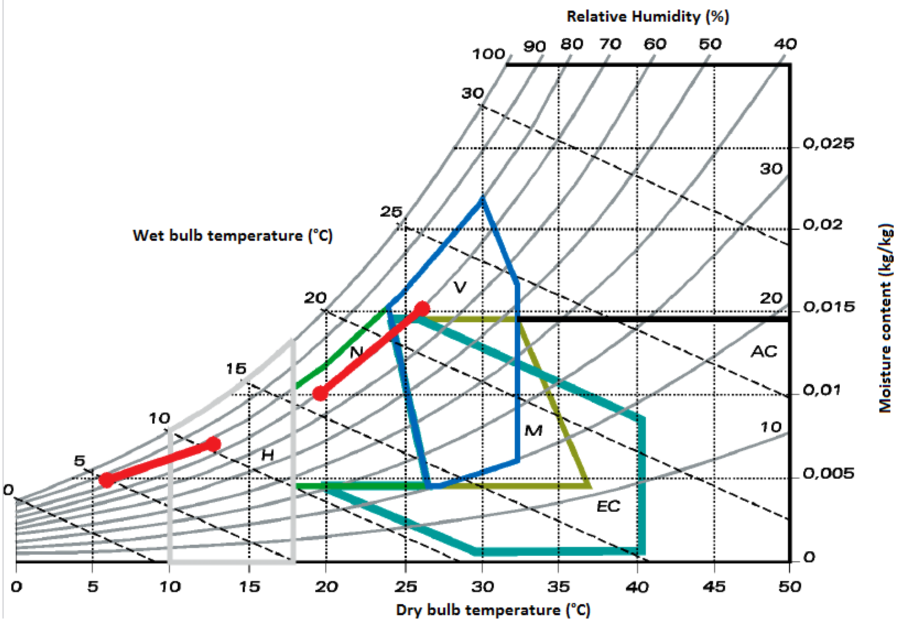

Figure 12 – Oporto *Serra do Pilar* bioclimatic chart (Baruch Givoni method) *in* Gonçalves and Graça (2004, p.19)

Based on the climate data available for Oporto city centre (*Serra do Pilar* weather station) Gonçalves and Graça developed the bioclimatic chart shown in figure 12. The authors concluded that several bioclimatic strategies for building design could be applied in Oporto, both for heating and cooling seasons (Gonçalves and Graça, 2004). For the heating season it is recommend the increase of the buildings thermal inertia, the reduction of the heat losses by conduction through the insulation improvement and the optimization of the solar gains. For the cooling season the authors advocate the same measures for the thermal inertia and the conduction losses, complemented with the reduction of the solar gains by shading the glazed elements, and the promotion of passive cooling, through night transversal natural ventilation and soil cooling using underground pipes (Gonçalves, 2010).

6.2.2 – Oporto's Historic Centre

The Oporto's historic centre corresponds mainly to the area which was limited by the former medieval city walls (figure 13). This area developed over centuries through the relation between the primitive wall plateau, providing security and spirituality, and the river settlement, where trade and fishing activities took place (Afonso, 2000; Carvalho *et al.*, 1996; Ferrão, 1985; Oliveira, 1973). The fourteenth century wall grouped the two nodes and allowed the densification of this urban area for the next 400 years.

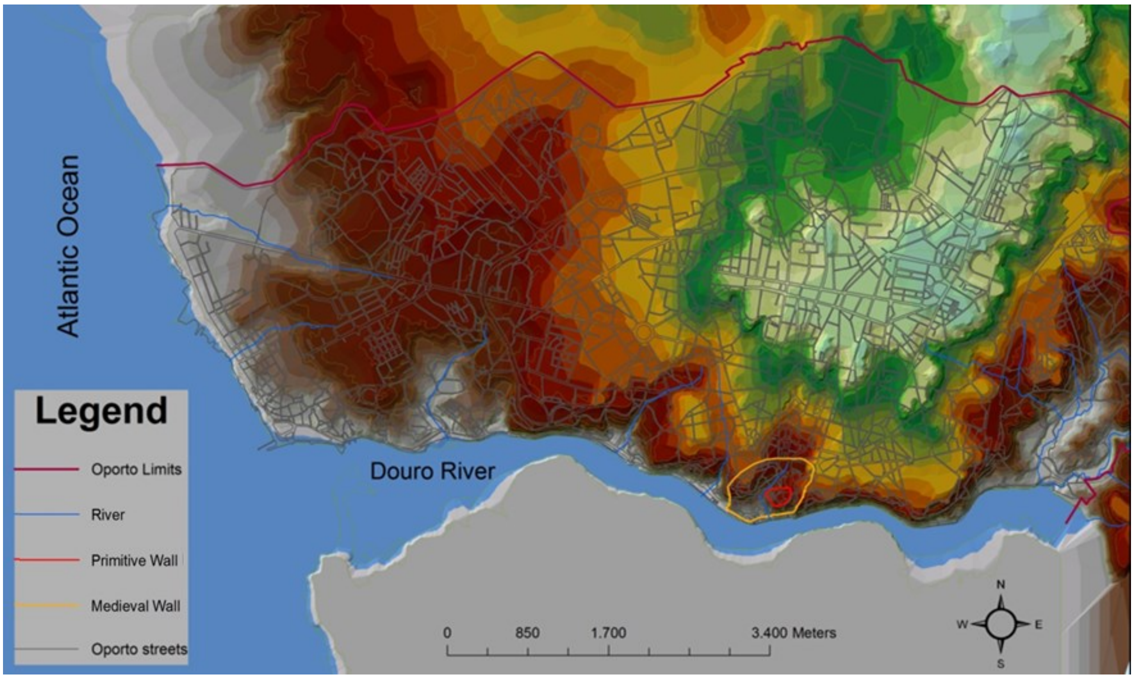

Figure 13 – Oporto Historic Centre over the Digital Terrain Model (DTM)

In the second half of the eighteenth century the small neighbourhoods located outside the walls started growing through the planned urban expansions promoted by the *Almada´s* city administration. Those plans also modernised the historic core by opening new streets, allowing the convenient and safe connections from the city port to the new developing centre, halfway between the two original nodes (Ferrão, 1985). This expansion continued during the nineteenth century, leading to new cuts on the historic urban tissue to create wider connections from the river to the new city centre or to the recently built *Luís I* iron bridge and new custom house (Abreu, 1986; Ferrão, 1985; Oliveira, 1973).

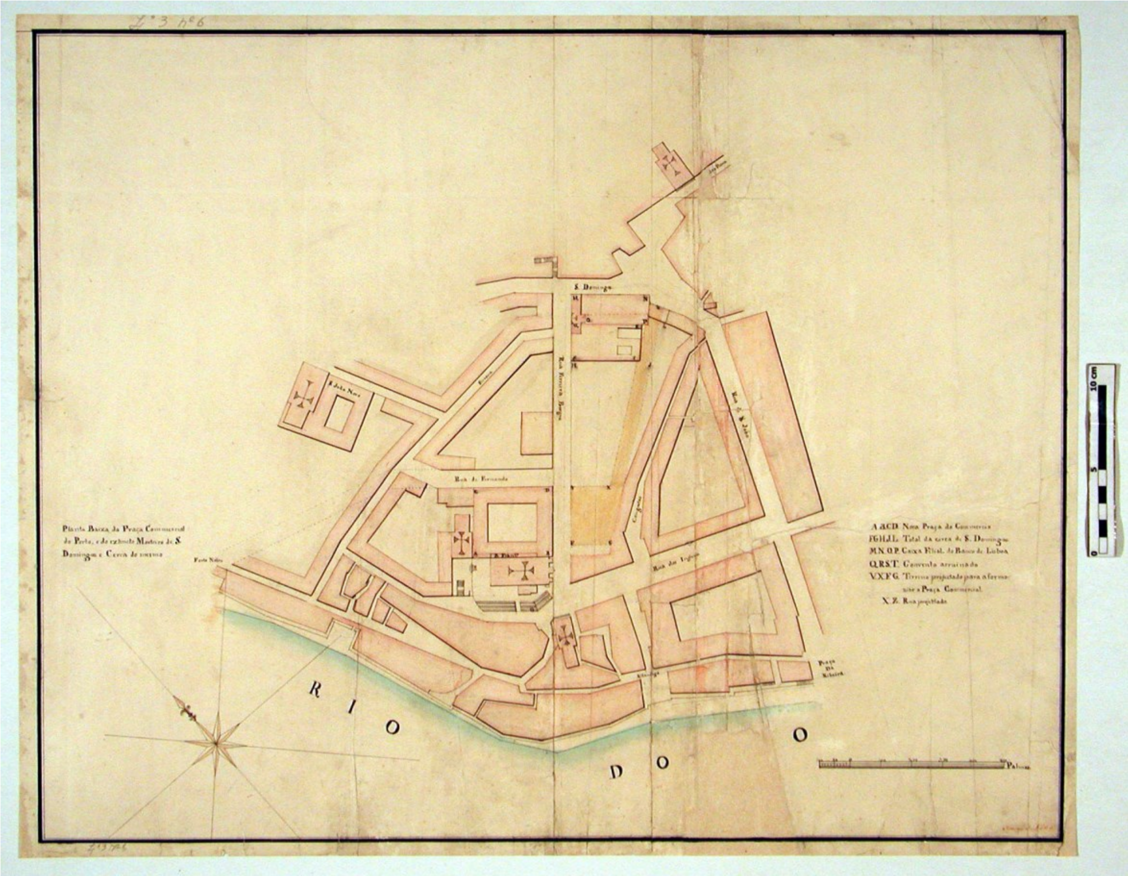

Figure 14 – *Infante* Research Area before the nineteenth century major urban transformations – AHMP (285 FD)

6.2.3 - Oporto World Heritage Area

In 1991 the Oporto city council initiated the process to inscribe the historic centre on the World Heritage List, which occurred in 1996 (UNESCO, 1996b). The decision was based on the cultural criteria iv (UNESCO, 1996b). The recognition of the outstanding universal value of the Historic Centre of Oporto implied also the recognition of its authenticity and integrity (UNESCO, 2006; UNESCO, 2008). The delimitation is almost coincident with the former fourteenth century's medieval wall, valuing the traditional buildings urban ensemble as a "townscape (…) of outstanding quality, in terms of both its homogeneity and its harmonious relationship with its river and hills" (UNESCO, 2006, p.2).

6.3 – Traditional Buildings Typologies

Based on previous research (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992) and on the professional experience as coordinator of the Oporto Architectural Heritage Record (City Council), it was possible to have a general overview of the Oporto traditional buildings typology and corresponding construction systems (Costa *et al.*, 2012; Teixeira and Belém, 1998; Teixeira and Póvoas, 2012; Teixeira, 2004). This background information was complemented by the analysis of the available surveys and of the data collected by the fieldwork undertaken for this research project.

The traditional buildings that exist today in Oporto's historic core have been mainly built or transformed over a three hundred years period, between the seventeenth and the nineteenth centuries. Those buildings can be briefly described as: terraced houses facing the street, inserted in narrow and long lots, built before 1919 and mainly residential (with shops on the ground floor). Moreover, they have hip roofs, 3 to 5 floors, 2 or 3 windows per floor, solid granite exterior walls, inner wood structure, and plaster or tiles in the main facade.

6.3.1 – Functional Typology

Even if it is not possible to identify the starting point of Oporto traditional buildings' typology, their medieval merchant genesis is consensual among the researchers who have addressed the theme (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992; Smith *et al.*, 1961). Inserted in narrow urban lots and conditioned by the morphology, those buildings were dependent of their commercial function, which required a direct connection to the street. The merchant or craftsman occupied the entire building living above the shop or workshop. The research and surveys undertaken in the 1950's by Oliveira and Galhano, lead them to affirm that until the sixteenth century the majority of the Oporto houses were slim, bourgeois or merchant, hybrid and functional (1992). They concluded that the houses were used from bottom to top, leading them to coin the term 'vertical life'. The merchant premises were located at the street level, while the middle floors were used for the living and bedrooms. The kitchen and the dining room were located on the last floor to avoid fire hazards and smells from cooking, leaving the attic for the servants' accommodation and store room. Placed in the centre of the building, the stair articulates the multiple floors and provides light from the skylight above for the inner rooms (figure 15 and figure 16). Based on this description, it is possible to stress that the void space of the stairs worked as a 'light and air-flow well'.

This functional distribution is confirmed in the Rebelo da Costa's description (1788) and in the research undertaken by Afonso (2000). This last reveals that even in the fourteenth century, when houses had mainly two or three floors, the use of the street floor for trade, the first for rooms and the last for kitchen, was current practice in the city.

As shown in figure 15, the building's entrance could be made directly through a corridor into the central stairs or by a direct flight of stairs to the first floor, from where the traditional one evolves. Those two access possibilities were very common in the past and are still persisting in the current unaltered buildings (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992). The Oporto's traditional buildings settled on this spatial organization through the centuries, reaching nowadays with minor adaptations and technical updates (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992).

Figure 15 – CRUARB Survey - Parcels 189 and 190 ground and first floors plans.[48]

48 - Survey for the parcels 188 and 189 archived *in CRUARB/Guia 11/2007, Armário F, nº30, parcelas 188 e 189, folha 3*.

Figure 16 – CRUARB Archive – Parcel 189 section[49]

In the first quarter of the nineteenth century the bourgeois way of life suffered a profound transformation caused by the dissociation of the unit house/shop (Fernandes, 1999; Oliveira and Galhano, 1992). The historic quarters located inside the former medieval wall progressively lost their commercial attractiveness, first to the illuminist remodelled areas and after, to the nineteenth century expansions, where a new centrality was progressively shaped (Fernandes, 1999; Fernandes, 1997; Ferrão, 1985). The vertical house turns gradually into horizontal, with several low income industrial labourer families occupying the same building (Oliveira and Galhano, 1992). As an additional consequence this area becomes socially depreciated and extensively inhabited by lower income classes turning it into a social ghetto (Martins *et al.*, 2008). The horizontal occupation of buildings is today the most usual, with one or two households occupying an entire floor divided by the central stair. When a single family occupies one floor, the front and back divisions of the dwelling are divided by the central stair, which remains as a communal space.

49 - Refurbishment project for parcel 189 archived *in CRUARB/Guia 11/2007, Armário C, nº1, parcela 189, folha 15*.

However, as analysed and typified by Fernandes (1999) and confirmed by several researchers (Ferrão, 1985; Oliveira and Galhano, 1992; Pires, 2000), the spatial matrix organization around the central stair persisted even in the new bourgeois houses of the nineteenth century, proving how embodied it was in Oporto social life. Additionally, Fernandes affirms that the specialization and increased complexity of the new houses' inner space, reduces their capacity of adaptation when compared with the former typologies. Those new houses are pointed out by some authors to be influenced by the Georgian houses in the United Kingdom (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992). This reveals the increasing British influence in the Oporto following the signature of the Methuen Treaty in 1703, which allowed the exponential increase in the Port Wine export to England and the establishment in the city of a large number of British traders (Cruz, 1984; Delaforce, 1988; Gonçalves, 2002). The influence is made also through the direct introduction in the city of the Neo-Palladianist architecture by the British architect John Carr (*Santo António* Hospital, 1779-1824) and by Consul John Whitehead (Oporto British Factory, 1785-1790) (Alves, 1988). This also confirms that Oporto's traditional buildings represent a common and wide spread urban traditional house typology, allowing a generalization wider than the case studies.

6.3.2 – Built Form

Based on the Rebelo da Costa's eighteenth century description, Robert Smith's (1961) pioneering study summarizes the main characteristics of the traditional house of Oporto: slim shape, strong granite impression, ceramic decorated eaves, balcony's granite corbels and British style influences. The author stresses that this the built form was reproduced in Recife and other Brazilian cities, an opinion that is shared by other researchers (Oliveira and Galhano, 1992). As previously mentioned, this description corresponds to the general impression produce by Oporto's traditional buildings, which corresponds also to the global image of the historic World Heritage City.

Buildings: Number of Floors and Height

The buildings are predominantly of parallelepiped form, facing the street and sharing side walls in a row. The slim shape is produced over the centuries by the vertical extensions made to accommodate the historic core densification. Presumably, the initial houses had predominantly two or three floors (Afonso, 2000; Ferrão, 1985; Oliveira and Galhano, 1992), corresponding to heights that were economically affordable and technically easier to build. The data of 2001's Census showed that in the *São Nicolau Freguesia* the predominant number of floors were three to four (50%) or more than five (44%), which was confirmed in the research area survey, revealing that the majority of the buildings had four or five floors (figure 17).

Figure 17 - Research area buildings floors

Buildings: Geometry and Urban Insertion

The statistical analyses of the data collected in the fieldwork showed that the buildings surveyed had a median total height of 15.90m and a mean floor height of 3.62m. The respective mean values are close to these ones, respectively 17.07m and 3.70m (Table 22).

Statistics		Elevation (m)	Area (m^2)	Volume (m^3)	Front width (m)	Length (m)	Floor Height (m)
Mean		16.07	141.07	2,200.04	7.66	15.72	3.70
Median		15.90	93.15	1,432.96	6.27	15.37	3.62
Std. Deviation		4,40	241.08	4,713.43	6.43	6.16	0.751
Minimum		4.71	26.88	221.84	2.33	4.38	2.36
Maximum		32.04	3,391.70	76,347.24	62.41	58.70	9.24
Percentile	25	12.58	64.84	866.00	4.90	11.64	3.24
	50	15.90	93.15	1,432.96	6.27	15.37	3.62
	75	19.04	141.22	2,419.71	7.83	19.21	4.01

Table 22 – Research area buildings' geometric parameters

Due to the strong historical relation with the street, Oporto's traditional buildings of the fieldwork area have mostly one or two street facades (92%) and are all inserted in rows facing the street, as can be seen in figure 18. Regarding the relation with the street, it is possible to point four different situations: building in rows with one facade (55%), building in rows with two facades for opposite streets (26%), building in rows/corners with two facades (11%) and building in rows/corners with three facades (8%). Moreover, it is possible to group the buildings into two basic categories: mid-terrace (81%) and end-terrace (19%). This data supports statistically the evidence of the traditional block pattern settlement.

Figure 18 – Research area buildings' facades facing the street

Figure 19 - Research area buildings' fronts (facades facing the street or backyard)

Regarding the number of exterior surfaces of the envelope, it is possible to further analyse the data adding the facades which are in contact with the block interior (figure 19). The most relevant is the fact that, from the buildings which have one street facade, 70% have also another facade to the backyard. From these analysis is possible to confirm the existence of a representative number of buildings with one facade facing the street and another to the lot interior (38%), followed by buildings with two facades for different streets (24%) and buildings with just one facing the street (16%). These correspond to the terraced buildings located in a row along the street and which are the most common in the research area (78%). The remaining are corner buildings with three or two street facades (8% and 10% respectively) or exceptional buildings (4%). Stand-alone buildings are less than 1% of the total, with very low representation in the area.

Solar Orientation

Analysing the solar orientation of the buildings' main façade, it is possible to conclude that the quadrants between the southeast and the northwest are the most represented, as shown in figure 20. From those was registered a prevalence for south, northwest and southwest orientations, grouping 64% of all buildings. This is related to the urban morphology previously analysed, as most of the buildings are located in streets parallel to the river, which runs along the south of the settlement. Even if this data could lead to the conclusion that most buildings are privileged by the sun exposure, the concrete knowledge shows that this is not the reality, because the narrow streets produce shadow in most buildings even if they are favoured by the orientation. Because this factor is so variable only the casuistic analysis of each building would allow specific conclusions to be made.

Figure 20 – Research area buildings' main facade solar orientation

Roof Types

Veiga de Oliveira and Fernando Galhano analysed the traditional roofs of the city, concluding that the hipped roofs were until the nineteenth century dominant in the city (1992), which is also supported by the eighteenth century iconography. The pitched roofs with side gable walls appeared only after that period. The survey undertaken also confirms it, as 91.8% of the buildings have traditional roofs; and from those 59.5% are hip roofs and 18.4% are hip roofs with three slopes.

Figure 21 – Research area buildings' roof types

As pointed out and typified also by the previous authors those traditional tile roofs are further characterized by the existence of dormer windows, terraces, canopies and volume extensions, revealing that the roof space is used for living. The Oporto traditional roofs are also noticeable by the skylights' sculptural conic form, which was also approached in Veiga's and Galhano's surveys and other research about Oporto Traditional Buildings (figure 22). Those elements arise above the roof, facilitating the light entrance and revealing their central stair typology.

The data from the research survey confirms that those skylights are still relevant in the area, being present in 59.5% of the total buildings. From those 24.4% are traditional skylights and 35.1% are contemporary adaptations for the same purpose. The last ones were classified as non-traditional skylights. The spatial distribution of the buildings with a skylight is uniform in the research area, revealing that those typologies cover several centuries of urban interventions and built forms, as shown in figure 23.

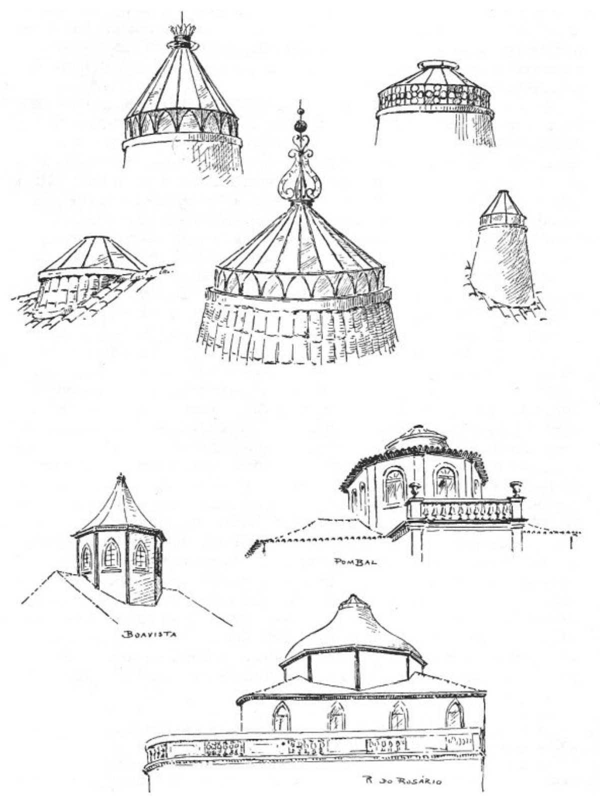

Figure 22 – Oporto traditional skylights *in* Oliveira and Galhano (1992, p.356)

Figure 23 – Oporto research area buildings’ roofs and skylights

Main Facade Design

Oporto’s traditional buildings have always been modest in their facade design with lack of exuberant decoration like in other cities’ urban traditional buildings. The original two or three floor buildings had straight or corbelled facades without balconies, according to the usual medieval typologies (Afonso, 2000; Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992).

The corbelled system represents the intention of gaining area over the public space, which evolved to the introduction of columns at street level to support the upper floors (Afonso, 2000; Fernandes, 1999; Ferrão, 1985). With time, this solution becomes solidified in archway galleries favouring the commercial life at street level, like in the very specific case of *Miragaia* (Fernandes, 1999). Those architectonic solutions still exist in a reduced number in localized areas of the historic city. From the seventeenth century onwards, the substitution of the wood and similar light system to heavy stone in the exterior walls, made the corbelled facades difficult to build, leading to the predominance of straight facades where balconies are later introduced.

As affirmed by some authors the design of Oporto's traditional buildings is not usually made by architects, but is contaminated by their erudite design present in exceptional urban buildings (Fernandes, 1999; Ferrão, 1985). The variations in design over the centuries are minor and made over the persistent typological matrix established. It consisted in the composition of the openings in the main facade, floor height variations and the design of the granite masonry decorated elements (Fernandes, 1999; Ferrão, 1985). According to the synthesis made by Oliveira and Galhano (1992), the seventeenth century houses had straight and severe designs, which were updated in the next century to show gracious and expressively curved lines, becoming poorly simplified and monotonous in the nineteenth century. Smith goes further, classifying the architectural references and stating that in the eighteenth century the Baroque influences of the Italian architect Nazoni, who worked extensively in Oporto at the time, are visible. From 1760 the Neoclassical reaction is shown through the oval design of the openings revealing the English influence (figure 24). In the nineteenth century the Neoclassical became dominant, through the use of Regency style, which follows directly the Georgian (Smith *et al.*, 1961).

Discussing the complete image of the building, Oliveira and Galhano state that sometimes the last floor has a smaller height than the other ones (1992). This could be related to the fact that a large number of upper floors correspond to extensions, which could be made lower for economic and structural reasons.

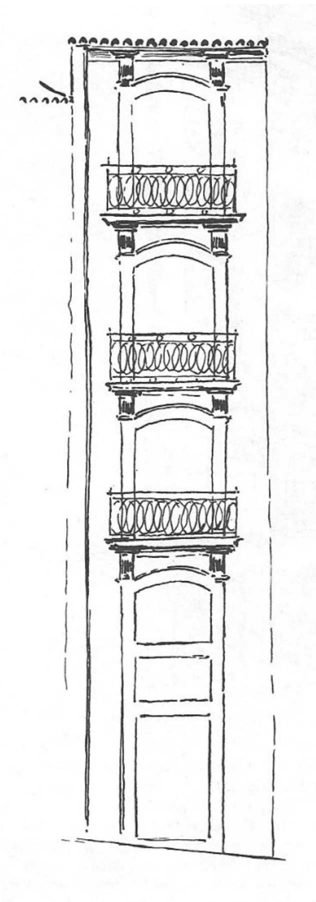

Figure 24 – Opening bays accentuating the verticality of buildings *in* Oliveira and Galhano (1992, p.313)

The number of openings per floor also gives Oporto's traditional buildings another specific characteristic. Those windows or French doors giving access to balconies are aligned in columns (bays) accentuating the buildings' verticality (figure 24) as pointed out by several authors (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992; Smith *et al.*, 1961). According to Ferrão, in the seventeenth century the openings lean to the buildings side, leaving a wall space in the middle, which was filled with minor architectural elements, like small windows (1985). Where possible, the ground floor had three openings, which became common in the remaining floors from the eighteenth century on. In almost all buildings the lot front is coincident with the house facade, determining the number of possible bays per floor. This is the main reason for the prevalence of buildings with two or three opening bays, reaching 78% of the total. Independently of the façade's design, the opening area represents the larger proportion of the facades, occupying most of the time a larger area than the opaque elements.

The openings are surrounded by granite, which constitutes another distinctiveness of Oporto buildings. Analysing the available surveys, it is possible to conclude that this elements width measure usually one span, ranging from 20 to 22cm revealing the common inaccuracy of this type of traditional constructions, as pointed out by Fernandes (1999). The nineteenth century projects found in the Oporto Historic Archive often present a graphic scale both in spans and in meters, allowing for a comparison of the two systems and to measure the window's granite frame; in that case the span equals 22cm, which is the usual equivalence.

Oliveira and Galhano also typified the windows and doors' fanlight frames, which are another distinctive element of this traditional architecture. Several authors point out the British Georgian style influences present on those designs (Fernandes, 1999; Ferrão, 1985; Oliveira and Galhano, 1992; Smith *et al.*, 1961). This has to be understood within the global windows frame design from the eighteenth century on. As stated by Wilhelm Giese, sash windows were brought by the British after the Methuen treaty, who themselves copied it from the Dutch (1963). From that date the wood balustrades were substituted by iron wrought balconies following the same design (Fernandes, 1999; Smith *et al.*, 1961).

The research survey showed that the traditional casement and sash frames are still dominant in 80.4% of the buildings, with a slight prevalence of casement (45.9%) over sash. The windows are normally divided by timber glazing bars into small square or rectangular shaped glass units. From the end of the nineteenth century, those tend to get larger in casement windows, by reducing the number of divisions, reaching at a certain point a single glass for each casement. This evolution is clear in figure 25, showing that the novelty of the eighteenth century sash windows faded during the nineteenth with the progressive substitution for the casement. This is clear when comparing the eighteenth century *São João* Street and the nineteenth century *Mouzinho da Silveira* Street, where sash is dominant in the first and casement in the second.

Figure 25 – Traditional windows evolution (from eighteenth to nineteenth centuries)

6.3.3 – Construction System

From the available surveys, literature and visual analysis of traditional buildings in ruins it was possible to characterize the construction system present in Oporto's traditional buildings, in order to further identify the energy efficiency parameters which are needed for energy simulations to be performed on in this research.

The initial houses were made predominantly of wood, probably with the ground floor built of stone (Afonso, 2000; Ferrão, 1985; Oliveira and Galhano, 1992). Real *et al.* identified in the archaeological excavations made near the Cathedral, the use of the Oporto granite in houses from the second century before Christ (1985-1986). Architect Rogério de Azevedo also states that wood remained the main construction material until the sixteenth century, being replaced by stone during the next two centuries (Smith *et al.*, 1961). From the analysis of fifteenth and sixteenth century documents, Afonso concludes also that wood was an extensively used material and only the exemplary houses at the time were made of stone (2000). The same author also found the documented existence of a quarry close to the city in the fourteenth century, which allowed the progressive use of that material for the building's envelope. Several more recent quarries were identified by Begonha, which served the construction of the eighteenth century's major buildings (1997). Nevertheless, wood has always remained the horizontal and roof support material, as shown in CRUARB's and Porto Vivo SRU surveys and available research (Costa *et al.*, 2012; Teixeira and Póvoas, 2012; Teixeira, 2004). Figure 26 illustrates this support system in two ruined buildings, allowing us to interpret Oporto's traditional house construction system. The system is based on the rectangular shape stone perimeter wall, which supports the inner wood beams. Taking advantage of the urban insertion between two side or shared walls, the beams are put in place during the construction, facilitating the elevation of the building and serving at the same time as a compression element that prevents the collapse of the party walls.

Figure 26 – Wood beams for pavement support in two ruined traditional buildings

Building Envelope: Walls

The facades were originally in the timber framed system filled with small clay brick (figure 27), which can be affiliated in the North European '*fachwerk*' where it was common in the medieval towns (1999; Ferrão, 1985). Even if these timber framing construction systems were imported and commonly used until the nineteenth century, in Oporto they are normally hidden under a uniform surface. The additions made in the nineteenth century used mainly light materials, such as wood, which was disposed to imitate the stone mouldings (figure 28). The light walls were used largely in the nineteenth century, both for external walls and internal partitions, consisting in a simpler timber framing covered with lath and plaster commonly denominated as '*tabique*' (figure 29). Teixeira identified two types of these walls, one with a layer of wooden planking and the other with two layers (2004). It is also possible to find variants of these walls, with studs or without. The timber used in the structure and planking of these are usually made from Portuguese pine wood (Teixeira, 2004).

Figure 27 – CRUARB's refurbishment work showing the timber framing construction system (Magalhães, 2010)

Figure 28 – Timber framing extension with wood imitating stone in a ruined building

Figure 29 – Exterior timber stud wall framing with lath and plaster in a ruined building

The walls were finished with plaster made of clay, grit and tallow, gaining a uniform painted surface (Fernandes, 1999). The most common mortar used was made of lime, aggregate and sand (Teixeira, 2004). The plaster was the dominant material covering the facades, which was complemented with tiles from the nineteenth century on (Oliveira and Galhano, 1992), allowing in both cases to establish a contrast with the granite stone masonry, giving Oporto's traditional buildings their characteristic image (Oliveira and Galhano, 1992; Smith *et al.*, 1961). The plaster and the tile coverings protected the granite walls (thermal and hygrometric), while performing an aesthetic uniform covering of the irregular stone. The interior surface of these walls was mostly covered with plaster, with the exception of the kitchen and bathroom spaces where ceramic tiles were also used. The thickness of the covering materials on both sides of the envelope walls is usually 3 to 4cm, above which the exterior granite stonework raises *circa* 2cm (figure 30).

Apart the plaster covering the gable facades (usually party walls), is also possible to find slate tiles or corrugated iron cladding, both nailed into a wood framing structure. Less frequently, the roof tiles are also used to cover the gable wall. The granite walls range frequently their thickness from 1.5 to 3 spans (*circa* 0.3 to 0.6m), while the finishing layers have usually between 1.5 to 3cm each (Teixeira, 2004)[50].

Figure 30 – Glazed ceramic tiles covering an exterior wall in a ruined building

Figure 31 - Slate tiles covering the exterior wall in a ruined building

50 - The literature information was complemented with direct measurements in some ruined houses.

Roof

As stated by Teixeira (2004), until the nineteenth century the roofs were supported by simple wood structures above which the clay roof tiles were disposed (figure 32), getting more complex in their geometry from then on. The system is supported mainly by a roof truss spaced at around three meters apart and made by round wood beams with a diameter of 20 to 30cm (Teixeira and Póvoas, 2010; Teixeira and Póvoas, 2012; Teixeira, 2004). Teixeira's research reveals also that in the nineteenth century the round beams gave way to more industrialized rectangular sections of 8 to 12cm width by 20 to 25cm height. The wood source remains constant over time: chestnut, oak and Riga pine wood, which are stronger and more durable than the pine used for walls.

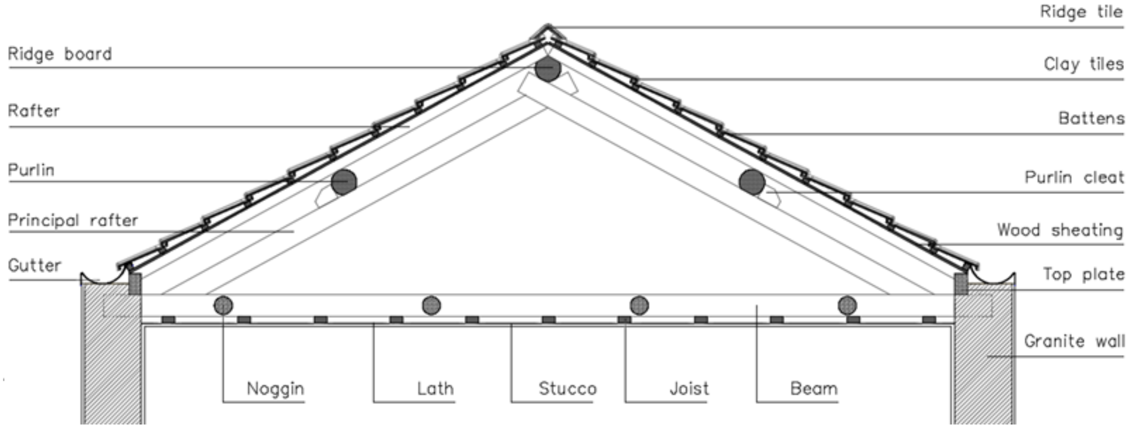

Figure 32 – Simplified roof construction system based *in* Teixeira (2004, p.97)

The roofs present slopes ranging most commonly from 27 to 22 degrees, depending on the type of roof tiles used: Portuguese traditional or Marseille, which was introduced and generalized more recently (Costa, 1955; Lopes, 2007; Segurado, n.d.).

Horizontal Structure

The horizontal structure which supports the system floor/ceiling uses a system which is similar to that used on the roof structure. The wood beam also has the same dimension and geometrical characteristics of the used in the roof structure (Teixeira and Póvoas, 2012; Teixeira, 2004). The maximum possible width for the wood beams is around 7m, determining also the maximum house width.

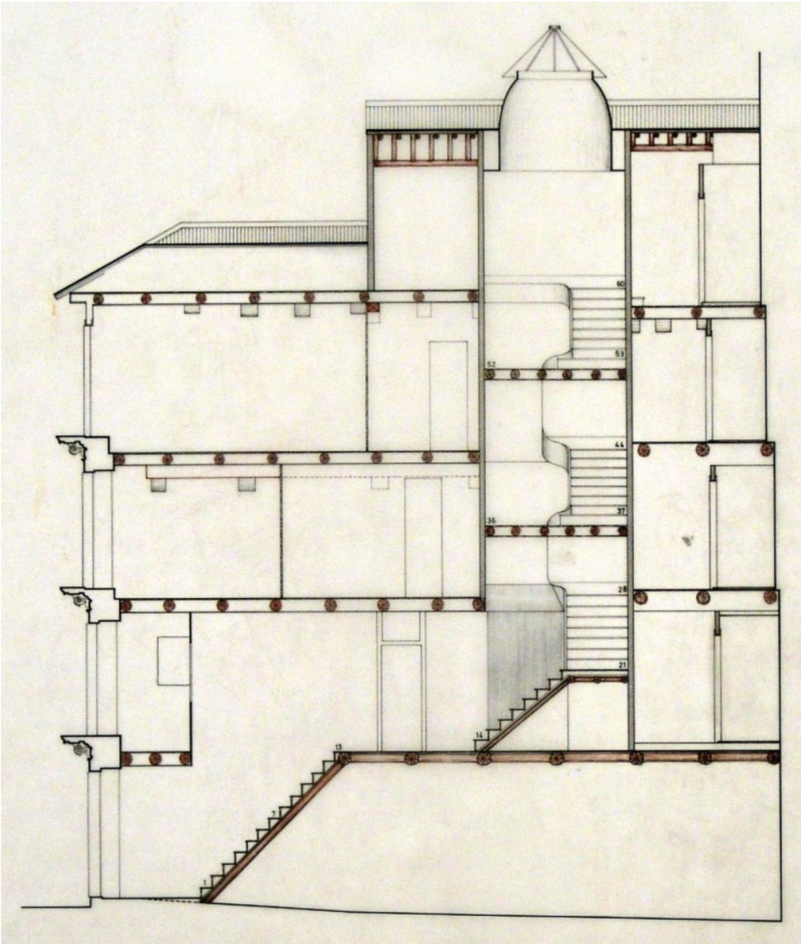

Figure 33 - CRUARB archive – Parcel 159 section.[51]

The chestnut, oak and Riga pine wood are also the materials used for these structures. Beams are laid transversally, spaced 50 to 70cm, connecting the party walls on which they insert two thirds of their thickness (Teixeira, 2004). Wood joists were inserted between the beams and spaced out 1.5m to give stability to the structure. Consequently, this horizontal system is independent of the front and back facades. The stair assembles with this system and uses the same type of materials. Both the floors and the ceilings are supported by this structure, turning into the upper and under finishes of it. Partition walls are also posed directly in the beams, connecting the floor and the ceiling through the top and sole plates.

Ceiling and Floor

Solid hardwood is the usual material of floors, which is nailed directly into the beams and noggins. The planks are used in a multiplicity of lengths (reaching 10 meters) and are mainly

[51] - Survey for parcel 159 archived *in CRUARB/Guia 11/2007, Armário F, nº30, parcela 159, folha 4*.

made of Portuguese pine wood with a usual thickness of 3cm and widths ranging from 12 to 30cm (Teixeira, 2004).

The ceiling is generally made of stucco, which can be just simple or present an artistic moulding. This finish is supported by the pinewood slats nailed directly to the beams or to an intermediated timber frame. This system is similar to those used in the partition walls, with slats gaining a trapezium shape in order to retain the stucco, mortar and plaster as shown in figure 34 (Segurado, n.d.).

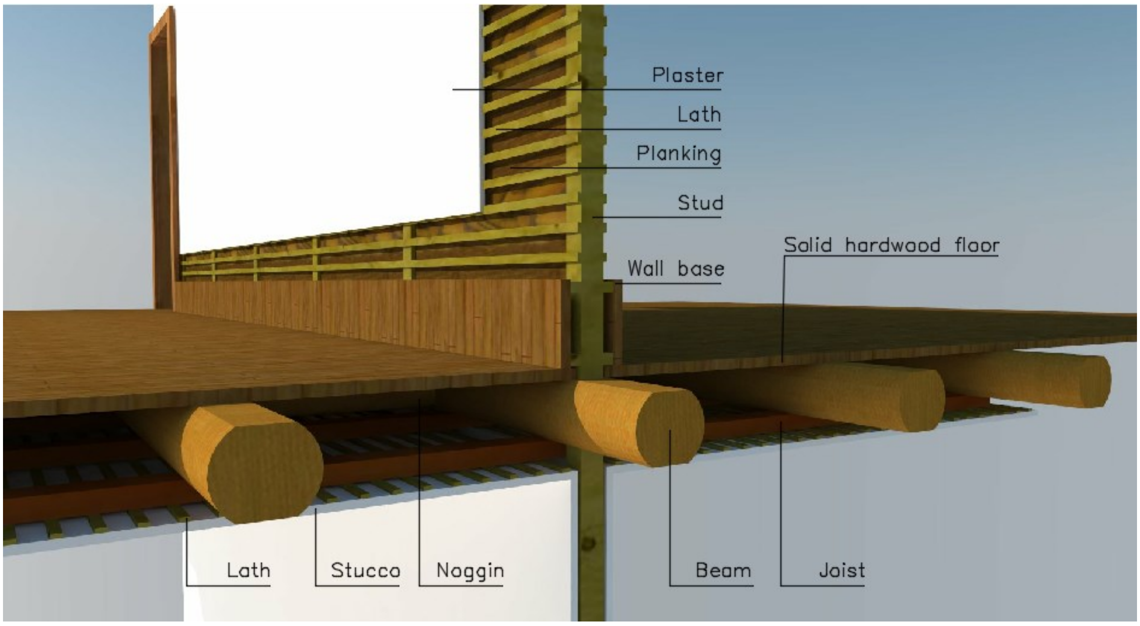

Figure 34 – Schematic 3D drawing of traditional timber stud partition wall, floor and ceiling systems.

Partition Wall

The traditional partition walls are similar to the '*tabique*' exterior light walls mentioned above (Oliveira and Galhano, 1992; Segurado, n.d.). In the ground floor, where weight is not a constraint, sometimes stone partition walls were also used (Fernandes, 1999). The partition types follow those described above according to Teixeira's classification for the light exterior wall (2004). They are generally 13cm thick, and the slats present the same shape as the described for the ceiling as seen in figure 34.

A wooden wall base made by a simple plank, usually 15cm wide, performs the transition with the floor hardwood planks. As referred to by Teixeira, in the richer houses could be applied an elaborated wood panelling reaching 50cm (2004). The single or double inner layers of Portuguese pine wood planking (2cm each) are disposed vertically or diagonally at 45 degrees (Costa, 1955; Segurado, n.d.; Teixeira, 2004) giving resistance to the walls, performing at the same time the role of thermal and noise insulation. The plaster on both sides is made with grit based mortars (Teixeira, 2004).

Windows and Exterior Doors

Most of the windows frames are made of painted pine wood[52] and have a single glazing of 3 to 5mm of thickness. The same wood is used for the inner shutters, which were used originally in all the houses. Both the frames and the shutters have a usual thickness of 3cm. The interior shutters are used simultaneously for security, privacy, light and thermal controls. It is also usual to use light curtains, which allow the entrance of daylight while preserving the privacy of the home. In figure 35 and figure 36 are shown the usual location of the inner shutters in relation to the exterior doors and windows.

Independently of the opening type (*i.e.* sash, casement or door), the insertion of the frames is always similar, placed slightly recessed from the exterior granite surface (2-3cm). The granite frames around the openings are the elements that receive the exterior wood frame, functioning as a jamb for the inner shutter. The form of the stone opening is completely adapted to their function, being prepared to work with the double system of window and shutter. The shutters are normally divided into three or four wood panels, which fold into the side, allowing the casement windows or doors to fully open. Some older models of shutters have small opening panels, which allow a more complex control of light (figure 37). Those are today rare and could probably be reminiscent of the time when no glazed frames were used.

The space remaining between the shutter and the opening frame works as a cavity when all the elements are closed, allowing the extra insulation of the glazed elements, which are the weakest points of the exterior envelope. The figure 38 shows this system in a window, being possible to observe that the inner shutter covers only the frame until the window sill, whose thickness is equivalent to a span creating a recess in the exterior wall where the shutter panels fold. Doors are naturally completely covered by the inner shutter as seen in figure 37.

[52] - In richer and rare cases the doors and windows can be made of oak.

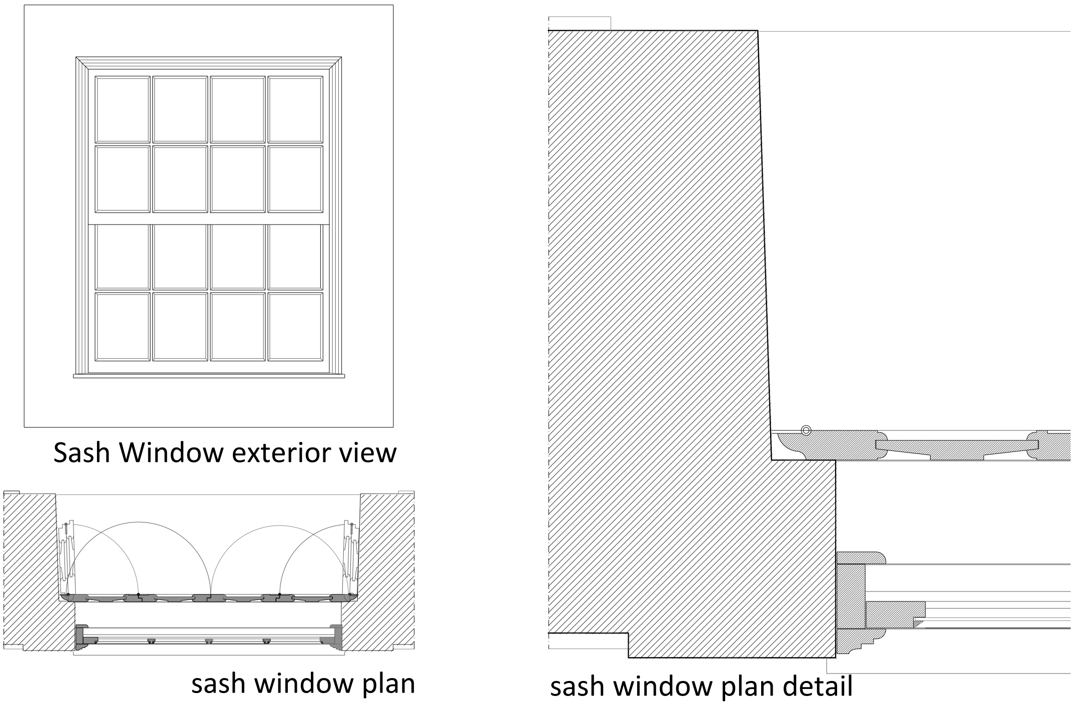

Figure 35 – Exterior view, plan and detail of the traditional sash window with inner shutters.

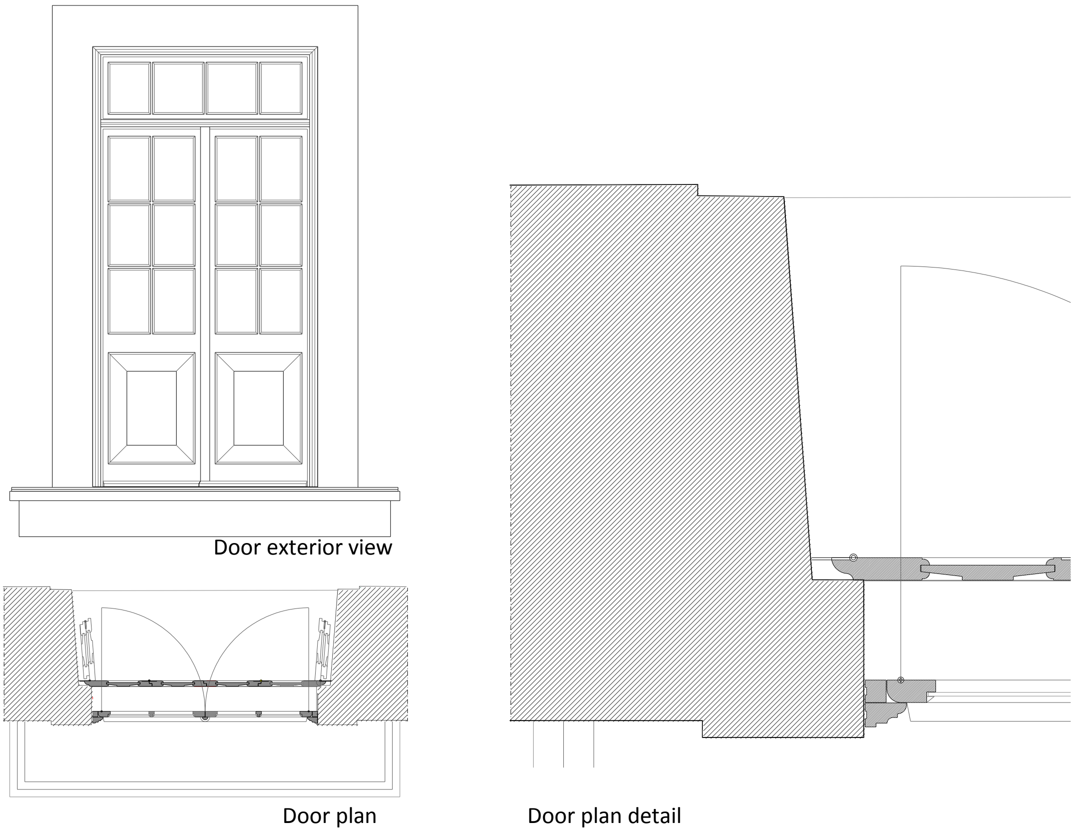

Figure 36 – Exterior view, plan and detail of the traditional balcony door with inner shutters.

Figure 37 – Ancient inner shutters

At the end of the nineteenth century the system was updated in richer houses, where all the inner stone elements were covered by painted wood panelling, which connects with the wood wall base and presents the same painted finish. On both sides of the wall were created recess spaces to where the inner shutters fold, creating an image of a complete panel (figure 39). It is possible that this evolution had the intention of covering the weak points (*i.e.* the thermal bridges) in order to achieve a better degree of comfort.

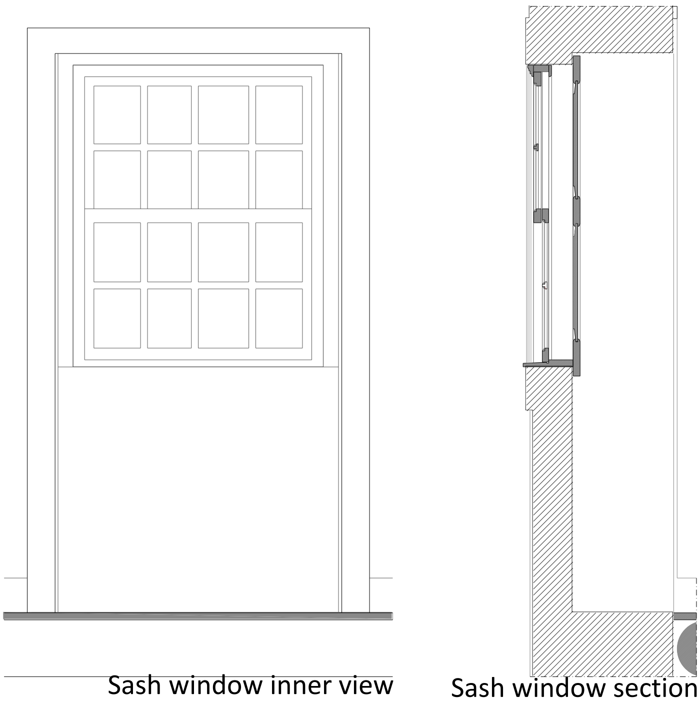

Figure 38 – Inner view and section of traditional sash window with inner shutters.

Figure 39 – Inner shutters/panelling: shutters opened, closed and top and bottom details.

Decorative Elements

Apart the stonework of the main facade, the traditional houses of Oporto are very sober in their decoration, including the interior spaces. Very rarely the richer owners invested in the decoration in detriment of using better materials (*e.g.* oak instead of pine). Some rare cases present wood carving in ceilings and walls, but they are not representative of the common traditional houses. The usual decoration of Oporto's traditional buildings consist in the stucco mouldings applied to the ceilings in several degrees of complexity, according to the owner's social status and fortune.

The stucco found in Oporto made in Adam's or Wedgewood's style with Victorian motifs testifies again to the English influence (Oliveira and Galhano, 1992). According to Vasconcelos, this neoclassical taste was introduced in the eighteenth century by the Consul John Whitehead in the British Factory House (1997). The most common stucco work is composed of a circular or elliptical motif in the centre of the room (figure 40) and a moulding around the entire ceiling, establishing the transition between the wall and the ceiling. These stucco ceilings are today one of the most considered heritage elements to be preserved in Oporto's traditional buildings as pointed out by Vasconcelos (1997).

Figure 40 – Traditional Oporto stucco ceiling

6.4 - Heritage Value

The small variants found in the homogeneity of the Oporto houses are their most valuable heritage as it produces the image of the historic city, contributing to it even in greater proportion than the monuments. The main heritage value of this architecture is its "remarkable testimony to the development over the past thousand years of a European city that looks outward to the west for its cultural and commercial links" (UNESCO, 1996a, p.83). This declaration of 'outstanding universal value' led UNESCO to declare the historic core of Oporto as World Heritage under the category of 'group of buildings'. So, the conservation of each building contributes also to the conservation of the urban ensemble.

Any transformation process undertaken on these buildings must preserve their authenticity and their urban image. The consequences of the opposite approach can be seen in figure 41, where the imitation of the traditional design can induce a slight resemblance with the originals, but it is always a bad design and a lie. So, authenticity can also be translated into the design which respects, interprets and acts with truth. As underlined before, if this apparently small aspect occurs systematically in the refurbishment of traditional buildings, it has also to be accounted for the consequences it produces to the image of the historic city.

Figure 41 – Original and new frames imitating traditional design.

Conclusively, it is possible to affirm that the Oporto World Heritage Site significance and OUV is related to the group of buildings which constitute it. Those are clearly a mix of historic and traditional buildings with a higher prevalence of the last ones, both by their larger number as by expressing the historic roots of a mercantile city. Then, the major value identified is the architectural value of Oporto's traditional buildings. This means that each building possesses the individual design characteristics that shape its architectural value, which contribute at the same time to the value of the group.

In each traditional building the main architectural characteristics which convey their value were discussed above and can be summarized by:

- Overall image of the building, namely the narrow and long rectangular shape;
- The granite elements of the facade and their relation with the historic renderings or tiles;
- The rhythm of the elevations;
- The historic materials covering the facades, namely rendering, ceramic tiles and slate;
- The traditional design of windows and balcony door frames;
- The shape and material of the roof, which forms the roofscapes of the historic city;
- The traditional design of the skylights;
- The artistic ironmongery work of the balconies;
- The stucco ceilings.
- The spatial matrix of the house organized around the central stair, which provides ventilation and natural lighting.

Then, based on the previous chapters and on the above summarized, the approach to introduce energy efficiency measures in the refurbishment of traditional buildings in Oporto should identify: the previous elements, which must be not be changed, the existing traditional techniques and construction systems, which present potential and must be enhanced (passive solutions) and the new compatible techniques that should be introduced to improve the buildings' performance (passive or active). The major challenge will be to identify the admissible change in each of those elements and the impacts that change can produce both in the building and in the overall World Heritage Site.

6.4.1 – Admissible Change

As seen in chapter four, the intervention in the buildings envelope as a whole to avoid heat losses is the most used technique to improve energy efficiency in buildings. Additionally, it is proposed specifically for Oporto's traditional buildings in the energy refurbishment guide (AdEPorto *et al.*, 2010). At the home scale, the internal walls, ceilings and floors which make the separation to the other housing units, have also to be addressed and assessed in terms of heritage elements that cannot be damaged.

The exterior walls, glazed elements and roofs were identified as the components of the envelope which have major potential for improvement and must then be assessed. Those are exactly the elements which convey the appearance to Oporto traditional buildings and should not be changed until certain limit. This means that solutions to be implemented have to be assessed against the consequences they pose in these elements and rated accordingly with the impact assessment grading.

Addressing the thermal performance of each element, the potential improvement solutions must be identified, covering both the technical aspect and the maintenance of the building component appearance. This is obviously variable for each element and must be addressed individually. It is expectable that the major improvements will be directed to envelope, as no insulation or double glazed elements are present in the traditional buildings.

Solid elements (walls) have to be considered accordingly with the wall finish layer and the relation between this surface and the stonework surface. As seen before, most of the buildings have plaster or glazed ceramic tiles in its facade. The last ones are widely recognized as presenting heritage value (Monteiro, 2001; Vasconcelos, 1996), which leads to the impossibility of removing or displacing them. So, any possible insulation has to be placed on the inner wall surface. The plaster cladding offers wider possibilities, as theoretically it can be replaced by an insulation system which presents the same type of finish. However, this poses two questions in their application. The first relates to the fact that old granite walls and their traditional mortar and plaster finishes form a system which is permeable, allowing it to 'breathe' (Appleton, 2003; Hughes, 1986; Mascarenhas, 2012; Mateus, 2002). So, in this situation as in any other intervention in traditional buildings, the introduction of a new system has to be carefully measured in its technical consequences and compatibility with the old system present. The second question concerns the image and aesthetical aspect of the building. As mentioned above, the relation between the stonework and the wall surfaces is crucial to safeguard the authenticity of the building. So, the stonework surface must always remain above the wall finish, allowing the shape of the stone to be fully seen. The introduction of insulation is only viable when this premise is possible to accomplish. Due to the irregularity of the existing stone this can only be considered when addressing each case.

Roofs and skylights must be addressed in their double interaction with the building and the roofscape levels. The introduction of solar panels or double glazing must account with the impact in these two scales.

The glazed openings also characterize Oporto's traditional buildings, being one of the major problems to be addressed in terms of heat transfer, as they are predominantly single glazed and represent an area of *circa* 50% of the facade. It is important to conserve the traditional wood frame design because it represents a craftwork which gives value to the facade, both at building and group levels. The adaptation of casement windows to double glazing may be possible without disrupting their design. Sash windows are more complicated to adapt, because the increase on their thickness prevents them to function. Concurrently, they tend to become heavier, which makes them even more difficult to use than before. As suggested by the Adeporto guide, a double frame placed on the inside could be a solution to this problem (2010). These solutions must be complemented with the traditional inner shutters, giving additional thermal protection.

Internal walls, ceilings and floors pose a diverse situation from the envelope, as they do not shape the image of the historic city and the inner decoration is usually rare, with the exception of stucco ceilings which must be preserved or restored. However, the authenticity of these buildings is also made by the traditional construction system which should be preserved when feasible, not only for heritage purposes but also for the economy of resources. The inner transformation of the construction systems should respect the principle of compatibility mentioned above, especially when regarding the introduction of new structural systems which can cause damage to the structural walls. The introduction of dry-line insulation could be viable, but it will depend on the concrete situation (*e.g.* the inner space available or the stucco on the ceilings).

6.5 – Conclusion

Oporto traditional buildings are major contributors to shape the image and identity of the World Heritage Site. Therefore, it is essential to conserve their authenticity to avoid damaging the OUV of Oporto Historic City. This chapter covered the overall characteristics of these buildings, allowing to conclude that the envelope encloses a potential for energy efficiency improvement. In parallel, the envelope upgrade poses the highest constrains to Oporto traditional buildings heritage value. It is further necessary to understand in detail how these buildings perform in terms of energy to identify specific measures to address their improvement. The next chapter focus on this objective by investigating ten case studies representing the variants identified.

Chapter Seven: Case Studies First Stage Findings

Chapter Seven: Case Studies First Stage Findings

7.1 - Introduction

This chapter focuses specifically on traditional buildings in Oporto. To obtain detailed information about real cases, ten homes were selected to serve as case studies for modelling and simulating energy efficiency improvements. These cases were representative of the diverse typological variants found in Oporto's historic centre. An explanation of the identification process is also given in the current chapter. This explanation covers the discussion of the research area, variants identification and the survey process.

Furthermore, the chapter aims to describe the surveyed case studies, focusing on their architectural heritage and energy efficiency performance, the - fundamental aspects of this research. The data collection for the ten case studies was done through observation, measurements and household questionnaires. Afterwards, the data was analysed and overall conclusions were drawn. Due to the extensiveness of the collected data, a selection was placed in the appendices, including detailed information about each case study. This data covers drawing surveys, construction systems and data obtained from the questionnaires.

7.1.1 - Oporto Building Stock

The urban fabric built before 1919 represents 17.65% of the total buildings in Oporto (figure 42). This number rises to 54.99% in the historic urban core[53] (INE, 2012). Additionally, the negative demographic development of the population in Oporto's historic centre, circa 30% during the last decade, and the large number of unoccupied dwellings (40.66%) suggest a significant decline of the area (INE, 2012). The dwellings in the historic centre of Oporto are mostly rented (82.49%), which places their conservation under the complex Portuguese legal framework for renting. The low investment in refurbishment or retrofit made by the owners, in conjunction with the usual low income of the tenants, leads to the physical decay of buildings. Refurbishment solutions for the occupied buildings must deal with these constraints, as they affect the feasibility of their implementation. Nevertheless, Oporto's urban core still maintains an over-occupation, with high densities ranging from 6,000 to 9,000 inhabitants per square kilometre (INE, 2012). At the same time, the historic city also accentuates the current ageing

53 - Comprising the three *Freguesias* of *Sé*, *S. Nicolau* and *Vitória*.

trends for the Portuguese population, with the elderly[54] accounting for 26.9% of the total residents (INE, 2012). This framework leads to the conclusion that Oporto's historic city presents displays a physical and social decay, which the regeneration policies to improve the energy efficiency of traditional buildings must address.

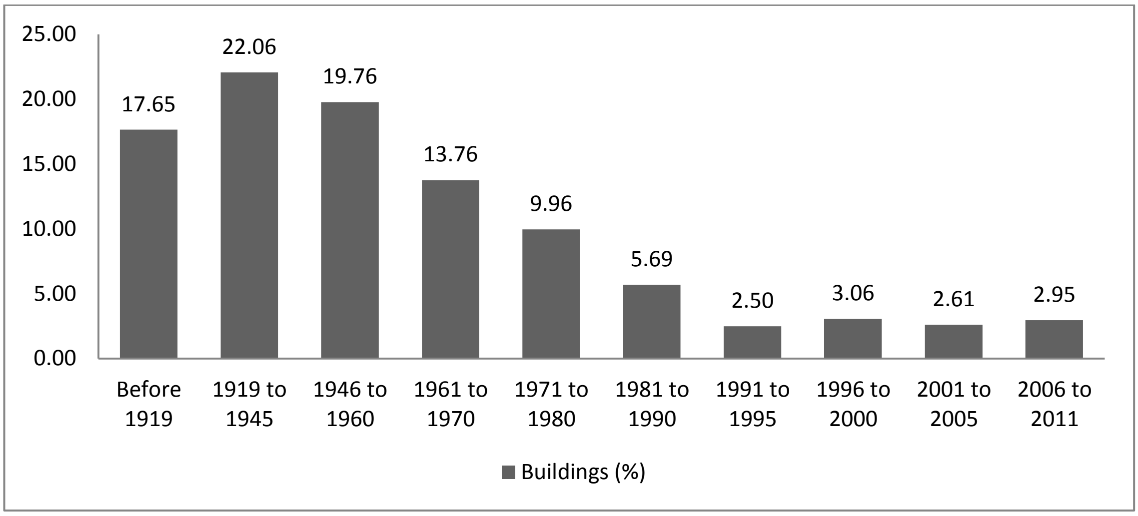

Figure 42 – Census 2011: Oporto buildings age (INE, 2012)

7.1.2 – Research Area Selection

A research area was delimitated in order to determine the typologies of traditional buildings in Oporto's historical centre. The area selection was based on the following criteria: it had to be part of the World Heritage Site and have a majority of traditional buildings with a high level of apparent integrity. Additionally, the area was also part of the intervention zones of the Porto Vivo SRU and the former CRUARB (*Ribeira-Barredo* Urban Renewal Committee), whose operations produced a significant amount of surveys, refurbishment projects and construction works (Fernandes, 1999). Figure 43 show a geographic overview of the large number of overlapping urban renewal schemes and conservation areas implemented during the past 40 years.

The selected research area corresponds to the SRU's *Infante* Priority Intervention Area (AIP) and is located inside the former medieval wall. It represents one of the oldest urban areas, while at the same time exhibiting the diversity of the urban renovations that took place in the historic city during the eighteenth and the nineteenth century. The CRUARB's intervention

54 - Defined as citizens of more than 65 years of age.

zone is also partially overlapped by this AIP, which allows taking advantage of the mix between refurbished and original traditional buildings. The research area is fully included within the World Heritage Site perimeter and in other specific conservation areas, set up to protect the historic centre.

Figure 43 – Research Area (AIP *Infante*)

7.1.3 – Research Area Survey

A direct survey was undertaken in the research area with the objective of identifying the typologies of the traditional buildings and their characteristics. Methodologically, the selection process used a bottom-up approach, initially covering all buildings. These were then further analysed and their common characteristics identified, which allowed grouping them under diverse typologies. The data collection was undertaken directly in the field covered each one of the 316 buildings, which were visually surveyed and photographed. The geometric parameters included in the protocol were previously retrieved from the CAD drawing analysis[55]. Prior to the fieldwork, all records were geo-referenced, which allowed putting them in relation to the created GIS database.

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[55] - Apart from acquiring the geometry of all buildings, the detailed analysis of the CAD drawings turned also made it possible to determine the geometry of all the lots. In terms of the elevation data, sections of the streets with the facades of all buildings were also included which further, allowed to have their height in the database. The CAD work also included the cleaning and simplification of the drawings and the creation of polygons for all buildings and lots, allowing their import into the GIS.

7.1.4 – Identification of Typological Variants

All the buildings meeting the established research criteria were initially included in the research. Then, singular remarkable buildings, such as churches, major institutions, hospitals and public administration were excluded. Traditional and mainly residential buildings were naturally predominant in the area, accounting for 89.4% of the total. Applying these criteria, the initial sample was reduced to 191 buildings.

In the compact historic cities, in most of Europe and South American, buildings are mainly terraced houses, enclosed in traditional blocks. In Oporto, this type of compact urban fabric also spreads through the entire historic core, far beyond the research area. The analysis of the selected buildings proves the typological homogeneity of the sample, which is composed almost exclusively of similar terraced houses. Hence, instead of identifying typologies, the survey showed the existence of several variants of one main typology. Taking into account the building's urban insertion and form factors, six variants and two sub-variants were identified. This classification accounted the number of facades facing a street or backyard, which establishes the building's relation with the urban block and the adjacent constructions. It is also directly related the exposed area of the envelope of the building, which influences its thermal performance. The variants were denominated as V1, V2, V3a, V3b, V4 and V5, and are listed in table 23. They can be grouped into three main categories: corners (end terraced), including V1 and V2; row houses facing the street (mid terraced), including V3a, V3b and V4; and detached, comprising V5.

Variant	Street Facades	Rear Facades	Party walls
V1	3	0	1
V2	2	0	2
V3a	2	0	2
V3b	1	1	2
V4	1	0	3
V5	1	3	0

Table 23 – Variants according to exposed facades.

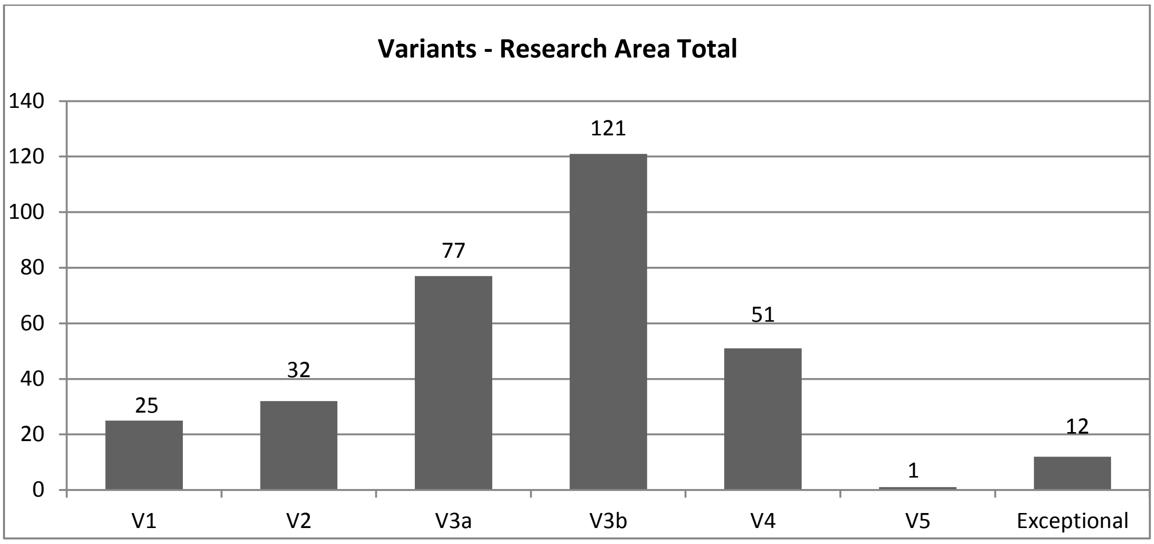

Figure 44 - Variants distribution in the total Research Area (316 buildings)

The analysis of the distribution of the selected buildings according to their variants shows that the mid terraced group (V3a, V3b and V4) is largely predominant, accounting for 91% of the total. This is consistent with the predominant compact urban block identified in the historic city. Variant five was excluded from further research due to its irrelevance in Oporto's historic centre (less than 1%).

The five variants to be modelled as case studies (V1, V2, V3a, V3b and V4) were further subdivided into the middle and top floors sub-variants, posing the hypothesis that these two categories would perform differently in terms of heat transfer due to their different exposure to the external environment.

7.2 – Case Studies

Following the process of determining the variants, it was necessary to identify the real cases that could represent them. The selection process was based on directly approaching the inhabitants in order to explain the research objectives to them and obtain their informed consent. This process is explained in the next sub-sections.

7.2.1 – Case Studies Selection

The assistance of some local institutions (*Centro Social e Paroquial de S. Nicolau*, *Porto Vivo SRU* and *Junta de Freguesia de S. Nicolau*) was crucial in approaching the households as the local community proved to be rather reserved towards outsiders during first approaches. The selection process was made in conjunction with local institutions, based on the defined criteria and on the suggestions made by these institutions.

As seen in figure 45, the cases are widely distributed in the research area, covering diverse urban development epochs. The cases also covered several types of integrity, ranging from buildings with their spatial and architectural structures intact, to buildings that were deeply refurbished by the CRUARB, or more recently by the Urban Rehabilitation Society.

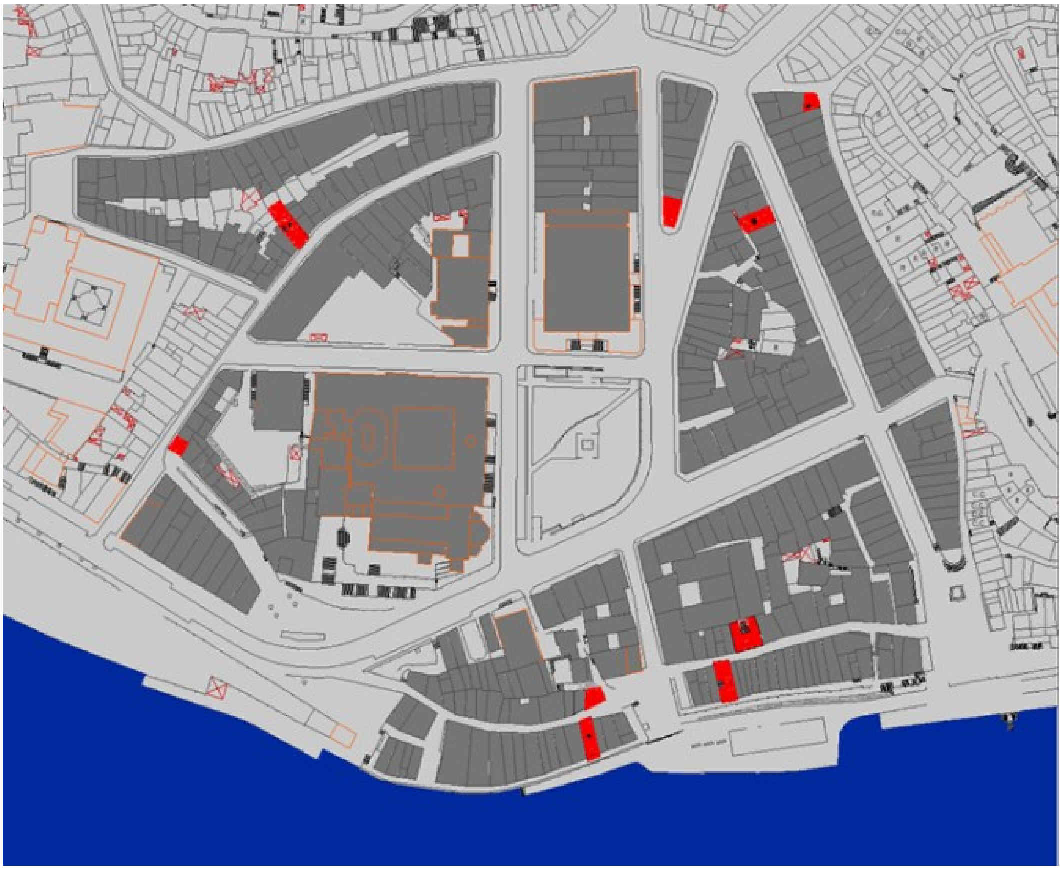

Figure 45 - Case study variants location

7.2.2 – Case Studies Survey

The geometrical and construction data retrieved from the initial fieldwork were entered in the CAD and analysed, both statistically and by literature comparison. To further complement this, a scrutiny was performed in the CRUARB[56] and PortoVivo SRU archives, in order to find available surveys and refurbishment projects. Furthermore, the glazed elements were

[56] - This archive is currently available at *Casa do Infante* – Oporto Historical Archive.

geometrically analysed in the CAD with the objective of obtaining the necessary parameters for the thermal modelling. Through direct observation, drawing analysis and direct household information, it was possible to define the materials and the construction systems present in the case studies[57]. The preparation of the survey and questionnaire was conjugated with the detailed analysis of the modelling software in order to ensure that all the necessary information was collected.

7.2.3 – Household Questionnaire

The objective of the questionnaire was to provide additional data about the human behaviour in the use of the dwelling, which was identified as a fundamental aspect in the energy efficiency framework for traditional buildings. At the same time, this information enables performing more accurate the simulations and avoiding bias.

To participate in the study, the households had to be living in their homes for at least one year, as this allows a correspondence between weather, energy and behaviour patterns in a normal yearly cycle. When these criteria could not be met, it was necessary to select another building of the same variant. The researcher filled in the questionnaire by directly inquiring the inhabitants. The person answering the questionnaire needed to be eighteen years or older in order to represent their family. The information obtained from the participants included the identification of their pattern of use, which influences the energy consumption. This covered the identification of available equipment[58], the general degree of satisfaction in terms of several comfort parameters, and the identification of their sense of identity towards the building and the historic site. Additionally, they signed a consent allowing access to their energy consumption data, covering two complete years (provided by the energy supplier).

The contact with the household was initiated once the ethical approval from the Oxford Brookes Ethics Committee had been obtained. The questionnaire and all documentation were translated into Portuguese and provided to the families participating in the study. All participants signed the informed consent to participate in the study.

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[57] - Drawings and data from the survey are in Appendix B.

[58] - This covers heating, cooling, DHW, cooking, entertainment and lighting. This information was also confirmed by the direct observation of the equipment.

7.3 – Survey Results

The case studies analysis allowed a detailed vision of each[59]. In the next sub-sections the results are analysed and described, in order to achieve an overall perspective that may be applicable for the entirety of Oporto's traditional buildings.

7.3.1 - Buildings and Energy in Oporto

The energy matrix for Oporto (AdEPorto *et al.*, 2008) and the household energy survey (AdEPorto and UCP, 2011) revealed in detail the actual energy consumption profile and consequent CO_2 emissions. Due to the historic background of the city, energy policies have always been promoting cheap electricity, which is also presently the most commonly used energy source in the city (figure 46). The final energy consumption for electricity was of 5.6 MWh/year per inhabitant, compared to the national average of 4.3 MWh (AdEPorto *et al.*, 2008). Consequently, the CO_2 emissions associated with electricity were also the most relevant, accounting for 50% of the total share (figure 47).

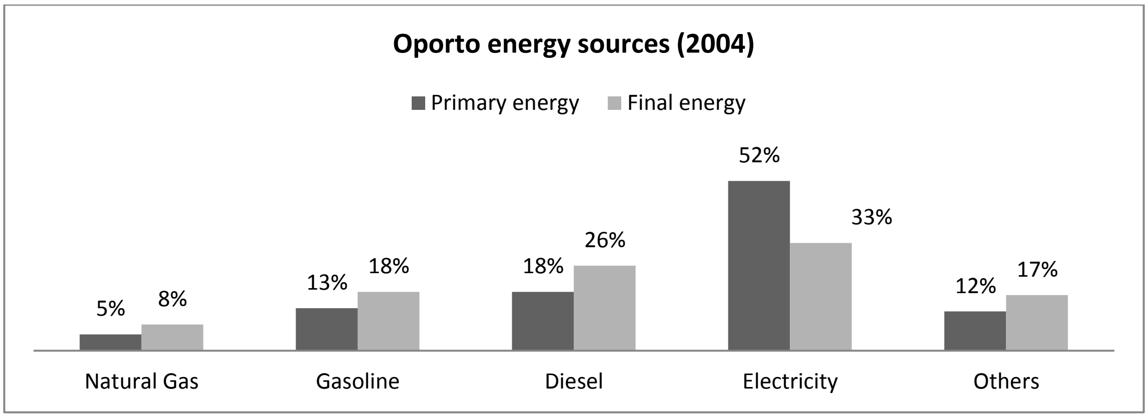

Figure 46 – Energy consumption in Oporto by energy sources based on AdEPorto *et al.*(2008, p.26)

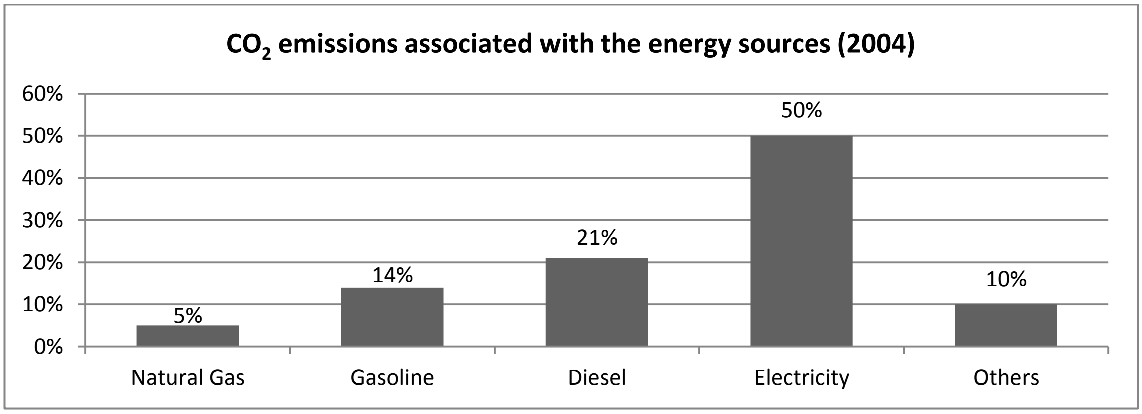

Figure 47 – CO_2 emissions associated with the energy sources in Oporto based on AdEPorto *et al.*(2008, p.26)

[59] - The detailed data was inserted in the Appendix B.

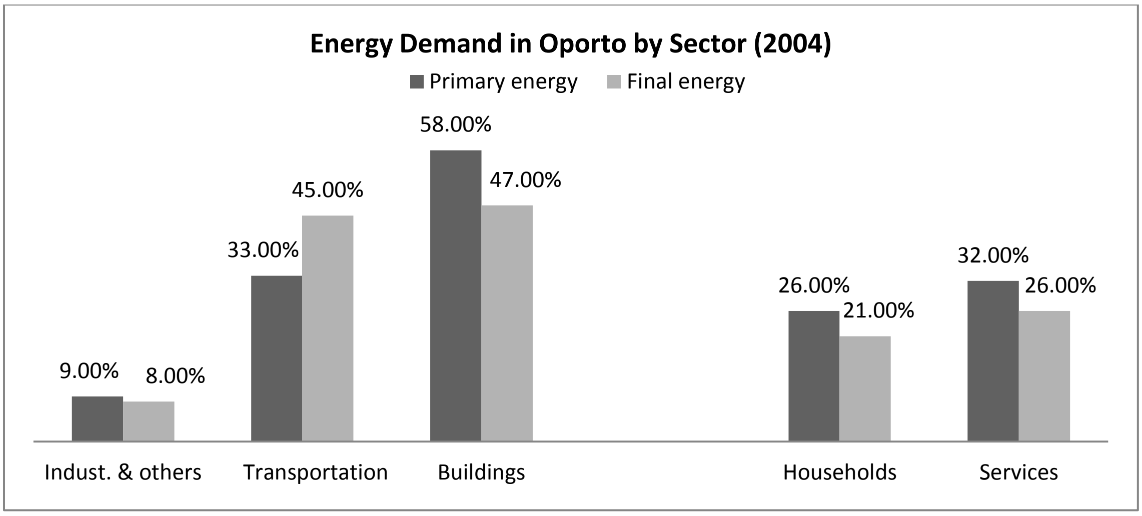

Figure 48 – Energy demand by sector in Oporto (detailing the building sector in households and services sub-sectors) based on AdEPorto *et al.*(2008, p.29)

The demand side of energy consumption for Oporto was mainly associated with buildings, both in primary and final energy (figure 48), with this sector being responsible for 55% of the total CO_2 emissions during 2004 (AdEPorto *et al.*, 2008). A detailed look into this sector reveals that the household and the service sub-sectors were relatively equivalent in terms of energy demand, which was also shown in their share of CO_2 emissions, 23% and 32% respectively. In residential buildings the primary and final energy consumption were also dominated by electricity (figure 49), which corresponded to 86% of this sub-sector's total CO_2 emissions (AdEPorto *et al.*, 2008). When comparing the energy-associated emissions from the domestic sector with the national scores, it is possible to verify that they were considerably higher (1.2 tons against 0.8 tons of CO_2 per inhabitant in a year) (AdEPorto *et al.*, 2008). This framework highlights the fact that the energy consumption in Oporto's residential buildings and its environmental consequences are a problem that must be mitigated. The *Oporto Energy Matrix* divided the domestic energy demand sub-sectors (AdEPorto *et al.*, 2008), showing that heat production (cooking, water heating and space heating) accounted for 71% of the total primary energy consumed (figure 50).

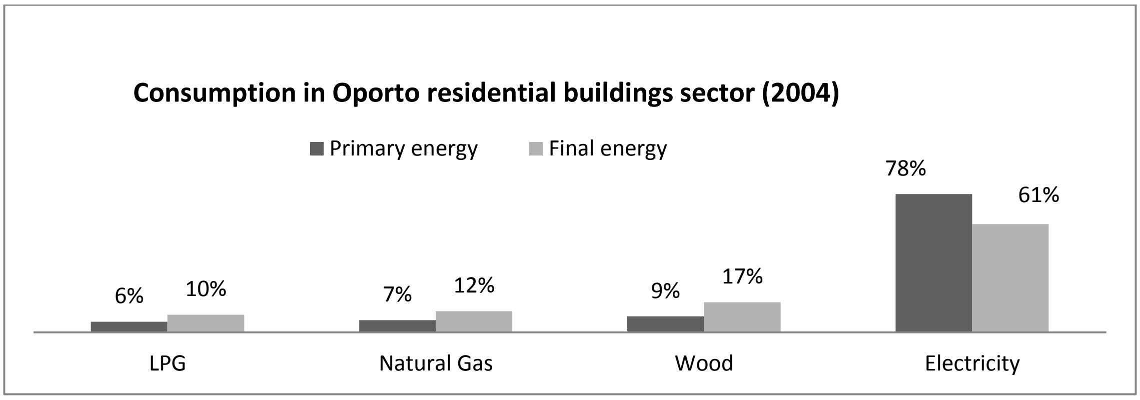

Figure 49 – Residential buildings' primary and final energy consumption for Oporto based on AdEPorto *et al.*(2008, p.32)

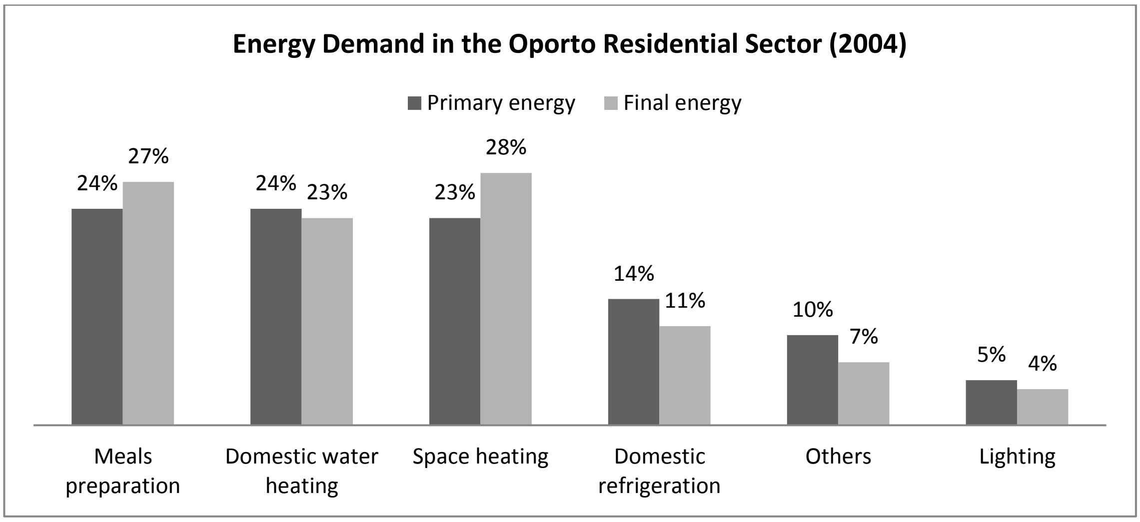

Figure 50 – Energy demand for Oporto's residential sector based on AdEPorto *et al.*(2008, p.35)

A national survey addressing the domestic energy consumption confirmed this scenario, showing that the three heating sub-sectors accounted for 84.1% of the total final energy consumed in Portuguese homes, which is close to the 78% identified in Oporto. This data also revealed that the cost involved with heat represented 78.3% of the total energy expenses in dwellings (INE and DGEG, 2011). Lighting had a small impact in the overall energy consumption, both at national and at Oporto levels. The amount of energy used for space cooling was insignificant at both levels, revealing the settled Portuguese cultural behaviour of disregarding the use of cooling equipment in homes. A recent energy survey for Oporto further detailed the three heat sub-sectors, confirming electricity as the main energy source (AdEPorto and UCP, 2011). For cooking, the use of mixed solutions (gas/electricity or gas cylinders) was identified, which complement the main energy source (figure 51). The space heating data showed that electricity was the most commonly used source for this purpose, with 54% of the household relying on electrical devices. Moreover, a significant number of households (23%) affirmed that they were not heating their homes at all. This could be associated with fuel poverty problems or attributed to the good thermal performance of their houses (figure 52). Diesel and natural gas were used scarcely for space heating, which lead to infer that the central systems were not commonly used and that most households probably use individual electric devices or gas cylinders for heating their homes. The DHW scenario reinforces the previous conclusions, as electric cylinders and gas water heaters were used in 90% of scenarios (figure 53).

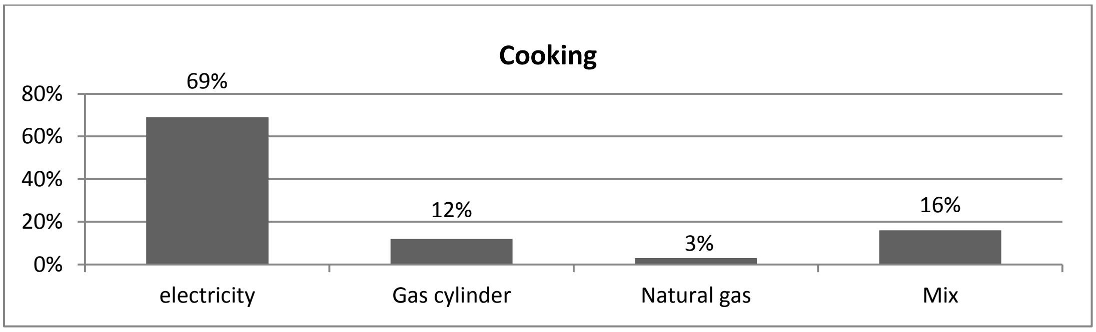

Figure 51 – Energy sources for cooking in Oporto's residential sector based on AdEPorto and UCP (2011, p.1)

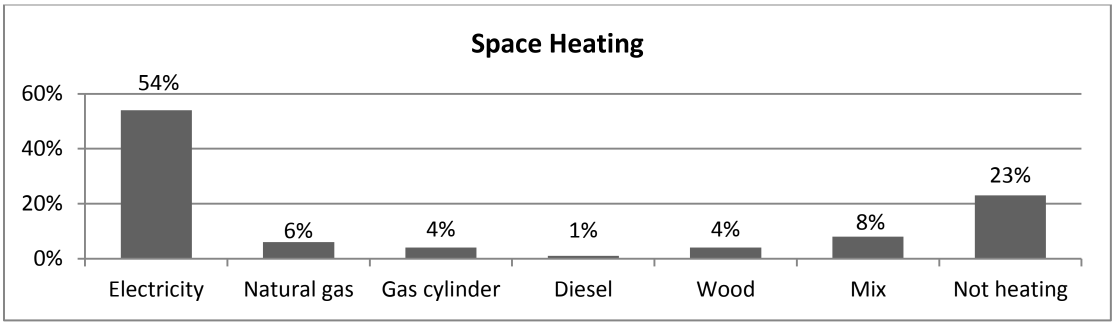

Figure 52 - Energy sources for space heating in Oporto's residential sector based on AdEPorto and UCP (2011, p.1)

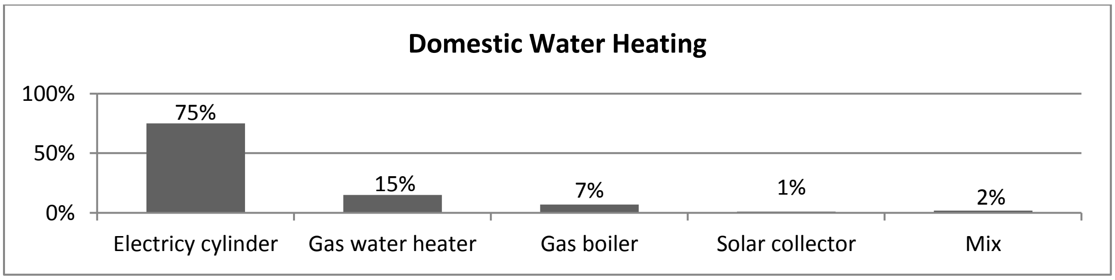

Figure 53 - Energy sources for domestic water heating in Oporto's residential sector based on AdEPorto and UCP (2011, p.1)

7.3.2 – Buildings

The survey of the case study dwellings confirmed the general description made in chapter six about Oporto's traditional buildings and reinforced the previously identified homogeneity. The physical characteristics of the case studies shown in table 24 also confirm the similarity with those identified in the research area's overall survey.

The case study buildings are mainly from the eighteenth and nineteenth centuries, which was identified as the predominant ages of the current constructions, although it is possible that some of them were originally from previous periods (cases 1, 3, 4, 5, 6 and 7). Cases 2, 8 and 9 belong to periods that can be identified more easily, as they resulted from the urban transformations of the eighteenth (case 2) and nineteenth (case 8 and 9) century. Case 10 was an exception, because it revealed complex overlapping construction ages prior to the eighteenth century. This scenario is consistent with the age distribution verified in the research area selection where the eighteenth and nineteenth centuries were dominant, accounting for 83.77% of the total building stock (figure 54).

			From street	Main Facade			
Case	**Variant**	**Main Age**	**Storeys**	**Width**	**Lenght**	**Bays**	**Refurbishment terms**
1	3b Mid	XIX	4	7	20.5	3	Moderate conservation work 2005
2	3b Top	XVIII	7	7	13.2	2	Moderate conservation work in C. 2006
3	3a Top	XVIII	6	5.4	15.6	2	No. (1979 CRUARB's project not executed)
4	4 Top	XIX	5	3 x 4.1	12.25	3 x 2	Substantial conservation work in 1976 by CRUARB's
5	4 Mid	XIX	5	3 x 4.1	12.25	3 x 2	Substantial conservation work in 1976 by CRUARB's
6	3a Mid	XVIII	6	3.4 + 3.7	15.8	2 x 2	Substantial conservation work C. 2000 by CRUARB's
7	2 Mid	XVIII	4	6.43	5.98	2	No
8	1 Top	XIX	5	C. 6.22	C. 11.68	4	Substantial conservation work in C. 2008
9	2 Top	XIX	5	C. 3.84	C. 7.9	2	No
10	1 Mid	Before XVIII	4	C. 9.27	C. 5.52	2	No

Table 24 – Main characteristics of the case study buildings

In terms of recent refurbishment, the cases covered a balanced distribution between buildings with intervention (6) and without (4). However, the refurbished cases encompassed diverse situations, which ranged from very light interior refurbishment (case 1) to deep remodelling where only the external envelope remained of the original building (cases 4, 5 and 6). Cases 2 and 8 were subject to deep conservation measures, maintaining their traditional construction systems, which retrofitted. Most of the buildings presented overall a good state of conservation, with the exception of cases 3, 7, 9 and 10, which were the buildings without recent refurbishment. From this last group, cases 7 and 9 were in a bad conservation condition, revealing the long-time absence of conservation works.

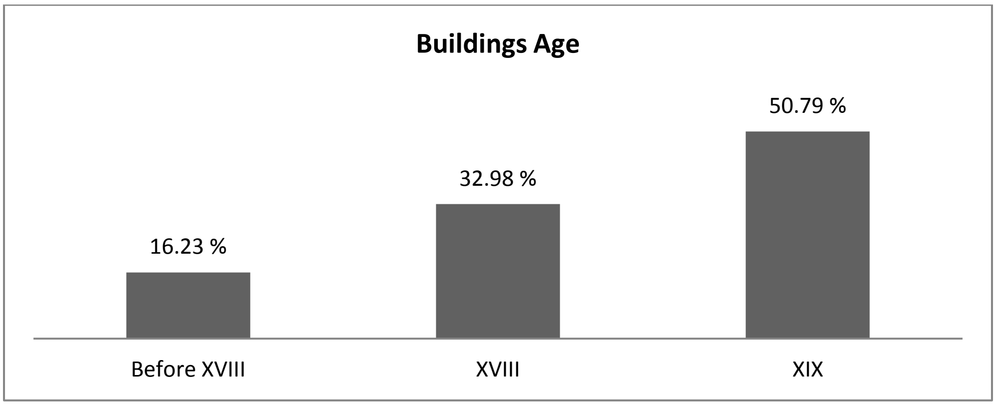

Figure 54 – Research area buildings age distribution

7.3.3 – Dwellings

It was possible to confirm that in the most common variants (3a and 3b), the central stairs were still a fundamental element for spatial organisation (figure 55). In the buildings without profound refurbishment, these stairs divided the house into front and rear parts. The variants located at the corners (1 and 2) presented an irregular shape, with the stairs being located in a corner to allow a better distribution of the rooms. In the ‘variant 4’, the stairs were located at the rear party wall, freeing up the single street facade for allowing natural light to enter into the rooms. Independently of their position, the stairs still functioned as an air and light ‘chimney’, as explained. Even in the deep-refurbished buildings, the traditional space organisation remained based around the stairs. However, these cases showed an effort on space rationalisation by reducing the circulation area (table 25). An extreme example for this is case 6 where the circulation area was reduced to 3% of the total dwelling area, as opposed to 27% in a similar, non-refurbished variant (case 3). The space organisation also shows that most of the buildings possessed ‘wet rooms’ (kitchen and WC) in the back facades, which allowed for the main rooms and/or living rooms to be located on the opposite street facades.

	Case 1	Case 2	Case 3	Case 4	Case 5	case 6	Case 7	Case 8	Case 9	Case 10
spaces	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**	**area (%)**
circulation area	11	21	27	7	10	3		15	8	
living room area	48	59	51	68	75	73	72	64	40	83
wet room area	17	10	15	11	11	23	28	19	16	17
common area	24	10								
storage area			7	14	4	1		2	36	

Table 25 – Area distribution in the houses

From the geometric parameters listed in table 26, it is possible to quantitatively confirm the relevance of the glazed elements ratio in relation to the external wall surface, reaching a maximum of 48.67% in case 6. The mean value identified was 27.6%; however, four cases presented values above 40% (cases 1, 5, 6 and 9).

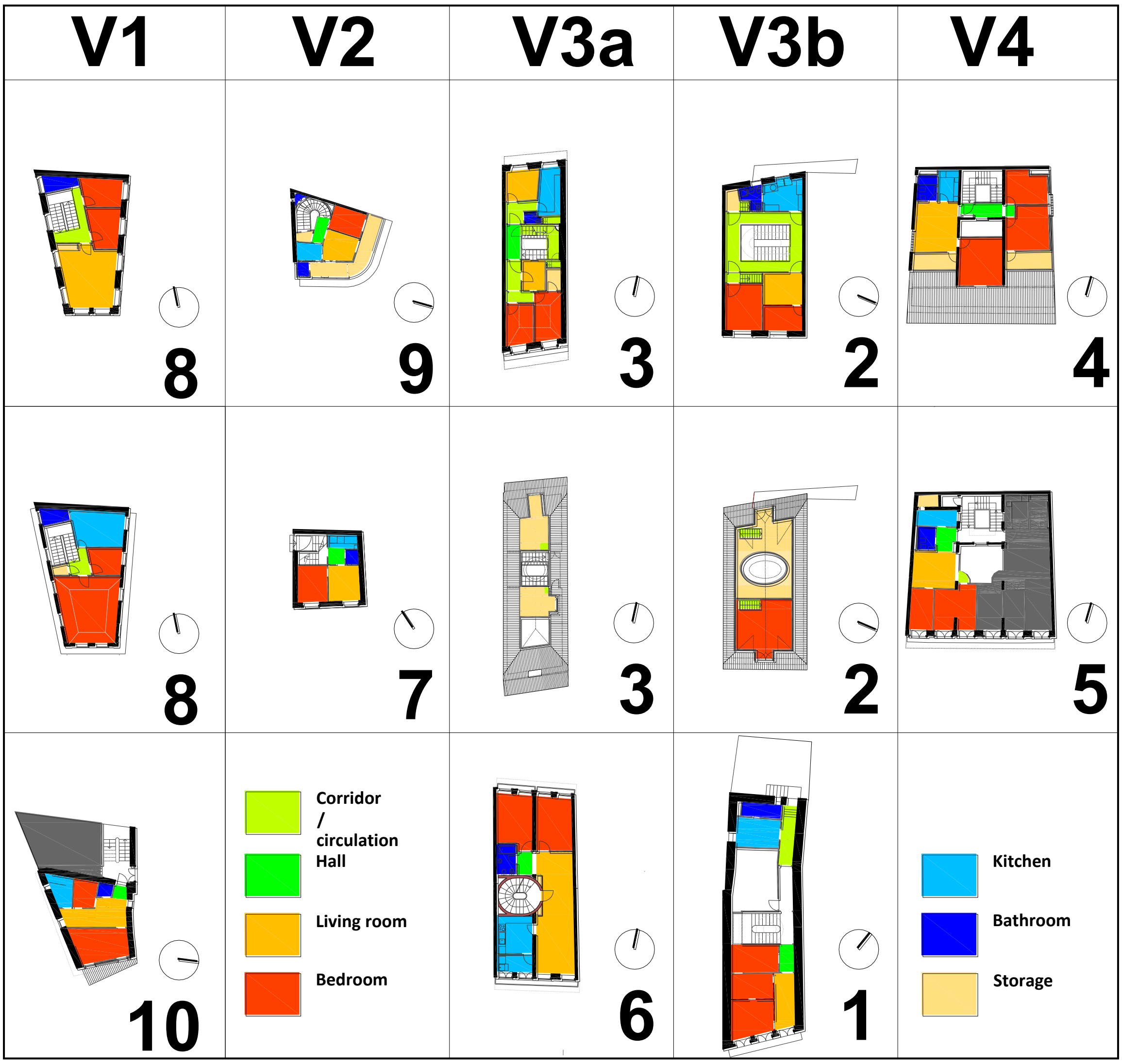

Figure 55 – Houses space organization

		Volume (m³)	Area (m²)					Average ceiling height	Ratio Volume to Area
Case	Variant		Floor	Ceiling	External Walls	Internal Walls	Total Glazing	(m)	(m)
1	3b Mid	160.30	61.20	61.20	28.70	254.30	12.50	2.86	23.09
2	3b Top	314.80	171.80	173.70	78.60	349.90	13.60	3.10	28.94
3	3a Top	269.50	209.30	210.80	134.40	428.60	12.20	2.93	35.05
4	4 Top	174.80	78.20	78.20	56.70	239.70	11.90	2.49	22.14
5	4 Mid	151.30	46.70	46.70	33.20	276.60	15.00	3.29	25.09
6	3a Mid	221.80	80.50	80.50	45.40	288.30	22.10	2.76	24.82
7	2 Mid	62.50	22.60	22.60	25.50	105.80	3.20	2.77	11.06
8	1 Top	360.80	186.00	186.00	161.80	433.70	38.10	3.46	27.69
9	2 Top	101.00	63.60	62.60	45.50	205.40	21.40	2.96	27.35
10	1 Mid	83.80	35.30	35.30	41.90	136.90	3.40	2.39	11.69

Table 26 – Case study dwellings main geometric parameters

7.3.4 – Construction Systems

The solid granite walls (0.40 to 0.70m thicknesses) were predominant on the building envelope, clad with several types of finishes. The traditional plaster was the most common of these, but slate and ceramic glazed tiles were also found. Plaster was predominant in the internal finishes, with ceramic tiles being present in the kitchen and WC spaces. The lightweight traditional walls were also present, made of timber studs and finished exteriorly with corrugated iron cladding or slate tiles. These usually appear in the extensions or closing facades between party walls, as traditionally occurring in the corbelled facades. No insulation was identified in any of the surveyed exterior walls. The roofs were all covered with the traditional ceramic roof tiles, confirming the results from the total research area survey. The traditional wood structure without insulation was still maintained in the roofs. Case 8 posed an exception, because insulation had been introduced during recent refurbishment work. In general, the buildings could be considered traditional in terms of their envelope, which was preserved even in the deeply refurbished cases.

The majority of the surveyed exterior window frames were original and single glazed. In the refurbished cases, a new windows design was replicated in the traditional frames. Once again, the exception was case 8, where a double glazed PVC frame was introduced. The existing original frames proved to be a weak point, because they allow air drafts due to a lack of maintenance over the years. The inner shutters were still the most common solar control device and were used in conjunction with light transparent curtains, which also serve the purpose of privacy. In the houses without inner shutters, they had obviously been removed, a step that the inhabitants expressed regret about.

In term of inner construction systems, a clear difference was found between the original and the significantly refurbished buildings, encompassing cases 4, 5 and 6. In the first group, the horizontal system was still based on the traditional wood beams with solid hardwood flooring and stucco or lath and plaster ceiling, as described in chapter six. The inner partitions were made from traditional timber stud walls covered with lath and plaster (0.13m – '*tabique*'). The same type of construction system was used for the exterior lightweight walls with the above mentioned cladding. On the other hand, in the deeply refurbished cases new construction systems, including heavy concrete in the structural elements and brick or gypsum plasterboard in the inner partition walls were introduced (figure 56).

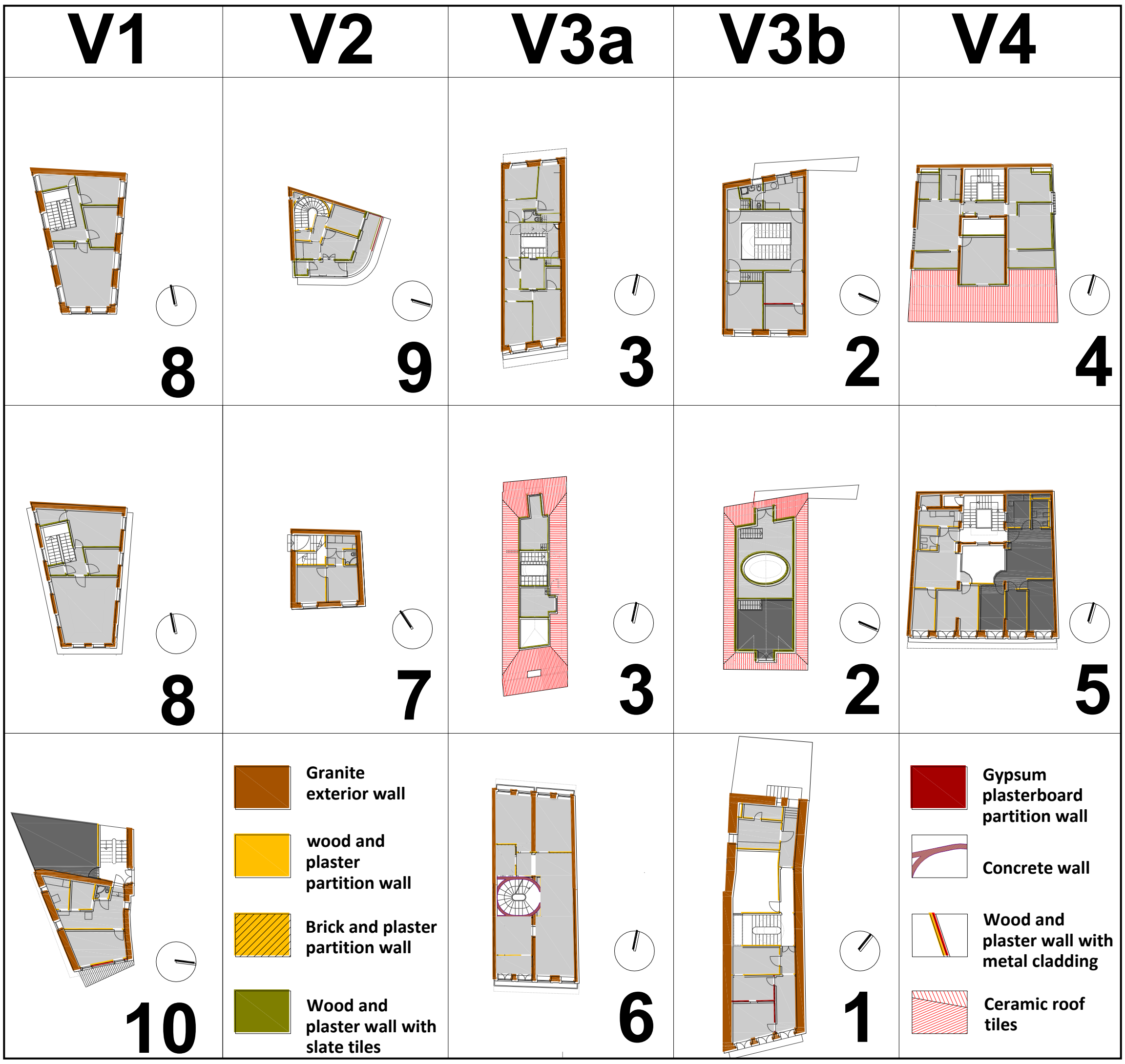

Figure 56 – Homes construction systems

7.3.5 – Occupation

The interviews with the inhabitants revealed that all houses were rented and owned by private proprietors, religious institutions and the Oporto city council, which was the most frequent. This confirms the previously explained dwellings ownership framework for Oporto (table 27).

Cases	Variant	Ownership	Owner
1	3b Mid	rented	Private
2	3b Top	rented	Religious Institution
3	3a Top	rented	Oporto City Council
4	4 Top	rented	Oporto City Council
5	4 Mid	rented	Oporto City Council
6	3a Mid	rented	Oporto City Council
7	2 Mid	rented	Private
8	1 Top	rented	Private
9	2 Top	rented	Private
10	1 Mid	rented	Private

Table 27 – Dwellings ownership

		Occupants per age			
Cases	**Variant**	<18	18-64	>65	**total**
1	3b Mid	3	2	0	**5**
2	3b Top	3	3	0	**6**
3	3a Top	1	3	0	**4**
4	4 Top	0	3	1	**4**
5	4 Mid	2	2	0	**4**
6	3a Mid	1	2	0	**3**
7	2 Mid	3	2	0	**5**
8	1 Top	0	0	1	**1**
9	2 Top	2	3	0	**5**
10	1 Mid	0	1	1	**2**

Table 28 – Cases occupation by age breakdown

Families composed of four or five persons occupied the majority of the dwellings (table 28). Due to the small sample, this data is not representative of the framework revealed by the last Oporto Census, where most of the dwellings were found to be occupied by families with 1 (31%) 2 (32%) or 3 elements (20%) (INE, 2012). The same situation occurs with the occupant's age, as most dwellings are occupied by individuals with less than 18 years (38%) or between 18 and 64 years of age (54%). The last Census revealed that in Oporto 23% of the inhabitants are older than 65 years, which confirms the perception of the existence of an aging population in the city. However, it is necessary to take a deeper look into the family composition found in the surveyed cases. Most of the adults were 50 to 59 year old and the couples were mostly grandparents, which had their grandchildren living with them, either permanently or just during the day. This reveals the existence of complex social networks that bias the statistics. The direct contact revealed that these families have a relatively low income and pay low rents.

This framework of tenants and homeowners increases the difficulty of retrofitting or refurbishing the buildings, reducing the feasibility of such operations as previously pointed out.

In terms of the occupation profile variation, it is evident that the pattern was stable along the year without holiday periods. Only two cases presented summer variations (cases 8 and 9) and in one of those, the absence in August was justified with family obligations. The same situation occurred with during weekends and bank holidays, as only one family showed a different pattern on the occasions (case 7). The weekday profile is directly connected to the mostly local professional and social life, as most of the dwellings were occupied during the day and many families have lunch at home every day.

The majority of the tenants exhibited a high level of attachment to the place and were proud of living in the historic city centre. Mainly, this resulted from the long lasting social bonds developed towards the place. Most of them were born there or were living in the area for decades. The cases with lower levels of attachment resulted from a more recent displacement to the area or to the high levels of social and home degradation. Moreover, it is possible to point out that the attachment found towards the buildings and the site was mainly a result from social and emotional values. Even though some tenants revealed awareness of the World Heritage condition, the architectural value of the building and/or its specific elements was not relevant.

In table 29 lists the overall comfort perception in the dwellings as stated by the inhabitants. The answers given may reveal the overall perception throughout the year and not the concrete conditions at the moment of the interview, which was the objective explained to the participants. This also became clear with the noise and light parameters, which were classified as quiet or bright, even when the measured values were contradictory to the participant’s opinion. Only two households (case 7 and 9) clearly remarked an overall bad comfort sensation, corresponding directly to those who were living in a degraded building. The majority of inhabitants (60%) had a positive or neutral perception of comfort. This could be explained by an acceptable thermal performance of the buildings and/or the adaptive behaviour of the households, and may explain the low use of space conditioning equipment.

		Outside Reference		Measurements				Comfort						
case	Variant	Outside Temperature (ºC)	Outside Humidity (%)	Temperature (ºC)	Humidity (%)	Noise (db)	Light (lux)	4. How do you fell the temperature at this time?	5. I would prefer to be:	6. How do you find the air movement in your house at this time?	7. How do you find the daylight levelat your house at this time?	8. How do you find the noise in the surronding areas?	9. How would you describe the air quality in your house	10. At this time, how would you rate your overall comfort in your house? Considering all the above factors
10	1 Mid	20.5	56	26.5	53	63.1	19.68	Comfortably neither warm nor cool	No change	Neither high nor low	Slightly bright	Neither noisy nor quiet	Good	Slightly good
8	1 Top	30.9	33	26.7	41	50.7	2031	Too warm	A bit cooler	Slightly high	Very bright	Slightly quiet	Neither bad nor good	Good
7	2 Mid	12.1	95	16.5	73	55.1	84	Too cool	A bit warmer	Slightly high	Bright	Very noisy	Slightly good	Bad
9	2 Top	19.6	70	26.2	52	67.6	2019	Too warm	A bit cooler	Neither high nor low	Slightly bright	Very noisy	Bad	Bad
6	3a Mid	12.6	49	15.3	44	61.9	272.9	Comfortably neither warm nor cool	A bit warmer	Neither high nor low	Bright	Slightly quiet	Good	Good
3	3a Top	12.6	50	15	59	40	191	Too cool	A bit warmer	High	Bright	Quiet	Neither bad nor good	Neither bad nor good
1	3b Mid	16.6	86	18	75	63.9	27.4	Too cool	A bit warmer	Very high	Bright	Noisy	Slightly bad	Slightly bad
2	3b Top	15.8	61	18	63	62.9	1141	Too cool	A bit warmer	Low	Bright	Very noisy	Neither bad nor good	Slightly bad
5	4 Mid	14.2	72	20	91	61	98.7	Comfortably warm	No change	Neither high nor low	Neither bright nor dim	Neither noisy nor quiet	Neither bad nor good	Good
4	4 Top	13.8	91	18.9	71	47.5	79.3	Comfortably warm	A bit warmer	Low	Slightly bright	Slightly quiet	Very bad	Neither bad nor good

Table 29 - Total questionnaire results

7.3.6 - Energy

All equipment used was powered by electricity, with the exception of the stoves, which are powered by 13 kg butane gas cylinders (table 30). Case 10 was the only case where all equipment was powered by electricity. The surveyed dwellings presented a very similar range of appliances, with washing machines and refrigerators being present in all houses. The majority of the appliances were old and inefficient, presenting an improvement opportunity. However, it is important to mention that in the recent acquisition of new equipment the households revealed a predisposition for choosing more efficient models. In table 31 the percentages of energy consumed by the diverse equipment types in each dwelling are shown, revealing that the LPG share is relatively high.

Most of the houses had a large number of TVs, with a significant share of plasma TV, which have a high energy consumptions. The group of entertainment equipment also comprised DVD players, several types of music players and cable TV decoders. The majority of the Hi-Fi equipment identified was old and the inhabitants mentioned that they use it very occasionally. The stand-by mode associated with this equipment was identified in all houses, constituting a potential source for improvement.

Lighting was done through a mix of compact fluorescent (CFL), traditional fluorescent, halogen and incandescent lamps. Although most of the families use CF Lamps, they coexist with the traditional incandescent ones. Halogen lamps were less common and the traditional fluorescents were identified in all cases, especially to light the kitchen spaces, where they remained turned on for longer periods. The replacement of the old lamps by efficient CFL's is also an improvement opportunity. Like equipment, the inhabitants revealed a predisposition to choose lamps that are more efficient.

All the houses used electric hot water cylinders to provide for their DHW needs, which is consistent with the city's general framework. This equipment clearly presents an improvement opportunity, because it is powered constantly while the hot water is only required during specific periods of the day. Moreover, most of the cylinders were old models with low insulation, which aggravates their performance and reveals another improvement opportunity.

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Lighting		6 CF lamps	3 CF lamps	7 CF lamps	18 CF lamps	1 CF lamp		3 CF lamps		1 CF lamp	
		1 fluorescent lamp	1 fluorescent lamp	2 fluorescent lamps	1 fluorescent lamp	1 fluorescent lamp	2 Fluorescent lamps	2 Fluorescent lamps	2 Fluorescent lamps	1 Fluorescent lamp	2 fluorescent lamps
		6 halogen lamps	15 halogen lamps				4 halogen lamps				
			5 lamps	16 lamps		14 lamps	15 lamps	6 lamps	20 lamps	11 lamps	8 lamps
Leisure		3 TV	3 TV	3 TV	1 TV	3 TV	1 TV	1 TV	3 TV		1 TV
				1 Plasma TV	1 Mini-TV		3 Plasma TV	1 small TV		2 Plasma TV	
			2 Cable TV box decoder			1 Cable TV box decoder	1 Cable TV box decoder			1 Modem Router	
		1 DVD player	2 DVD Player				2 DVD Player	1 VCR		1 Radio	
				1 Hi-Fi		1 Hi-Fi	1 Hi-Fi	1 Hi-Fi		1 Hi-FI	
		1 Desktop computer				1 Phone		1 Phone		1 Laptop computer	
Appliances		1 Gas stove/oven	1 Gas stove/oven	1 Gas stove/oven	1 Gas stove	1 Gas stove	1 Gas stove	1 Gas stove	1 Gas stove	1 Gas stove	1 Electric stove
					1 Electric Oven	1 Electric Oven	1 Electric Oven	1 Electric Oven	1 Electric Oven		
		1 Microwave	1 Microwave	1 Microwave	1 Microwave	1 Microwave	1 Microwave	1 Microwave		1 Microwave	
			1 Extractor hood	1 Extractor hood	1 Extractor hood	1 Extractor hood	1 Extractor hood			1 Extractor hood	
		1 Electric frying pan	1 Toaster			Coffee machine		1 Toaster			
		1 fridge / freezer	1 fridge	1 Fridge / freezer	1 Fridge / freezer	1 Fridge / freezer	1 Fridge / freezer	1 Fridge	1 Fridge / freezer	1 Fridge	1 Fridge
			1 freezer				1 Freezer				
		1 Dish washer			1 Dish washer						
		1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 Washing machine	1 washing machine
		1 Iron	1 Iron			1 Iron	1 Iron				
						1 Vacuum cleaner					
						1 Hair dryer					
Environment	DHW	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	electric hot water cylinder	1 Electric hot water cylinder
	Heating		1 Electric oil-filled radiator heater	1 Electric oil-filled radiator heater	1 electric resistance heater	1 Electric oil-filled radiator heater	1 electric fan heater	1 Electric oil-filled radiator heater	2 old Electric oil-filled radiator heater		
	Cooling		1 electric fan			1 electric fan	1 electric fan			1 Electric fan	

Table 30 - Equipment comparison

Variant	%	Total LPG	Entertainm ent	Appliance	Lighting
V1 mid	case 10	0.00	5.51	56.86	21.19
V1 top	case 8	22.00	4.67	13.61	8.44
V2 mid	case 7	41.16	7.90	22.86	10.53
V2 top	case 9	69.24	6.19	12.28	5.90
V3a mid	case 6	34.64	24.82	20.20	7.92
V3a top	case 3	54.42	6.78	10.34	7.05
V3b mid	case 1	48.58	10.31	25.77	4.31
V3b top	case 2	14.88	7.94	24.22	6.84
V4 mid	case 5	34.90	4.38	18.64	9.96
V4 top	case 4	18.15	3.22	28.31	6.87
Total	Mean	33.80	8.17	23.31	8.90

Table 31 – Percentage of equipment (LPG, entertainment and appliances) and lighting in the total yearly energy consumed (estimated from the equipment simulation)[60]

Space heating and cooling in the dwellings was performed exclusively by portable space-based equipment. These heaters appeared in 70% of the surveyed homes and the most frequent type were the electric oil-filled radiators. The use of cooling devices was not very frequent, appearing in only 40% of the homes and was done exclusively through electric fans. This behaviour is consistent with the usual Portuguese pattern regarding heating and cooling, but can also be a consequence of the positive comfort sensation identified in the survey. In some of the cases, it could also be pointed out as a result of fuel poverty, especially in terms of heating.

The global results of the energy consumption on each of the ten cases, during the reference years of 2009-2010[61] are listed in table 32. The Figure 57, figure 58 and figure 59 present graphically the comparison of all cases electricity consumption, respectively by day average, day average per m^2 and day average per inhabitant. The figures reveal dissimilar patterns, reflecting the diversity of dwellings, occupant behaviour and equipment type. However, when comparing the consumptions by inhabitant they revealed to be relatively homogeneous, with the exception of case 8 that systematically presented higher values. This can be explained by the fact that it is the only single occupied dwelling as well as the one with the largest floor area. Case 5 always presented high electricity consumptions, independently of the type of

[60] - The values were obtained by estimating the consumption referring to the information obtained in the direct surveys about each device power rating and hours of use.

[61] - The electricity company (EDP) supplied the consumption data covering the period between the middle of 2008 until the middle of 2011. The years of 2009 and 2010 were the only considered, because they were complete. The householders informed directly their average gas consumptions.

analysis performed. It is important to point out that this building was extensively refurbished, with the introduction of concrete floors, a closed inner patio and a large area of single glazed metal frame facing the patio. Furthermore, this case is a middle floor in a narrow street, which reduces the solar gains and aggravates the indoor environmental conditions, leading to a high use of heating equipment as confirmed by the tenants in the survey.

The average consumption of energy per person among the 10 cases was of 1,734.6 kWh per year, which is significantly lower than the average of 3,067.66 kWh identified for Portugal in 2011 (Eurostat, 2013; INE, 2012). Case 7 presented a yearly consumption of 1,574.85 kWh, evidencing the area bias. Only case 5 presented a yearly consumption above the national average (4,446.68 kWh/person), which is consistent with the pattern identified for this case in all the indicators. The results also confirmed the doubts raised in recent literature about the established vision that systematically refers to traditional buildings as performing poorly in terms of energy and associated building physics parameters (Baker, 2010; Baker, 2011; May and Rye, 2012; Rye, 2011; Rye and Hubbard, 2012; Rye *et al.*, 2012).

Case	Variant	Butane Gas Consumption kWh/year	Electricity Consumption (kWh/year)	Total energy Consumption (kWh/year)	Day average electricity consumption (kWh/day)	House usable area (m2)	kWh/m2 year	kWh/person year
1	3b Mid	2049.84	3641.97	5691.81	9.98	60.73	**93.72**	**1138.36**
2	3b Top	1024.92	5978.26	7003.18	16.38	109.52	**63.94**	**1167.20**
3	3a Top	3074.76	2950.27	6025.03	8.08	61.74	**97.59**	**1506.26**
4	4 Top	819.94	3896.90	4716.83	10.68	78.17	**60.34**	**1179.21**
5	4 Mid	3074.76	5692.66	8767.42	15.60	43.42	**201.92**	**2191.86**
6	3a Mid	2049.84	4139.04	6188.88	11.34	80.39	**76.99**	**2062.96**
7	2 Mid	1352.89	1796.81	3149.71	4.92	22.70	**138.75**	**1574.85**
8	1 Top	1024.92	3421.76	4446.68	9.37	119.27	**37.28**	**4446.68**
9	2 Top	3074.76	804.13	3878.89	2.20	30.26	**128.19**	**775.78**
10	1 Mid	0.00	2605.74	2605.74	7.14	35.36	**73.69**	**1302.87**

Table 32 - Total energy consumption results (electricity data from the supplier and gas data from the occupant's information)

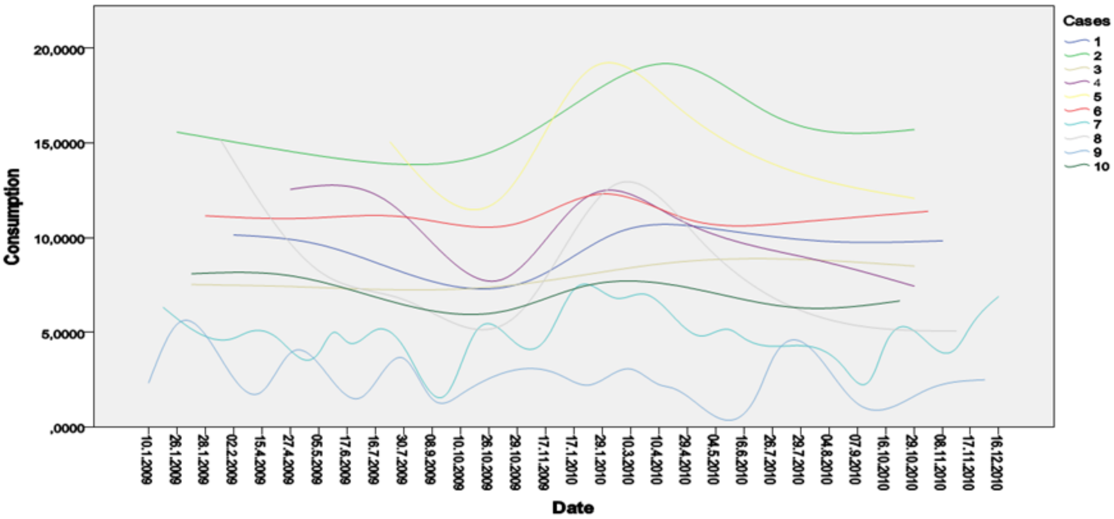

Figure 57 – Electricity daily average consumption for all cases in 2009-2010 (data from EDP Company)

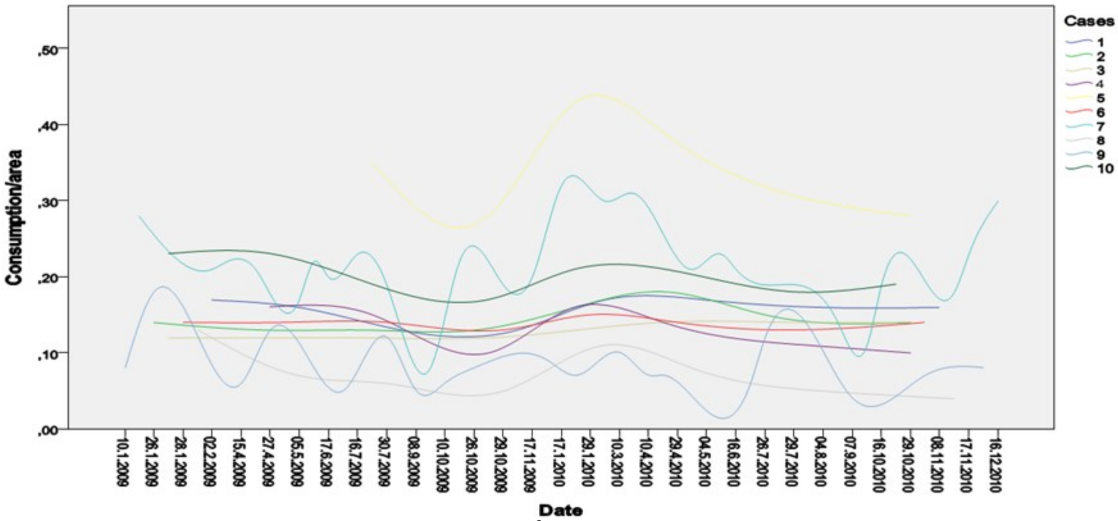

Figure 58 - Electricity daily average consumption per m^2 for all cases in 2009-2010 (data from EDP Company)

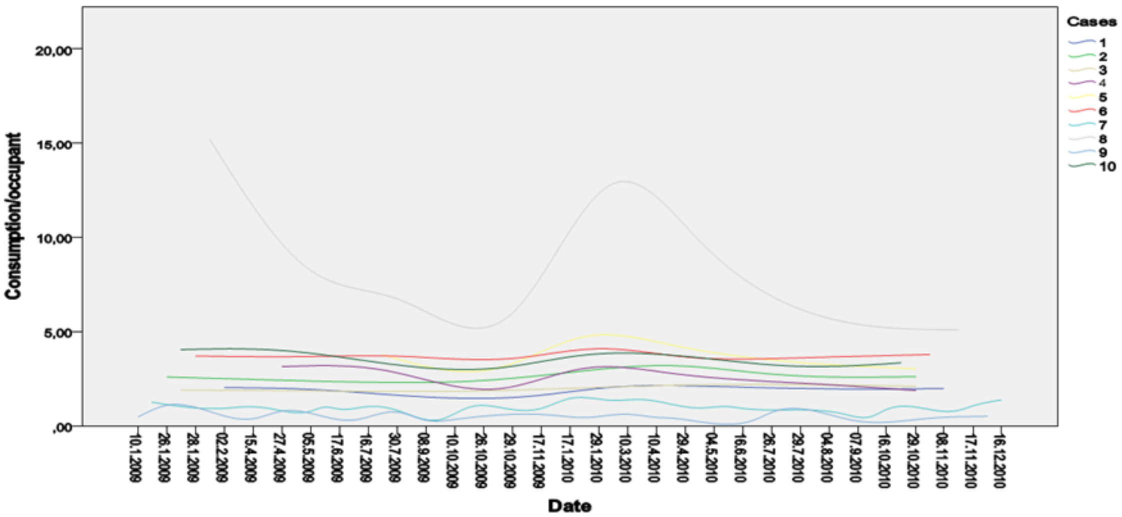

Figure 59 - Electricity daily average consumption per person for all cases in 2009-2010 (data from EDP Company)

7.3.7 – Sensors Survey

Additional temperature measurements were taken in some selected case studies, with the objective of obtaining detailed data about the thermal behaviour of these traditional buildings. Referring to this data, it was possible to calibrate the thermal models and achieve more accurate results.

Eight sensors were placed in four case studies (2 sensors each), logging information during a month at half hour intervals, from the middle of May until the middle of June 2011 (table 33). This period has usually moderate temperatures, reaching average maximum values of 22.8˚C and occasional peeks of more than 30˚C (Instituto de Metereologia, 2012). The acquired temperatures were crossed with the data for the same period from the Portuguese Weather Institute (*Instituto de Meteorologia*), used as reference.

Case	Variant	Sensor	Sensor Number	Floor	Room
1	3b middle floor	ibutton	91 21 0000001EC9E9	2	Living room - SE wall
1	3b middle floor	ibutton	FE 21 00000022A9E6	2	Corridor back - NW wall
2	3b top floor	ibutton	6A 21 0000001D0738	5	Stairs hall - SW wall
2	3b top floor	ibutton	A9 21 00000022B692	6 (attic)	Bedroom - wood ceiling
3	3a top floor	ibutton	B4 21 0000001CCE9C	4	Kitchen - SE Wall
3	3a top floor	ibutton	9D 21 0000001CFCCC	4	Bedroom -NW Wall
8	1 top floor	ibutton	F5 21 0000002077A1	3	Living Room - W wall
8	1 top floor	ibutton	5A 21 0000001D6680	4	Bedroom - W wall

Table 33 – Temperature and humidity sensors placement

In case 1, the temperature variation showed a constant pattern between the front and the back sensors. The values ranged from 1˚C to 3˚C in average, with the front room being always hotter than the back one. The comparison with the reference data gives a relatively stable pattern, with variations between day and night values. During the day, the temperature was averagely lower inside the house (4˚C to 6˚C). On the other hand, during the night the pattern verifies average higher values inside the house (6˚C to 9˚C). The temperature turning points occurred in the middle of the morning (10.00h to 11.00h) and in the beginning of the evening (18.00h to 19.00h). The differences between the solar exposition of the back and front facades, and the influence of the high thermal mass of the building, could explain this behaviour.

The results of case 2 showed a constant variation between inside and outside temperatures, which remained always lower. Interiorly, the difference varied between 2˚C and 7˚C, with the upper floor normally remaining hotter. The top floor sensor logged higher measurements during the day, reaching 5.5˚C higher than the one on the fifth floor. During the night the inverse occurred, with the lower floor achieving temperatures 2.5˚C higher than the higher floors. The turning points usually occurred at 23:00h-00:00h and 11:00h-12:00h. The relation between the exterior temperatures also showed day and night variations, with the higher values occurring in the interior in the middle of the night (10˚C downstairs and 9˚C upstairs). The turning point happens in the middle of the morning when the inner measurements reached 4.5˚C and 2˚C lower than the outside, on the 5th and on the 6th floor respectively. These patterns can be justified by the uninsulated lightweight construction system of the traditional roof, which renders the top floor very permeable for the outside temperatures. In contrast, the lower floor with higher thermal inertia presents higher temperatures during the night when the wall is releasing the accumulated heat.

The case 3 sensors revealed a constant variation between the front and back sensors (2˚C to 3˚C), with the southeast room always remaining hotter. The general profile is very similar to case 1. The comparison with the reference data gave a slightly irregular pattern, with variations between day and night values. During the day, the temperature was irregular, sometimes being lower inside the house (6˚C to 7˚C). When the temperatures were higher inside, they usually reached the lowest difference during the day. During the night, the pattern showed a stable average, reaching the interior measurements 7˚C to 10˚C higher. The turning points were generally in the beginning of the morning (08.00h to 09.00h) and in the beginning of the evening (18.00h to 19.00h). The different solar exposition of the back and front facades and the high thermal inertia of the building wall may explain this pattern.

For case 8, the higher interior measurements occurred predominantly in the top floor (maximum of 2˚C), with a high variability during the first half of the day. The comparison between outside and inside temperatures showed variations between day and night, with the higher inner values occurring in the middle of the night (maximum of 10˚C). During the day, the pattern is not uniform and the temperature gets lower inside (maximum of 5˚C). The difference between inside and outside temperatures achieved the lowest values when the highest daily temperatures were reached (around 30˚C). Despite this variability, it was possible to identify a turning point in the beginning of the morning (7.00h to 8.00h), when the inner measurements start approaching the outside values, and in the beginning of the evening (18.00h to 19.00h) when the values start to diverge. These patterns can be explained by the performed refurbishment, which insulated the traditional roof, leading to lesser variations between the two floors, when compared to the similar situation of case 2.

The importance of thermal inertia for a building's performance is a factor widely pointed out in the literature (IES, 2009; The Concrete Centre, 2012). The above results confirmed its role in the thermal performance of Oporto's traditional buildings, which was verifiable through the measured temperature variation patterns in the four cases. In figure 60 the simplified thermal behaviour of these solid walls along the year is graphically interpreted. The major question to be addressed refers to the necessity of identifying the summer turning points in the heat exchange patterns, in order to devise a natural ventilation strategy that helps dissipating the heat accumulated in the walls. This is of special importance, not only for the current situation, but also when taking into account the future weather predicting the raise of the temperatures.

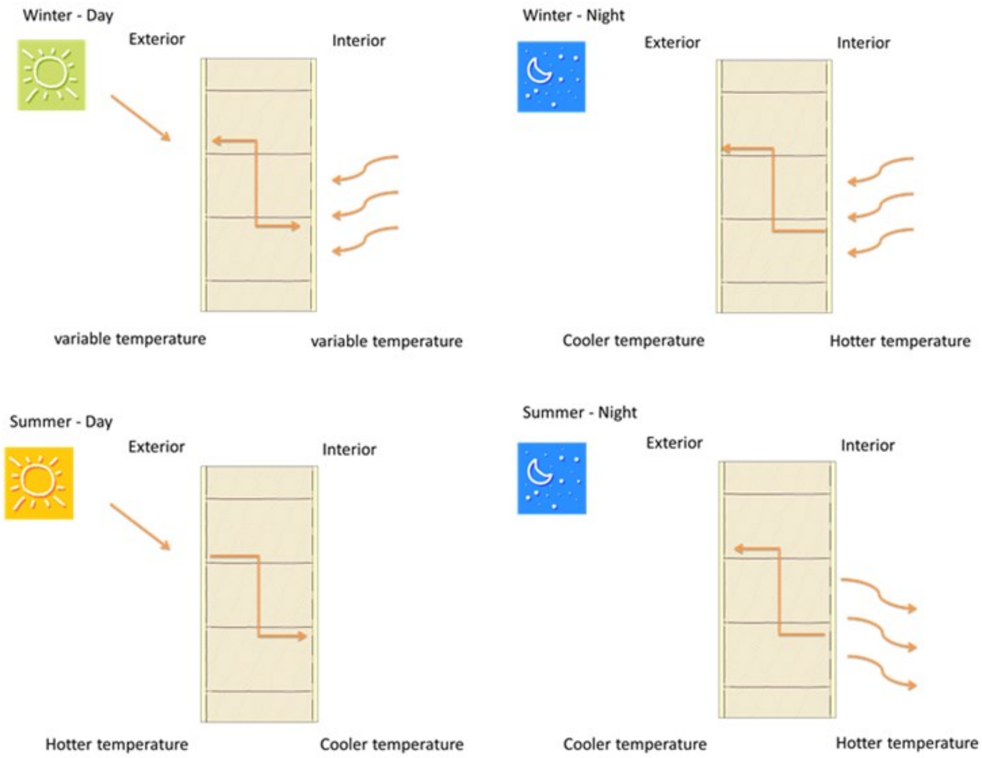

Figure 60 - Oporto traditional buildings solid walls thermal behaviour

7.4 – Building Heritage

The surveyed cases also validate the main architectural features that are responsible for shaping the visual integrity of Oporto's traditional buildings that was identified in the previous chapter. The relation between the granite moulding and the cladding surface is clear in all buildings, with the exception of case 4 where no granite elements exist. Figure 61 shows an example of a facade where the granite architectural elements were coloured, highlighting the relation to be preserved. Breaking this delicate visual relation, damages the building's heritage significance and consequently the World Heritage Site. This is extremely important when it comes to the introduction of external insulation, which must consider this surface balance. Figure 62 shows the negative impact resulting from this situation in a traditional building of the Oporto World Heritage Site.

For a similar reason, the glazed ceramic tiles used in the walls of case 6 render the use of external insulation impossible (figure 63). The traditional tiles are included in the architectural heritage elements to be preserved. The slate tiles or corrugated iron cladding[62] placed on the facades pose similar constraints. However, in these cases it is technically possible to introduce insulation under the external cladding, along the timber battens used for their fixing. If this situation occurs in a street facade with granite mouldings, as shown in figure 64, it poses a similar problem for the surface relation mentioned above. When it occurs in party walls or in facades without granite elements, where the window studs are wooden and integrated in the cladding system (figure 63), the degree of flexibility is higher and mainly limited by the technical factors.

Figure 61 – Case 2 main facade with granite mouldings in light yellow.

[62] - For decades, corrugated iron has been the material used traditionally for cladding the extensions in traditional buildings in Oporto and as such is a remarkable feature of the city.

Figure 62 – Historic centre building in Oporto where plaster is above the granite jambs

Figure 63 – Case 6 main facade showing the relation between granite mouldings and glazed ceramic tiles

Figure 64 – Case 3 facade with slate tiles cladding

The design of the traditional wood frames is another architectural element defining the heritage significance of traditional buildings. Their upgrade requires a careful approach in order to avoid negative heritage impacts. Figure 65, figure 66 and figure 67 illustrate several examples of negative consequences resulting from the changes introduced in the frames of various traditional buildings in Oporto. These are respectively, the replacement of the traditional wood by PVC or aluminium frames imitating the original design, the use of new frames imitating the sash, but using a different opening mechanism, and the introduction of special reflective glass. All these solutions may prove to be more energy efficient; however, they may cause diverse degrees of loss of the building’s authenticity. Therefore, it is possible to conclude that any upgrade addressing the traditional window frames (double glazing, secondary glazing or efficient glass) must retain the building’s authenticity by avoiding introducing dissonant visual changes in the original frame. Any change must be previously assessed with that objective.

Figure 65 – Aluminium frame imitating traditional casement design in traditional building in Oporto

Figure 66 - Wood frame imitating the traditional sash design in a traditional building in Oporto

Figure 67 – Original balcony door with special glass in a traditional building in Oporto

The roofscape of Oporto's historic city is another relevant aspect of the World Heritage Site. Changes to individual roofs have to be assessed in order to determine their impact on the overall site. The introduction of renewables (solar panels or wind turbines) must also consider this factor to avoid negatively affecting the traditional buildings (figure 68 and figure 69). The cumulative impact on the site is another crucial aspect, as shown in the photomontage of figure 70. What appears to have only a small impact on an individual building, even following the rules specified in the Oporto guidance (AdEPorto *et al.*, 2010), turns into a major disruption when applied on a large scale, compromising the historic city roofscape and consequently the World Heritage Site. All design solutions must consider the aspects identified above and address them on the various levels of significance: element, building and site.

Figure 68 – Traditional building in Oporto with Photovoltaic panels on the roof

Figure 69 – Traditional building in Oporto with DHW solar thermal panel on the roof (street level view)

Figure 70 – Oporto World Heritage Site panoramic view from the South and solar panels photomontage

Figure 71 - Oporto World Heritage Site panoramic view from the South and solar panels photomontage (detail)

7.5 - Conclusion

Overall, the characteristics identified in the case studies validate the revision made in chapter six. This covers the building parameters, the dwellings' spatial distribution, the construction systems and the architectural heritage elements. Moreover, this also validates the bottom-up approach as the identified variants verify the main typological characteristics of the selected research area.

The occupants' survey revealed the existence of a complex social network in the historic area, leading to a very wide inter-generational use of the dwellings, which are usually occupied by a large number of persons. The attachment of the inhabitants to the historic site was mainly high, confirming the established long-term bonds. All inhabitants were tenants, which means that any energy efficiency improvements to the buildings have to be done in accordance with the Portuguese legal framework for renting, a factor that may lead to increased difficulties for undertake the measures.

The overall perceptions of comfort related by the tenants were mainly positive. This was also confirmed in the energy use as heating and cooling was done by individual, space-based devices. This observation also coincides with the identified Portuguese energy framework.

The DHW, appliances and lighting equipment revealed a potential for improvement as it was often shown to be inefficient. The poor conservation of the original frames leaded to high levels of air drafts, marking another margin for improvement.

The temperatures measured by the sensor showed that the thermal mass of these buildings play a key role for their performance. The night and day variations also confirm this, highlighting the role that nocturnal ventilation can play to avoid overheating.

The identified heritage constraints pose diverse limitations for improvements to the building envelope. The conservation of the visual integrity of Oporto’s traditional buildings is crucial to preserve the significance of the entire World Heritage Site. Based on this principle, were identified the main heritage limitations of the envelope.

Furthermore, it is necessary to model the case studies in order to determine the baseline against which the simulation of the identified improvements will be assessed. The heritage constraints should be accounted for by incorporating all dimensions of the research in order to achieve the most efficient solutions.

Chapter Eight: Case Studies Modelling and Simulation

Chapter Eight: Case Studies Modelling and Simulation

8.1 - Introduction

This chapter presents the results from the simulations performed on the case studies. Firstly, the methodology and the process used to accomplish it are covered. It starts with a definition of the baseline model, based on the physical and behavioural data acquired from the survey. The design scenarios were chosen beforehand based on the technical, behavioural and heritage perspectives. They were afterwards simulated and the results were benchmarked against the baseline for reference.

8.1.1 – Modelling and Simulation

Swan and Ugursal identified two variations of the bottom-up modelling, which were defined as the statistical and the engineering approaches. The first is based on the analysis of statistical data and simple surveys (including energy bills) and is used to “determine the energy demand contribution of end-uses inclusive of behavioural aspects” (2009, p.1833). The second uses detailed quantitative data and intensive computer simulations, encompassing the impact of new technological developments. Basically, this points to a division between the physical (fabric, systems) and the social modelling (behaviour of use in building, systems and equipment). The authors also mention the validity of crossing methodologies due to the complexity involved in the modelling of building stock and the limitations posed by a single approach on its own. The bias provoked by the use of subjective households’ data is larger than the limitations identified in lack of accuracy of the physical factors. Still, to achieve the best results the system relies on combining the two factors to obtain a realistic simulation.

Accordingly, these two types of approaches were undertaken at the same time through three separate development stages. The approaches partially separated the physical elements (buildings’ fabric) from the occupancy and behaviour data, which presented variable degrees of accuracy and allowed diverse possibilities of implementing and measuring the design scenarios (figure 72). Moreover, the dynamic simulation took the interaction between the occupants, fabric and equipment control, into account which were correlated in the software. The assessment of the possible improvements in behaviour and equipment was done separately, which allowed measuring the results directly and in a simpler way, as they were harder to simulate in the software. Using the thermal simulation model it was possible to evaluate fabric improvements, but also some behavioural aspects, like the use and control of natural ventilation, space conditioning and lighting. Despite the specific limitations of this research, it can be affirmed that the ideal process should have been to perform a unique simulation that integrates all the information into the thermal software.

The first stage was based on modelling the direct energy, behaviour and equipment raw data achieved through the direct contact with the householders. This was described in the previous chapter, where the energy behaviour was identified through the case studies. The second stage outputted the baseline model from the thermal simulation software and from the equipment data. The last stage resulted from the simulation of the design scenarios and allowed making further conclusions by comparing the diverse stages. The simulated design scenarios followed the performed literature review and integrated the information of chapters six and seven, covering the buildings' thermal performance and their heritage limitations.

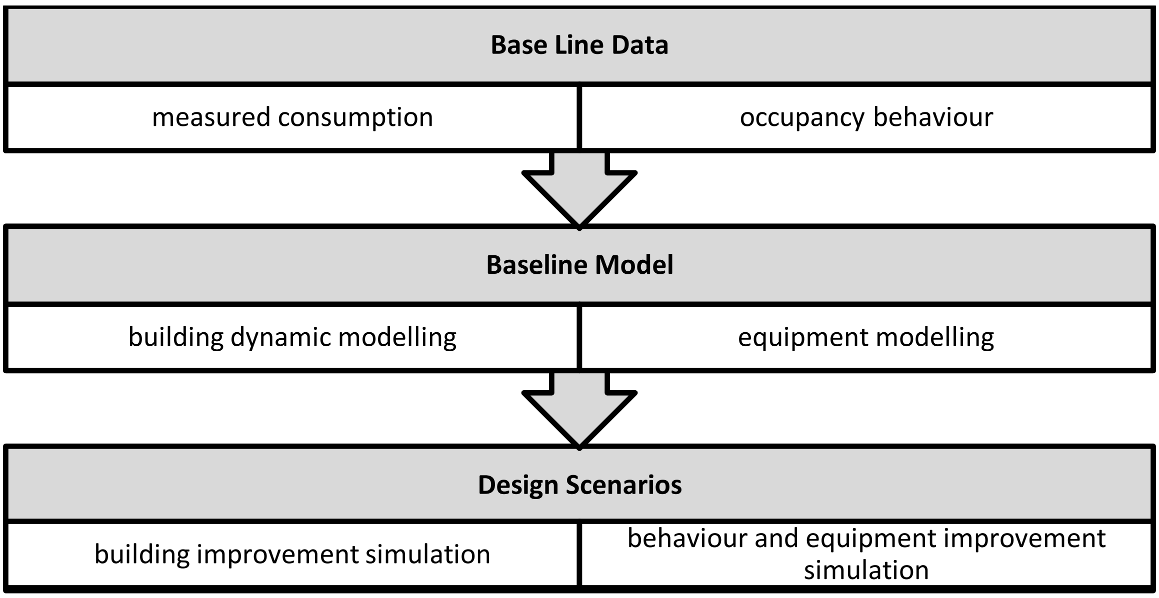

Figure 72 – Variants modelling framework

8.1.2 - Model Calibration

The simulation's accuracy and reliability is improved by calibrating the model, as stressed in the literature (Heo *et al.*, 2012; Tahmasebi *et al.*, 2012; Weber *et al.*, 2012). In the case of existing buildings, the ideal process should be done through on-site monitoring over a certain period of time. As this was not possible, some procedures were devised in order to overcome this situation.

The electricity consumption was calibrated by crossing three sources: the measured data, outputs from the equipment and thermal models (table 34). The data from the EDP Company was statistically analysed in order to obtain the mean for two years. The values for each of the ten case studies were compared with the two models. The calibration process was done by levelling the consumptions of the models with the real data through fine-tuning the hours of use, which presented a higher degree of uncertainty. Gas-powered equipment (stoves) was not considered, as no actual measurements were available. As becomes evident in table 34, the dynamic model baseline revealed to be closer to the real consumption. The differences shown in the equipment model are irregular and very small in most of the cases. However, in certain cases it they were revealed to be more than 1,000 kWh per year. Nevertheless, it is possible to confirm that both models are reliable enough for measuring the variations in energy consumption from the respective simulations.

	Real comsumption (kWh/year)	Equipment model (kWh/year)	Dynamic model (kWh/year)
	electricity	electricity	electricity
Case 1	**3641.0**	**2261.9**	**3040.1**
Case 2	**5978.3**	**6113.9**	**5344.0**
Case 3	**2950.3**	**2685.3**	**2420.8**
Case 4	**3896.9**	**3854.5**	**3667.6**
Case 5	**5692.7**	**5978.8**	**5289.4**
Case 6	**4139.0**	**4032.0**	**4041.0**
Case 7	**1796.8**	**2016.4**	**1974.2**
Case 8	**3421.8**	**3789.3**	**3409.1**
Case 9	**804.1**	**1423.9**	**1028.9**
Case 10	**2605.7**	**1954.7**	**2427.1**

Table 34 – Electricity consumption comparison between the real data and the equipment and dynamic models baseline

The temperatures acquired by the sensors were compared with the ones outputted from the dynamic simulation for the same time period and for the same room. The objective was to validate the thermal behaviour of the models and identify if they presented remarkable divergences or were reliable.

The data was compared and graphically analysed for each sensor, as exemplified in figure 73 and figure 74. The temperature patterns were similar in most of the cases and exhibited all a diverging at the end of the period. This is most likely caused by a climate anomaly regarding the typical weather used in the simulations. Overall, it can be affirmed that the measured data confirms the validity of the dynamic simulation, which can be classified under this aspect as accurate.

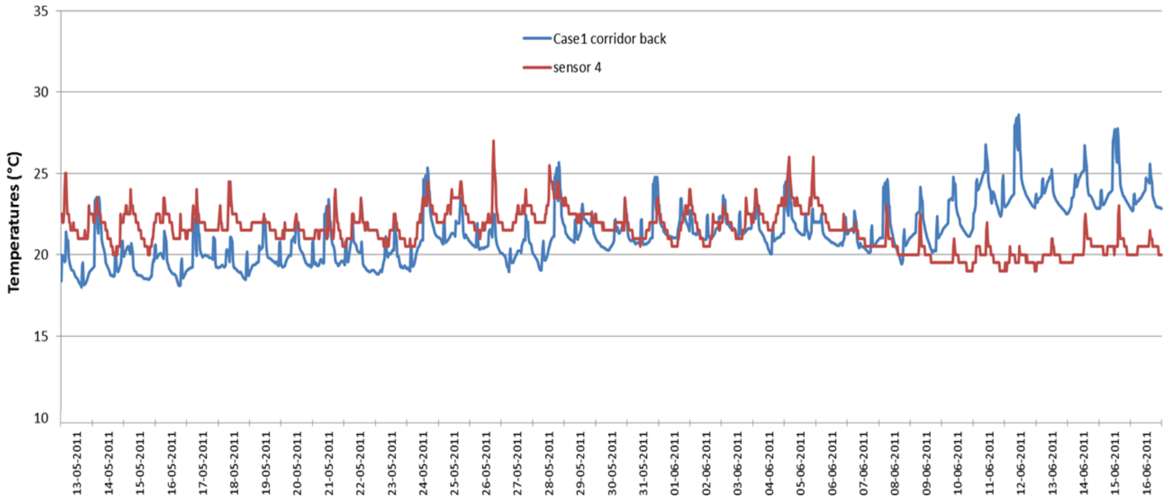

Figure 73 – Comparison between modelled and measured temperatures (Case 1 – Sensor 4)

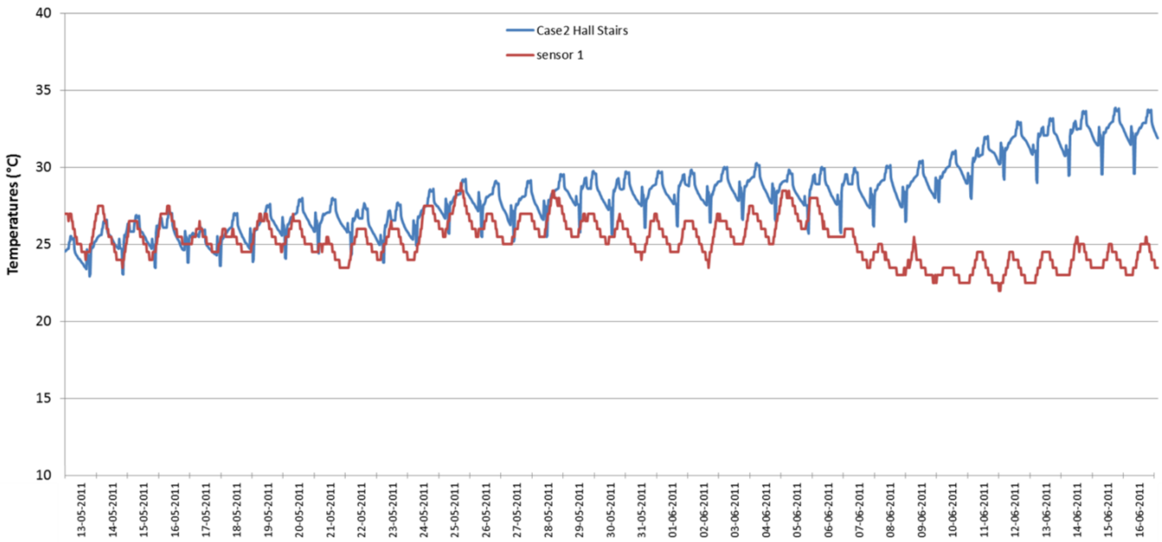

Figure 74 - Comparison between modelled and measured temperatures (Case 2 – Sensor 1)

8.1.3 – Equipment Model

The protocol used to obtain information in the survey was based on a similar study undertaken by Gupta and Chandiwala (2010). It was designed to collect data about the equipment (model and brand), its location, the power rating and the average usage hours. Assuming a year with

365 days or 52 weeks, the use was converted into hours/year and then multiplied by the power rating, obtaining the estimated yearly consumption. The process was performed for all equipment as well as lighting, where a similar consumption was estimated. The total sums correspond to the household's yearly consumption in kWh (electricity and butane gas), constituting the equipment model baseline[63]. The data was also introduced in the simulation software to achieve more accurate results, both in terms of the internal gains for each room as well as for the total energy consumption.

8.1.4 – Dynamic Model

To perform the dynamic simulation it was necessary to collect a large amount of data, covering the fabric's thermal and geometrical properties, building systems, equipment and the profiles of occupation and use. The templates, databases and data relations used in the software are shown in figure 75. After the creation of the 3D physical model, the introduction of data focused on the construction and profile databases, which provided information about the thermal properties of the fabric and about the control of lighting, equipment, systems and openings. The data was mainly obtained through the surveys and complemented with archive material, CAD analysis and literature. Behaviour and control were contributed from the householders[64].

It is widely pointed in the literature that the materials of traditional construction systems still have some uncertainty associated with their thermal parameters. Therefore, the existing guidance was reviewed by cross referencing several sources. The absence of combined layers in modelling software was revealed to be a weakness, because many of the traditional construction systems combine several materials in a layer. To overcome this, the combined layers were modelled externally in the *BuilDesk-U 3.4* software, using the detailed information achieved in the dwellings survey and complemented with the literature review. The results obtained were then applied in the thermal software as a simple layer in the construction systems database[65].

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63 - The tables with the detailed calculation for each case study are in the appendices.

64 - Detailed information about all the variables used in the thermal modelling is listed in the appendices.

65 - All the parameters of the materials used in the modelling of the ten case studies construction systems are listed in the appendices.

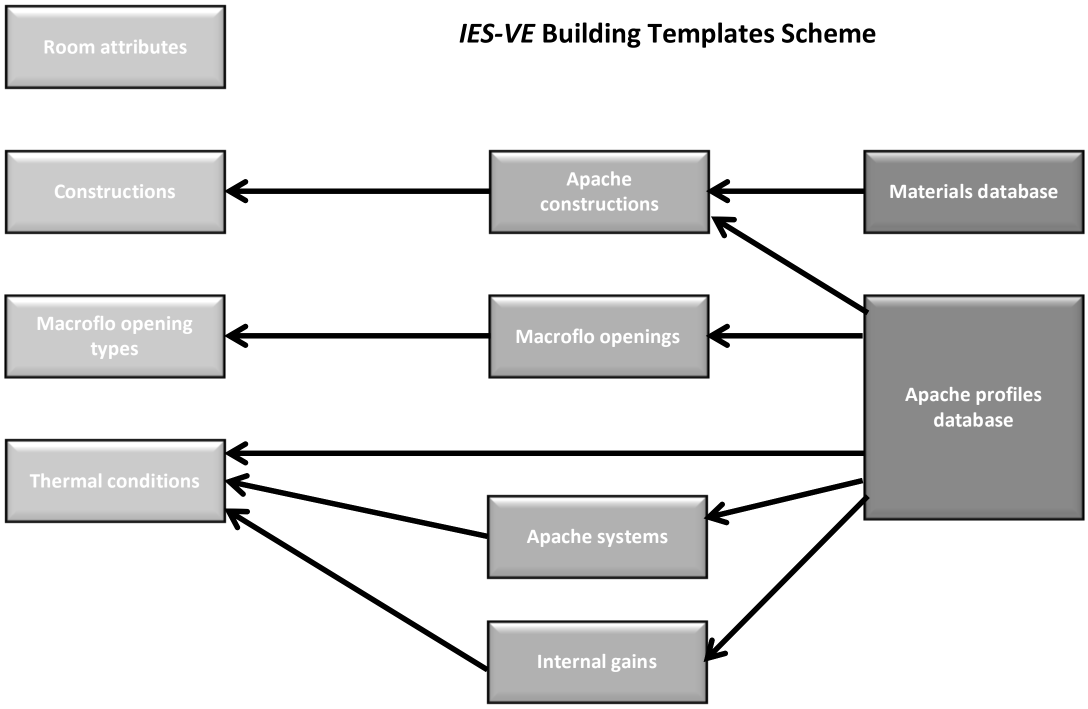

Figure 75 – *IES VE PRO* data and modules integration

8.2 – Modelling

The thermal and the equipment baseline models were performed using the *IES-VE PRO* and the *Microsoft Excel* spreadsheet tools. The first model aimed to identify comfort levels in the usually occupied rooms (bedrooms and living rooms), global energy consumption and associated carbon emissions. The second model outputted the average energy consumed in a year, subdivided by all the equipment identified in the survey. The baseline models allow establishing a reliable reference to evaluate the results obtained from the simulations, following the method used by the Historic Scotland (IES, 2009).

After the calibration, the design scenarios were simulated in both models, addressing the improvement opportunities identified from the analysis of the baseline and from the direct survey. They were selected from the framework identified in chapter four and further assessed for their predicted heritage impact in the previous chapter. The final step aimed to identify the efficiency of the solutions by weighting the several previously defined components global heritage impact assessment, energy and carbon savings, cost effectiveness, and comfort against each other.

8.2.1 – Design Scenarios

Several design scenarios were simulated, all addressing the improvement opportunities detected in the previous chapter. A conservative approach was taken to address the most feasible scenarios, *i.e.* simple solutions which can be easily implemented by the households. Additional measures could have been considered, but their technical difficulty and costs led to their exclusion from the design scenarios. These included the introduction of natural gas[66], the use of more efficient and sophisticated systems to perform DHW, heating and cooling (central systems), or the introduction of emerging insulation materials. The gas equipment was not simulated, because it consisted only of stoves, whose replacement was not relevant in terms of energy savings. For this reason, the final savings achieved by this simulation refer to electricity only.

The efficient equipment data used in the design scenarios was selected from the European project Topten database (Quercus, 2012). The stand-by data was retrieved mainly from the SELINA project database (2011). To obtain the pay-back indicator, the cost of each measure and the calculated savings, both in energy and cost, were determined (Cype Ingenieros, 2011; Quercus, 2012). With this data, it was possible to determine the years necessary to obtain a return from the investment.

To address the identified improvement opportunities, three scenarios were selected to be simulated in the equipment model (table 35). The first scenario simulated turning off the stand-by mode on entertainment devices (TVs, DVD players, HI-FI, cable/TV boxes, etc.), which is a behavioural approach without any financial costs involved.

Scenario	Measure	Modelled in Excel table
1	Nulling equipment standby	Removed the values of stand-by in entertainment
2	Replace existing lamps with more efficient CFL	Replaced the incandescent and halogen lamps power rating with CFL equivalent
3	Replace existing equipment with more efficient models	Replace the identified inefficient equipmet power rating with the equivalent from more efficient models

Table 35 – Design scenarios used in the equipment simulations

66 - More environmentally friendly than electricity, but not available in the area.

The next scenario addressed the replacement of inefficient lamps (incandescent and halogen) with compact fluorescent. The majority of the householders revealed a predisposition to implement this measure. A gradual replacement of the existing lamps was considered the most feasible way for this scenario. Therefore and because of its relatively low cost, this scenario was disregarded in the pay-back analysis.

The last scenario was based on the replacement of inefficient appliances identified with new models. This measure focused on the electric equipment with high consumptions, covering mainly large appliances (washing machines, dishwashers, ovens, fridges and freezers), but also the TVs. To increase the feasibility of this measure, it was only approached in a medium-term scenario, again based on their gradual replacement. Beside the technical scope, this is also a behavioural approach, as it relies on the householders' choice to replace the malfunctioning devices. This measure is highly dependent on cost, so a pay-back analysis was performed to evaluate its feasibility. The selection of the new models was made by balancing the highest possible efficiency with the lowest available cost.

Scenario	Measure	Modelled in IES-VE
1	Draughtproofing windows and doors	Reduced crack flow in doors and windows (MacroFlo)
2	Improve single glazing with insulating film	Modelled in glazed constructions
3a	Use of internal shutters	Modelled in external glazed elements (internal shade)
3b	Use internal shutters and change the profile	Modelled in external glazed elements (internal shade)
4	Reduce DHW temperature from 60° to 55° C	Modelled in Apache system
5	Upgrade DHW storage tank insulation (to 100mm)	Modelled in Apache system
6	Introduce double glazing	modelled in glazed constructions
7	Introduce secondary glazing	Modelled in glazed constructions
8a	Introduce insulation in floors and ceilings	Modelled in floor/ceiling constructions
8b	Introduce insulation in roofs	Modelled in roof constructionsn (just top floor cases)
9	Introduce exterior insulation in party walls	Modelled in external wall constructions (just top floor or cases higher than side buildings)
10	Scenario 9 + introduce exterior insulation in facades	Modelled in external wall constructions
1_4_5	Composite scenario (1, 4 and 5)	Combination of 1, 4 and 5
1_4_5_3	Composite scenario (1, 4, 5 and 3)	Combination of 1, 4, 5 and 3
Solar Thermal	Introduction of solar thermal DHW	Modelled in Apache system
Solar Thermal and 4	Introduction of solar thermal DHW and scenario 4	Modelled in Apache system

Table 36 – Design scenarios used in the dynamic simulations

The dynamic thermal simulations addressed fourteen design scenarios. Additionally, two other scenarios were simulated with the objective of evaluating the results of using solar thermal energy for water heating. In table 36 the sixteen simulated design scenarios are listed. The first six are characterised by their high feasibility due to low costs and non-intrusiveness regarding the building's heritage. In terms of costs, scenarios 3a and 3b may turn into an exception, as the introduction of internal shutters can be relatively costly. Scenario 2 may also turn into an exception, but in terms of heritage, as the applying the film on the glazed elements may be damaging to the visual integrity of the building, as was explained in the previous chapter.

The next two simulations address upgrading the glazed elements, which is costly when compared to the previous solutions and has to be done with care to avoid incompatibility with the existing frames. The insulation of the horizontal partitions was addressed in scenarios 8a and 8b. This included the loft insulation in the case of a cold roof, or otherwise, the direct insulation of the roof. In terms of cost, heritage and compatibility constraints, these scenarios have to be approached like the previous two.

Simulations 9 and 10 refer to the introduction of external insulation, which is an expensive solution and may be highly intrusive for the building's integrity. The first addresses exclusively the party walls, while the second encompassed the entire envelope, which may have a significant impact on the heritage value.

Furthermore, composite scenarios, combining the solutions that presented the highest effectiveness were created. The remaining two scenarios addressed solar thermal solutions, which are intrusive for the image of the buildings and the character of the historic city as a whole. Nevertheless, it was necessary to identify their potential gains, because they are related to DHW improvements, which were revealed to have the highest effectiveness out of the previous scenarios.

8.3 – Results

The two types of simulations (equipment and dynamic) were benchmarked against the baseline situations in four indicators: energy, CO_2 emissions, comfort and cost. Only electrically powered equipment was simulated and therefore energy and emissions results refer to this power source only. The final energy and CO_2 indicators also include the LPG, which was summed to the previous as a fixed component. The conversion factors used to determine the carbon emissions were retrieved from the energy supplier's monthly mix (electricity) (EDP, 2008) and from the Portuguese Energy Regulator Entity (LPG) (ERSE, 2011). The remaining indicators intended to cross-evaluate the efficiency and feasibility of the simulated design scenarios from a wider perspective, addressing the social framework identified during the research.

8.3.1 - Baseline Performance

The two modelling approaches outputted the energy consumptions listed in table 37 and divided them into the two types of energy used. The dynamic model was used as reference for the energy benchmarking of the simulations, while the equipment model was used to simulate the variation in the equipment consumption.

	Equipment model (kWh/year)			**Dynamic model (kWh/year)**		
	electricity	LPG	**Total**	electricity	LPG	**Total**
Case 1	2261.9	2137.2	**4399.1**	3040.1	2137.4	**5177.5**
Case 2	6113.9	1068.6	**7182.5**	5344.0	1068.6	**6412.6**
Case 3	2685.3	3205.8	**5891.1**	2420.8	3205.8	**5626.6**
Case 4	3854.5	854.9	**4709.4**	3667.6	854.9	**4522.5**
Case 5	5978.8	3205.8	**9184.6**	5289.4	3205.8	**8495.2**
Case 6	4032.0	2137.2	**6169.2**	4041.0	2137.2	**6178.2**
Case 7	2016.4	1410.6	**3427.0**	1974.2	973.9	**2948.1**
Case 8	3789.3	1068.6	**4857.9**	3409.1	1024.7	**4433.8**
Case 9	1423.9	3205.8	**4629.7**	1028.9	2200.1	**3229.0**
Case 10	1954.7	0.0	**1954.7**	2427.1	0.0	**2427.1**

Table 37 – Energy baseline comparison between the equipment and the dynamic models

The results of the yearly mean values of the 'Predicted Percentage Dissatisfied' (PPD) in the living areas[67] show relatively low percentages, ranging from 16.63% to 30.17% (table 38). Cross referencing these results with the use of cooling and heating (table 38), it is possible to verify that cases 1 and 10 present the lowest percentage of PPD, which is coincident with the absence of equipment for space conditioning. While not entirely excluding the economic factor

[67] - Areas of the house used for living (rooms, living rooms, kitchen), which exclude the circulation spaces (corridors, halls) and WCs.

as a reason for the low energy consumption, it is still possible to conclude that it does not oppose to the thermal comfort. It is worth mentioning that case 5 presents in its living room the highest value of PPD (54.19%), which is coincident with the highest energy consumption verified in this dwelling. It is also important to remember that this living room belongs to a significantly refurbished and altered house and one of its walls has a large single glazed iron frame, which performs poorly in terms of thermal resistance.

Room	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Livingroom	12.80	34.03	27.05	22.26	54.19	18.22	25.22	28.92	30.45	15.59
Bedroom 1	15.26	26.25	28.22	25.13	24.47	23.38	27.36	29.59	22.81	21.42
Bedroom 2	18.36	25.68	22.89	30.41	21.61	25.27		29.23		15.28
Bedroom 3	20.09	24.01	27.78	29.21				31.68		
Bedroom 4								31.45		
Mean	16.63	27.49	26.49	26.75	33.42	22.29	26.29	30.17	26.63	17.43
heating	no	yes	yes	yes	yes	yes	yes	yes	no	no
cooling	no	yes	no	no	yes	yes	no	no	yes	no
kWh/m^2 year	93.72	63.94	97.59	60.34	201.92	76.99	138.75	37.28	128.19	73.69

Table 38 – Predicted Percentage Dissatisfied (PPD) from the thermal simulation

		Cost (€/year)		Cost (€/day)		Cost (€/year)	Cost (€/day)
Case	**Variant**	**electricity**	**LPG**	**electricity**	**LPG**	**Electricity + LPG**	
1	**V3b M**	**629.2**	**124.8**	**1.7**	**0.3**	**754.0**	**2.1**
2	**V3b T**	**1033.0**	**62.4**	**2.8**	**0.2**	**1095.4**	**3.0**
3	**V3a T**	**509.8**	**187.2**	**1.4**	**0.5**	**697.0**	**1.9**
4	**V4 T**	**673.4**	**49.9**	**1.8**	**0.1**	**723.3**	**2.0**
5	**V4 M**	**983.7**	**187.2**	**2.7**	**0.5**	**1170.9**	**3.2**
6	**V3a M**	**715.2**	**124.8**	**2.0**	**0.3**	**840.0**	**2.3**
7	**V2 M**	**310.5**	**82.4**	**0.9**	**0.2**	**392.9**	**1.1**
8	**V1 T**	**591.3**	**62.4**	**1.6**	**0.2**	**653.7**	**1.8**
9	**V2 T**	**139.0**	**187.2**	**0.4**	**0.5**	**326.2**	**0.9**
10	**V1 M**	**450.3**	**0.0**	**1.2**	**0.0**	**450.3**	**1.2**

Table 39 – Case studies energy costs (2013 base prices including VAT)

Using 2013's energy prices for butane gas and electricity, the total and the daily energy costs for the surveyed cases were obtained (table 39). In the ten cases, the average cost of electricity per dwelling was of €603.50, while gas was amounted to €106.80, again reinforcing the prevalence of electricity in Oporto.

8.3.2 – Equipment Simulation

Table 40 presents the summary of the obtained results, which reveal a high potential for energy total savings, ranging from 8.38% (case 4) to 46.57% (case 6), and with an average of 25% per dwelling. From the three scenarios, the nulling of stand-by and the adoption of more efficient lighting emerged as the most effective measures, as their costs are low or nil. Additionally, the large number of multimedia devices further justifies the potential of standby nulling.

The savings achievable specifically by each of these two measures are presented in table 40. The replacement of appliances with more efficient models is economically unattractive with an average return of investment ranging from 20 to more than 50 years. Hence, an equipment upgrade should best be done when their lifecycle finishes and substitution has to be considered.

		Potential Savings						
Variant	**Case**	**Total (kWh/year)**	**Total (€/year) 2013**	**Total (%)**	**Lighting (kWh/year)**	**Lighting (€/year) 2013**	**Standby (kWh/year)**	**Standby (€/year) 2013**
V3b mid	Case 1	404.58	69.91	17.89	78.84	13.62	70.22	12.14
V3b top	Case 2	1152.62	199.17	18.85	263.44	45.51	222.70	38.49
V3a top	Case 3	726.05	125.46	27.04	246.54	42.60	79.28	13.70
V4 top	Case 4	322.93	55.80	8.38	0.00	0.00	22.38	3.87
V4 mid	Case 5	1215.57	210.05	20.46	442.85	76.52	214.42	37.05
V3a mid	Case 6	1877.81	324.49	46.57	290.37	50.17	148.30	25.63
V2 mid	Case 7	586.60	101.36	29.09	141.96	34.44	67.90	10.83
V1 top	Case 8	737.89	127.51	42.25	251.33	44.64	83.28	14.35
V2 top	Case 9	455.96	78.79	31.03	166.73	31.48	31.67	5.99
V1 mid	Case 10	328.68	56.80	16.81	35.04	6.06	42.00	7.26

Table 40 - Potential savings from the appliances simulation results

8.3.3 – Dynamic Simulation

The results obtained from the dynamic simulation are summarised in table 41, showing the potential savings achievable from each design scenario[68]. The same results are graphically presented in figure 76, showing the percentage of variation from the baseline obtained. The results reveal variable patterns and the savings were generally lower than the results achieved from the appliances simulation, reaching a maximum of 14% in energy and CO_2 reduction.

[68] - In the appendices include detailed information about the individual results of each solution, including the cost and payback analysis.

Furthermore, most of the scenarios only achieved savings of 2% and, in a few specific cases, the measures even aggravated the consumption. The comfort results presented higher variations, showing both improvements of 30% and decrements close to 20%. It is also remarkable that the comfort improvements were not directly related to the achieved energy savings, making it possible to verify that some low-saving scenarios resulted in a significant decrease in the percentage of dissatisfied people. This highlights the possibility of implementing some scenarios to reach acceptable thermal comfort, even if the results on energy savings and carbon cuts are not that significant.

The first two design scenarios simulated the draught proofing of windows and doors and the introduction of insulating film on the glazed elements (including skylights), which are both low-cost and easy to implement measures, often pointed out in the literature as being adequate for the energy efficiency improvement of traditional buildings (Changeworks, 2008; Drewe and Dobie, 2008; English Heritage, 2011; Ferguson, 2011; Rye and Hubbard, 2012). However, the results revealed low reductions in energy and carbon, with a maximum of 1.38% in the first scenario and insignificant percentages in the second. Consequently, the payback period for both scenarios was extremely long, even though the costs involved were relatively low. The comfort improved in all ten cases, achieving averages from 2 to 4%. Results are however very variable across the several building variants and mostly depend on the size of the glazed area and frames' crack length in each case. In some houses, decreases of 7.59% (case 1) and 7.44% (case 2) in the inhabitants' dissatisfaction were verified. Assuming that these dwellings do not present large loads of heating and cooling, it is possible to affirm that the results of design scenario one point to its effectiveness for improving comfort, despite the low energy savings. The introduction of insulation film resulted in most cases in very low upgrades, both in terms of energy and comfort.

The re-introduction of traditional internal shutters and/or the variations of their usage profile were simulated in scenarios 3a (closed at night and open during the day) and 3b (closed at night and open during the day in winter and the inverse in summer). For the same reason as in the previous design scenarios, the results in energy conservation improvement and carbon cuts were negligible, with average percentages below 1% in most cases. Consequently, the return of the investment period is extremely long. In terms of comfort, a reduction of the PPD from 2.82 to 11.99%, with an average of 6%, was verified. Overall, the use of shutters revealed to be more effective in scenario 3b, highlighting the versatility offered by environmental control. Like in the previous scenarios, it can be concluded that these measures were mainly effective for the comfort improvement. Presumably, with higher heating and/or cooling loads, the four previous scenarios could increase their effectiveness.

Scenarios 4 and 5 directly addressed domestic water heating. The first of these solutions applied a reduction in the water temperature of 5°C. As there are no costs involved in this, its effectiveness was high, even if the savings did not surpass 242.8 kWh/year (€41.96), corresponding to a decrease of 3.79% from the reference consumption. The second scenario retrofitted the electric hot water cylinder with a 100mm insulation jacket, achieving slightly higher savings, which reached a maximum of 6.69% (428.8 kWh/year and €74.10). Nevertheless, the average savings obtained in these two scenarios reached respectively circa 2% and 3.5% in a year, with an average pay-back period of seven months in case 5. Naturally, these solutions are closely related to the number of occupants in the dwelling, a variable that directly determines the savings and pay-back period, with more densely occupied houses obtaining higher gains.

The design scenarios 6 and 7 explored upgrading the glazed elements through the introduction of double and secondary glazing, respectively. These are also solutions widely pointed out in the literature and explored by Baker in the improvement of traditional sash windows (2010). Based on the large area of glazed elements present in Oporto's traditional buildings' facades and skylights, the local literature addressing this subject also reinforces these solutions as potentially efficient (AdEPorto *et al.*, 2010; Restart Project, 2000). The technical difficulty of introducing these additional elements to the existing frames without prejudicing the image of the traditional buildings is also widely stressed in the literature. Therefore, these solutions must be assessed casuistically to verify their design compatibility and impact on the building's visual integrity. A conservative approach was taken in the simulations by using light and cheap solutions available in Portugal, which averagely improved the U-values to 3 and 2.8 W/m^{2}K, from the initial 4.6 W/m^{2}K. The thermal conductivity improvements obtained from the two types of solutions reveal that secondary glazing is slightly more effective. The energy savings confirmed this pattern, but like in the previous scenarios the energy consumption profile leads to small gains, reaching a peak of 2.76%. However, the improvement average is lower than 1%, which once again makes these two scenarios economically unattractive. The comfort indicator also confirms the previous patterns, performing 8.13% better than the baseline. The results are however very variable, presenting negative and positive values in both solutions, which prevents reaching a clear conclusion about the most effective scenarios.

Case	Indicators	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 8b	Scenario 9	Scenario 10	Scenarios 1, 4 and 5	Scenarios 1, 4, 5, and 3	Scenario Solar DHW	Scenario Solar DHW and scenario 4
Case 1	Energy (kWh/year)	0.30	0.30	0.30	0.30	121.10	157.60	0.30	0.30	0.30		0.30	0.30	251.70	251.70	373.00	449.10
	CO2 (kgCO2)	0.00	0.00	0.00	0.00	28.00	36.00	0.00	0.00	0.00		0.00	0.00	58.00	58.00	85.00	103.00
	PPD (Mean %)	-0.09	0.01	0.01	0.93	0.00	0.01	0.25	0.17	-0.01		0.01	0.39	-0.09	-0.08	0.00	0.00
Case 2	Energy (kWh/year)	21.10	3.00	63.20	72.50	242.80	428.80	92.50	81.40	75.70	52.30	138.70	321.60	638.50	709.90	733.00	898.90
	CO2 (kgCO2)	5.00	1.00	15.00	17.00	56.00	98.00	22.00	19.00	18.00	12.00	32.00	74.00	146.00	163.00	169.00	206.00
	PPD (Mean %)	-0.60	-0.05	-2.99	2.22	0.00	0.00	-1.14	-1.53	-0.36	-0.27	-1.94	-5.01	-0.60	1.66	0.00	0.00
Case 3	Energy (kWh/year)	21.40	-0.30	31.40	18.00	201.20	346.00	3.30	26.80	16.30	16.30	36.40	36.30	524.00	555.90	618.90	762.40
	CO2 (kgCO2)	4.00	-1.00	7.00	4.00	46.00	79.00	0.00	6.00	3.00	3.00	8.00	8.00	119.00	127.00	141.00	174.00
	PPD (Mean %)	0.56	-0.01	0.88	1.62	0.00	0.00	0.17	0.78	0.84	0.82	4.00	3.99	0.56	1.62	0.00	0.00
Case 4	Energy (kWh/year)	61.60	2.60	58.50	33.50	115.10	160.30	67.80	121.90	82.20	80.80	422.70	422.70	311.40	365.20	459.10	515.30
	CO2 (kgCO2)	14.00	1.00	14.00	8.00	26.00	37.00	16.00	28.00	19.00	19.00	97.00	97.00	71.00	84.00	105.00	118.00
	PPD (Mean %)	-0.18	-0.01	-0.83	1.95	0.00	0.00	0.01	-0.33	0.19	0.16	-3.72	0.00	-0.18	-1.03	0.00	0.00
Case 5	Energy (kWh/year)	66.20	0.00	0.20	0.00	242.20	393.80	-0.30	66.20	5.20			4.80	648.30	645.20	735.40	900.90
	CO2 (kgCO2)	15.00	0.00	0.00	0.00	55.00	90.00	0.00	15.00	1.00			1.00	148.00	147.00	168.00	206.00
	PPD (Mean %)	2.54	0.07	-1.52	0.00	0.07	0.07	0.14	2.72	-0.06			0.00	2.54	0.98	0.00	0.00
Case 6	Energy (kWh/year)	41.00	0.50	0.00	-15.40	80.00	103.40	8.50	57.40	3.20			7.40	206.50	210.10	238.40	284.10
	CO2 (kgCO2)	10.00	0.00	0.00	-3.00	19.00	24.00	2.00	13.00	1.00			2.00	47.00	48.00	55.00	65.00
	PPD (Mean %)	0.57	1.04	0.00	2.09	1.01	1.01	0.00	1.52	0.94			1.37	0.57	0.74	0.00	0.00
Case 7	Energy (kWh/year)	4.10	0.10	13.90	10.90	41.80	26.90	4.60	9.80	-0.30			20.60	63.60	66.50	87.50	108.60
	CO2 (kgCO2)	1.00	0.00	3.00	3.00	10.00	6.00	1.00	2.00	0.00			5.00	15.00	15.00	20.00	25.00
	PPD (Mean %)	-0.05	0.43	-0.91	1.02	0.44	0.44	0.25	-0.38	0.38			1.40	-0.05	0.00	0.00	0.00
Case 8	Energy (kWh/year)	18.00	0.50	59.20	-41.70	9.50	-71.40	-36.70	0.00	20.60	359.40		138.40	-45.70	-45.70	-57.80	-54.40
	CO2 (kgCO2)	4.00	0.00	13.00	-10.00	2.00	-17.00	-9.00	0.00	4.00	82.00		31.00	-11.00	-11.00	-14.00	-13.00
	PPD (Mean %)	2.27	2.24	2.78	3.62	2.24	2.24	2.10	0.00	2.11	4.03		1.63	2.27	2.27	0.00	0.00
Case 9	Energy (kWh/year)	0.00	0.00	0.00	0.00	18.70	-144.30	0.00	0.00	0.00	0.00	0.00	0.00	-133.80	-133.80	-12.60	-5.00
	CO2 (kgCO2)	0.00	0.00	0.00	0.00	4.00	-34.00	0.00	0.00	0.00	0.00	0.00	0.00	-31.00	-31.00	-3.00	-1.00
	PPD (Mean %)	1.33	0.00	0.88	0.75	0.00	0.00	0.22	1.71	0.90	1.13	0.00	0.57	1.33	2.20	0.00	0.00
Case 10	Energy (kWh/year)	0.00	0.00	0.00	0.00	68.00	72.40	0.00	0.00	0.00			0.00	125.30	125.30	239.10	268.00
	CO2 (kgCO2)	0.00	0.00	0.00	0.00	16.00	17.00	0.00	0.00	0.00			0.00	29.00	29.00	55.00	61.00
	PPD (Mean %)	0.01	0.01	0.00	0.75	0.00	0.00	0.23	0.26	-0.02			0.35	0.01	0.75	0.00	0.00

Table 41 – Potential savings from thermal simulation results

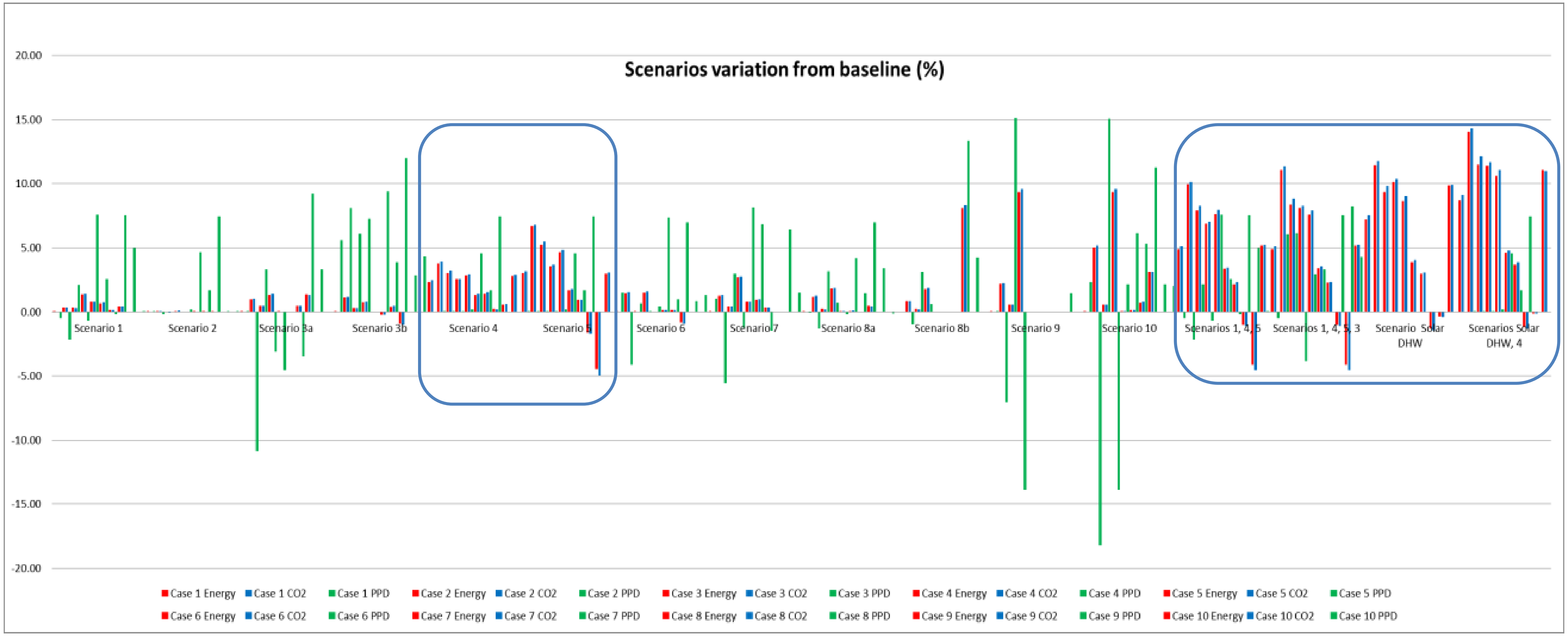

Figure 76 – Energy, CO_2 and PPD percentage variations from the baseline

The next two scenarios simulated the introduction of insulation in the floor/ceiling systems (8a) and roofs (8b). The simulated insulation was mineral wool with a thickness of 50mm, inserted under the floor or between the rafters, following the recommendations in the literature , which points to their lower cost, easiness of application and compatibility with the traditional buildings' breathability (Changeworks, 2008; English Heritage, 2011; Richarz *et al.*, 2007; Yates, 2006). The simulations also included the variations of loft and warm roof insulation, depending on the situation identified for each case study. The Oporto energy agency guidance also stresses roof insulation as one of the best measures to address upgrading the energy efficiency of traditional buildings (AdEPorto et al., 2010). The results from these scenarios reinforced the previously identified patterns, revealing again low energy savings that remained under the 2% mark. These results, in conjunction with the relatively high cost of the measures, resulted in extremely high return periods. The comfort improved in most cases for an average of 1.83% and 4.06% in scenarios 8a and 8b respectively.

The external insulation of the walls was simulated in two different scenarios, addressing the insulation of party walls (scenario 9) and the insulation of all external walls, including the party walls, (scenario 10), which poses a high level of heritage constraints. From these, the introduction of insulation in party walls or back facades is argued in literature to pose lower limitations to heritage (AdEPorto *et al.*, 2010; Ferguson, 2011; Restart Project, 2000). The specific shape of Oporto's buildings favours the use of insulation in party walls, as they often are the biggest area of the envelope. Due to the cladding and the absence of granite architectural elements they have lower heritage and technical limitations. The second scenario can be highly intrusive to the building's integrity, as is consensually pointed out in the literature, where the use of dry-lining insulation is suggested alternatively. Rye *et al.* pointed out the advantages of internal wall insulation, which enhances the solar gains in winter by raising the temperature of the wall, allowing "more of the internal room heat to be retained for a longer period of time" (2012, p.46). The dry-lining insulation of Oporto's traditional buildings is problematic due to the internal granite salience of external windows and doors, whose thickness prevents the use of effective insulation. In addition, the rooms' dimensions will be compromised by the use of the conventional thick insulation. The use of technologically advanced thinner insulation (*e.g.* aerogel) is hardly commercialised and applied in Portugal, rendering it expensive and non-effective in terms of cost. Another alternative was the introduction of 'Phase Change Materials' (PCM) in interior finishes, developed from Portuguese research which resulted in a very attractive cost effectiveness (Monteiro *et al.*, 2005; Sá *et al.*, 2012). However, the *IES VE* software presents severe limitations in modelling PCM materials, which likely would lead to low accuracy in the results (IES, 2010). The limitations led to the decision of not including these emergent solutions in detriment of more conservative and feasible approaches. Nevertheless, it can be affirmed that aerogel and PCM in plaster may become feasible solutions in the future and the results from the ongoing research should be monitored (BRE, 2012; Cartwright *et al.*, 2011; Energy Saving Trust, 2010; Ferguson, 2011).

The scenarios modelled refer to the inclusion of conventional 50mm and 25mm EPS boards, respectively in the party walls and the street facades. Case 6 was not insulated because the main facade was covered with tiles, which made the application impossible. The first scenario was simulated in five cases, where the exposed party walls allowed insulation, resulting in energy savings of respectively 5.14% and 9.58% in two top variants (cases 2 and 4), but were insignificant for the remaining three cases. The second scenario presented a similar pattern, showing a slight saving (3.14%) for case 8. The obtained economic gains were directly conditioned by the size of the area of insulation, which resulted in large investments and in low economic benefits for all cases. The comfort outcomes revealed an irregular pattern, with a tendency for inverting the energy and carbon outcomes.

Two additional composite scenarios were simulated by combining the previously identified most effective measures addressing the DHW improvement with other scenarios of easy implementation. The first of these simulations combined scenarios 4 and 5 (DHW) with the draught proofing of windows and doors, aiming to improve the general comfort (scenario 1). The other scenario added the use of internal shutters to the aforementioned, using the most effective scenario for each case (3a or 3b), while also aiming at additional improvements in comfort. The energy and carbon outcomes confirmed the pattern previously verified for each individual scenario, achieving cuts from 2.16% to 10.14% in the first simulation, and from 2.31% to 11.32% in the second. Cases 8 and 9 were the exception in both simulations, showing increased energy consumptions. From these results, a slightly better improvement was obtained for the second scenario. Inversely, the payback period of the first scenario was more advantageous, which can be explained by the cost associated with the re-introduction of shutters in the cases where they had been removed, consequently increasing the average return of investment period from 2.8 to 19 years. The comfort measurements did not significantly change the results' framework, being higher in the second scenario with a peak improvement in case 9 (8.24%).

Despite the heritage constraints posed by the introduction of solar panels, two additional scenarios were modelled using them to enhance the DHW. The first of these scenarios merely introduced a solar thermal system, while the second conjugated it with a reduction of the hot water temperature (scenario 4). The objective was to test the effectiveness of a wide-spread energy efficiency improvement measure for the buildings (English Heritage, 2011; Ferguson, 2011; Richarz *et al.*, 2007; Yates, 2006). Furthermore, this is a mandatory improvement under the Portuguese thermal regulation and subject of specific concern on the thermal improvement guidance for Oporto's traditional buildings (AdEPorto *et al.*, 2010). The first scenario reduced the energy consumption by 7.9% on average, reaching up to 9.4% when combined with a reduction of the hot water temperature. From an economic perspective, the savings achieved do not compensate the investment necessary to pay the solar system installation, with payback periods above 25 years. The analysis of comfort is not applicable in solutions addressing the DHW because they do not affect people's thermal sensation.

The data graphically presented in figure 76 clearly shows that the design scenarios directed at DHW upgrade are the most effective in terms of energy savings and carbon dioxide emissions reduction. From these, heating water with solar energy presents the highest reductions

8.3.4 – Future Weather

To evaluate the performance of Oporto's traditional buildings, predicted climate changes and respective adaptation have to be taken into account and as such a future weather scenario was simulated (year 2080). The weather file was created using the *CCWorldWeatherGen* software tool developed by the *Sustainable Energy Research Group* from the University of Southampton (2012), which morphed the original Oporto weather file using the IPCC HadCM3 climate change scenario data. The dynamic simulation outputted an increase of 3.39°C in the yearly mean temperatures (figure 77). The same pattern was identified when comparing the minimum and maximum peak temperatures, which increased by 2.30°C and 8.30°C respectively, confirming the forecasted tendency for higher temperatures and peak weather events.

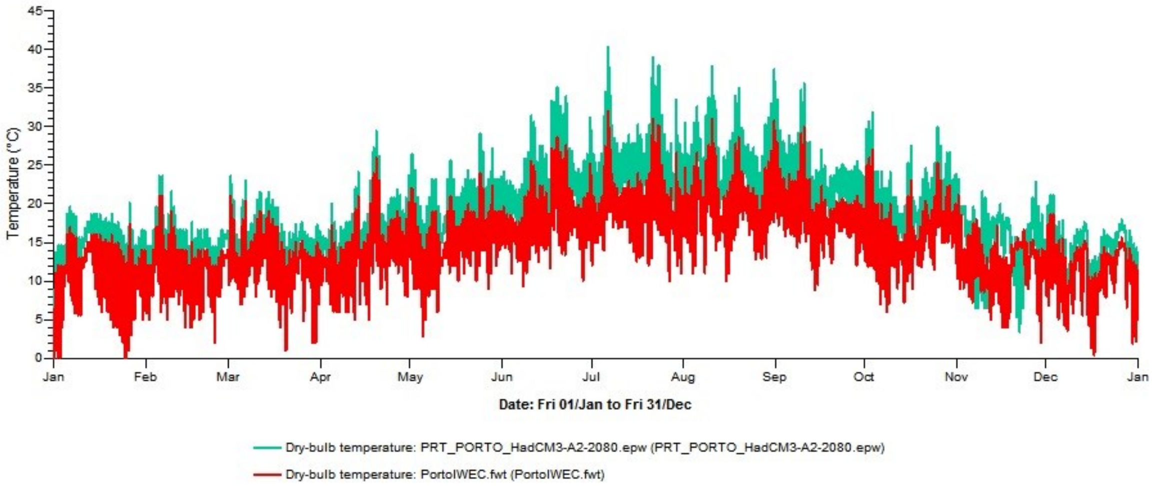

Figure 77 - Comparison between yearly dry-bulb temperatures in Oporto baseline and future weather 2080 simulations, using the *IES VE PRO* software

Variant	Case	Indicators	Baseline	Scenario Future 2080	variation
V3b	Case 1	**Energy**	5177.6	5088.00	**1.73**
mid		**CO2**	1131	1111.00	**1.77**
		PPD	16.63	25.90	**-55.77**
V3b	Case 2	**Energy**	6412.6	6062.90	**5.45**
top		**CO2**	1440	1360.00	**5.56**
		PPD	27.49	41.68	**-51.60**
V3a	Case 3	**Energy**	6632.9	6506.40	**1.91**
top		**CO2**	1437	1409.00	**1.95**
		PPD	26.49	24.60	**7.12**
V4	Case 4	**Energy**	4522.5	4136.30	**8.54**
top		**CO2**	1013	925.00	**8.69**
		PPD	26.75	36.62	**-36.88**
V4	Case 5	**Energy**	8495.3	8481.10	**0.17**
mid		**CO2**	1863	1860.00	**0.16**
		PPD	33.42	38.75	**-15.94**
V3a	Case 6	**Energy**	6178.3	6098.00	**1.30**
mid		**CO2**	1360	1341.00	**1.40**
		PPD	22.29	28.26	**-26.78**
V2	Case 7	**Energy**	2948.1	2794.20	**5.22**
mid		**CO2**	650	615.00	**5.38**
		PPD	26.29	36.29	**-38.04**
V1	Case 8	**Energy**	4433.7	3557.10	**19.77**
top		**CO2**	988	788.00	**20.24**
		PPD	30.17	31.53	**-4.49**
V2	Case 9	**Energy**	3229	3231.00	**-0.06**
top		**CO2**	684	684.00	**0.00**
		PPD	26.63	23.34	**12.35**
V1	Case 10	**Energy**	2427.1	2427.10	**0.00**
mid		**CO2**	555	555.00	**0.00**
		PPD	17.43	25.92	**-48.71**

Table 42 – Comparison between energy, CO_2 and PPD indicators in baseline and future weather design simulation (Year 2080)

In table 42, the results from the baseline simulation were compared with the 2080 weather simulation. A decrease in the energy consumption and associated CO_2 emissions is clearly identifiable in almost all cases. In contrast, the PPD aggravates in all dwellings, except for two. The energy and carbon savings are more expressive in the top cases, while the comfort decrease is transversal without revealing a specific pattern. A more detailed look at the results, confirms that the energy spent on space conditioning and DHW decreases or remains stable in all cases. As space conditioning refers to heating only, it becomes clear that the energy systems related to heating are directly influenced by the new temperatures. The modelled cooling equipment, which was only composed of electric fans, revealed an opposite pattern, with all cases increasing or maintaining (systems with no fan) their energy consumption. A decrease in comfort is a direct consequence of the weather changes. However, even with a worsened performance, the PPD still remains lower than 45%, with around 30% in most cases.

8.3.5 - Heritage Impact Assessment

In the context of this research the previous measures addressing the stand-by mode, appliances and lighting, are clearly innocuous in terms of their heritage impact. Using ICOMOS assessment grading, they can be classified as 'neutral' because they produce "no change to fabric or setting" (2011, p.9), as listed in table 43. These measures will prove effective for existing buildings, independently of the heritage factor. Hence, under the scope of this research they can be neglected because they have no impact on the heritage of traditional buildings and are generic and applicable in any energy efficiency operation. They will only be accounted for in the evaluation of energy and CO_2 improvements.

Scenario	Measure	Impact on Fabric (+3 to -3)	Impact on visual integrity (+3 to -3)	Impact on site (+3 to -3)	Overall impact (+3 to -3)
1	Nulling equipment standby	0	0	0	0
2	Replace existing lamps with more efficient CFL	0	0	0	0
3	Replace existing equipment with more efficient models	0	0	0	0

Table 43 – Heritage impact assessment of the equipment simulation design scenarios

The dynamically simulated design scenarios pose a wider range of impacts on heritage, either adverse or beneficial, as presented in table 44. Using the 'professional judgement' (ICOMOS, 2011) and based on the previous elements of the research and city heritage management instruments, the scale of change was identified for each scenario and graded accordingly[69]. The judgement process relies mainly on the previous analysis regarding the heritage impact of concrete situations identified in Oporto's historic centre, as explained in chapter seven. The benchmark is made accordingly with the impact produced on the fabric, visual integrity, townscape and the overall impact from the previous three.

The 'beneficial' and 'neutral' impacts of the measures can be neglected under the scope of the current research, as they do not present constraints from heritage perspective. Consequently, their feasibility must be measured by their efficiency under the remaining parameters. On the other hand, solutions that reveal to have a 'very large' adverse impact, like the solar panels in the current research, cannot be accepted regardless of their proven efficiency under the other indicators. In between these two extremes resides the major challenge, represented by the measures which range from 0 to -2 of potential risk. This means that the process is driven by a maximum admissible limit of change regarding heritage. Under this limitation, the other indicators have to be assessed to identify the effectiveness and overall feasibility of the solutions. The most expressive example for traditional buildings in Oporto is the limitation to insulate the exterior walls due to the windows granite casing (figure 78). Because of this limit, the insulation must be evaluated against the energy, CO_2, cost and comfort parameters in order to measure its effectiveness. This weighting process means that if the insulation proves to be ineffective, it becomes unfeasible even if it respects the set heritage limit. Moreover, and despite the exemplified impact on visual integrity, the other levels must also be cumulatively assessed (fabric and townscape). Returning to the same example, the impact on the fabric must also be verified, and it must be validated if the introduction of the insulation poses a compatibility issues with the existing wall.

The determination of the 'limit of change' is then the next, crucial step in evaluating the feasibility of any energy efficiency improvement measure. It is naturally dependent on preserving the identified fundamental elements in the traditional buildings that give significance to both the building and for the entire World Heritage Site. In this sense, traditional buildings must be evaluated independently of their type or geographical location in terms of what can be called 'Group Impact Significance'. For the simulated scenarios, the limits of change were identified based on the elements identified in chapters six and seven. This

[69] - In accordance with the method identified in chapter five.

'professional judgement' approach was coincident with the city regulations for the WHS management (PORTO VIVO, 2008; Portugal, 2012), which made the maintenance of the urban historic image mandatory. However, neither the city's urban planning nor the WH management plan specifically detail how to perform such maintenance, assigning the responsibility for it to council and heritage body technicians.

Scenario	Measure	Impact on Fabric (+3 to -3)	Impact on visual integrity (+3 to -3)	Impact on site (+3 to -3)	Overall impact (+3 to -3)
1	Draughtproofing windows and doors	0	-1	0	0
2	Improve single glazing with insulating film	0	-1	-1	-1
3a	Use of internal shutters	1	1	0	1
3b	Use internal shutters and change the profile	1	1	0	1
4	Reduce DHW temperature from 60° to 55° C	0	0	0	0
5	Upgrade DHW storage tank insulation (to 100mm)	0	0	0	0
6	Introduce double glazing	0	-1	-1	-1
7	Introduce secondary glazing	0	-1	0	0
8a	Introduce insulation in floors and ceilings	-1	0	0	0
8b	Introduce insulation in roofs	-1	0	0	0
9	Introduce exterior insulation in party walls	-1	-1	-1	-1
10	Scenario 9 + introduce exterior insulation in facades	-2	-2	-1	-2
1_4_5	Composite scenario (1, 4 and 5)	0	-1	0	0
1_4_5_3	Composite scenario (1, 4, 5 and 3)	0	-1	0	0
Solar Thermal	Introduction of solar thermal DHW	-1	-2	-3	-2
Solar Thermal and 4	Introduction of solar thermal DHW and scenario 4	-1	-2	-2	-2

Table 44 – Heritage impact assessment of the building dynamic simulation design scenarios

Figure 78 – Windows granite casing in a 19th century traditional building (in ruins) in Oporto

In table 45, the limits of change identified for the simulated design scenarios are listed. Conclusively, it is possible to affirm that the limits of change must be driven by maintaining the visual integrity and authenticity (building and townscape), the compatibility with the fabric (traditional building systems) and the reversibility of the solutions.

Scenario	Measure	Limit of change
1	Draughtproofing windows and doors	Strips should not be visible
2	Improve single glazing with insulating film	Image of the glass should not change
3a	Use of internal shutters	Not applicable
3b	Use internal shutters and change the profile	Not applicable
4	Reduce DHW temperature from 60° to 55° C	Not applicable
5	Upgrade DHW storage tank insulation (to 100mm)	Not applicable
6	Introduce double glazing	Design of the frame should not change
7	Introduce secondary glazing	Exterior image of the frame should not change
8a	Introduce insulation in floors and ceilings	Ceiling plaster mouldings and wood floor should not be damage
8b	Introduce insulation in roofs	External image of the roof should not change
9	Introduce exterior insulation in party walls	External image of the building should not change
10	Scenario 9 + introduce exterior insulation in facades	External image of the building should not change
1_4_5	Composite scenario (1, 4 and 5)	Strips can not be visible
1_4_5_3	Composite scenario (1, 4, 5 and 3)	Strips can not be visible
Solar Thermal	Introduction of solar thermal DHW	External image of the roof should not change
Solar Thermal and 4	Introduction of solar thermal DHW and scenario 4	External image of the roof should not change

Table 45 – The limit of change identified for simulated design scenarios

8.4 - Conclusion

Overall, the models were revealed to be accurate enough for the purpose of the research, and allowing adequate measuring of the potential savings in energy, carbon emissions, cost and comfort in traditional buildings. However, the use of on-site measurements can significantly improve the accuracy of the models and must be performed in future research.

From the analysis of the scenarios it can be concluded that the low-cost solutions, such as stand-by nulling and light bulb **replacement, presented highest** efficiency, as they are non-intrusive in terms of heritage and presented feasible pay-back periods. From the dynamic simulation, it was possible to conclude that the measures addressing water heating revealed higher efficiency for energy savings and carbon cuts (scenario 4 and 5), and are also innocuous in terms of heritage disruption. The envelope upgrade approach, which is usually pointed out to be a highly effective measure, was in this case revealed to be ineffective for reducing the energy consumption as well as potentially endangering the heritage value of traditional buildings. The most effective measures were ‘low cost’, based on the occupants’ behaviour and on simple interior retrofit.

The assessment of the measures’ heritage impact affirms that the introduction of solar panels and/or external insulation in main facades will likely produce high negative impacts at building and World Heritage Site level. Improvements to the window frames present a relatively low risk, but their design must be monitored to avoid negative impacts at all levels. It is important to stress that the used solutions were conventional in order to improve their feasibility of implementation. The use of specific solutions may produce different results, depending on their concrete design. Furthermore, some of solutions may suffer technological and design advances that can produce changes for their future evaluation.

The future weather scenario highlighted that the traditional buildings’ thermal mass is an advantage when dealing with the predicted increase in temperatures during the day. The challenge is to avoid overheating during the night by promoting adequate nocturnal ventilation and avoiding thermal distress. During the direct contact with the householders and through the simulation, it was identified that some of the behavioural measures are already being implemented to effectively address this problem. By combining windows and shutters control (closed during hot days and open in hot nights), some householders are already achieving good comfort results.

Chapter Nine: Energy Efficient Measures in Traditional Buildings

Chapter Nine: Energy Efficient Measures in Traditional Buildings

9.1 - Introduction

In the current chapter the results of the previous chapters are discussed. It will conclude with establishing which are the most effective measures to improve energy efficiency in Oporto's traditional buildings without negative impacts on their heritage significance. For this the results will be discussed by comparing them with the frameworks identified in the early chapters. This will allow benchmarking their current performance and identifying the most efficient measures.

The prospects and outcomes from implementing these measures at the research area level are also approached. From this discussion, the main findings of the research will be highlighted in regards to the traditional buildings in the Oporto World Heritage Site. The applicability of these findings outside of the research area as well as major strengths and limitations will also be discussed.

9.2 – Energy Efficiency Measures for Oporto's Traditional Buildings

The surveyed case studies revealed the 'inside' of traditional buildings in the Oporto World Heritage Site, which allowed establishing their performance based on real data. The simulation permitted identifying the measures that yielded the most efficient results to improve the energy efficiency of Oporto's traditional buildings. These measures need to be discussed from an overall perspective to allow further conclusions under the framework of traditional and historic buildings. This includes putting the results in comparison with the previously identified literature and with the results from similar research. Accordingly, both the results from the baseline study and from the simulations will be discussed.

9.2.1 – Baseline Performance

Energy

In table 46 the baseline models (equipment and dynamic) are compared with the national (INE and DGEG, 2011) and Oporto energy survey (AdEPorto *et al.*, 2008). The values are not directly comparable, due to the dissimilar categorisation of energy consumptions used. To facilitate the comparison, similar categories were grouped together in the table. The classification in 'DHW' and 'lighting' is commonly used, while classifying 'heating' and 'cooling' as two separate parameters is a debatable decision due to the low significance of energy used for cooling in Portugal. The remaining categories are uncertain as they refer to different energy uses: cooking, electric equipment, appliances, entertainment, domestic refrigeration and LPG equipment, which are partially interrelated and sometimes overlap. In the last column, the category of 'cooking and equipment' was added to facilitate comparison.

National energy survey (2010)	Heating	Cooling	DHW	Cooking	Electric equipment		Lighting	Cooking + equiment
% of total energy consumption	21.5	0.5	23.5	39.1	10.9		4.5	50
Oporto energy survey (2004)	Heating		DHW	Cooking	Domestic refrigeration	Others	Lighting	Cooking + equiment
% of total energy consumption	28		23	27	11	7	4	45
Thermal simulation	Space conditioning		DHW	LPG equipment	Electric equipment		Lighting	Cooking + equiment
% of total energy consumption	8.4		27.81	33.31	28.34		2.14	61.65
Appliances simulation	Heating	Cooling	DHW	LPG equipment	Appliance	Entertainment	Lighting	Cooking + equiment
% of total energy consumption	20.17	0.26	7.29	34.91	20.8	8.4	8.17	64.11

Table 46 – Compared mean energy consumption between simulations, national and Oporto energy surveys

Using this table, it is possible to verify that the results were not entirely coincident. In general, the two surveys showed similar results, while the simulations presented some differences. However, it is necessary to consider some aspects which may explain these results. First, it is necessary to point out that the surveys that were conducted were designed for existing residential buildings in general and not specifically for traditional buildings. Secondly, the LPG consumption in the simulations was calculated from the estimates given by the householders, which may have been inaccurate and thus have changed the balance between the percentages in the total energy calculations. Nonetheless, it should be stressed that the LPG was only used for cooking and was not simulated, so it can be disregarded as it remains unchanged and does not affect the simulation results. The energy used for cooking and equipment is also influenced by this situation, making it very difficult to achieve detailed results. This category presented very similar results between the two surveys and between the two simulations, while at the same time showing a discrepancy of 10 to 15% between the surveys and the simulations. The appliances consumptions was derived from the direct surveys performed in the houses, which allowed obtaining a detailed control of the simulated data when compared with the thermal simulation, where the equipment was mainly incorporated to achieve the correct inputs for the internal gains. This consideration can also be applied to lighting, which was detailed based on the type of lamps and profiles named in the household's survey.

The energy consumption for the DHW was very similar in the surveys and in the thermal simulation while showing a discrepancy with the appliances simulation. However, the latter is a simplified mean day estimation that was disregarded against the dynamic simulation, which accounts for the complex variables interacting with the DHW system. For the same reason it was also decided to use the results presented in the thermal simulation for the space conditioning, even though their pattern was quite dissimilar from the other three. This can be explained by the overall performance that was identified for the traditional buildings. Moreover, the mean consumption achieved for space conditioning was influenced by the fact that three of the cases do not consume energy for this purpose. If these cases were to be disregarded, the mean consumption would reach 11.70% of the total energy.

In Portugal, residential buildings built before 1950 consume an average of 200 kWh/m^2, while the ones built between 1950 and 2005 consume an average of 140 to 110 kWh/m^2 (BPIE, 2011). Further data states that the most recent and efficient residential buildings (2006-2010) consume an average of 109 kWh/m^2 per year in Portugal (BPIE, 2012). The case studies representing the most common building variants (V3a and V3b) were in the survey (real data) revealed to have average consumptions below these values, ranging from 63.94 to 97.59 kWh/m^2. It must be stressed that the most recent buildings were built according to post-thermal regulations, which made the use of insulation and solar panels for domestic water heating mandatory.

The small floor area of some dwellings can bias the results, as can be seen in case 7, where the 138.75 kWh/m^2 consumed per year were directly influenced by its extremely reduced area (22.70m^2). When analysing case 7's yearly consumption per person, the result reveals a regular value of 1,574.85 kWh, which is very close to the average consumption verified in ten cases (1,734.6 kWh per year/person). Nevertheless, these consumptions are again much lower than the average of 3,067.66 kWh that was identified for Portugal in 2011 (Eurostat, 2013; INE, 2012). Of all the dwellings studied, only case 5 presented a yearly consumption above the national average (4,446.68 kWh/person). This may be explained by the significant remodelling of this property, where only the original exterior walls were maintained. These works introduced new construction systems regardless of their compatibility with the existing structures; namely the replacement of the original wood beams by a concrete structure, and the substitution of the lath and plaster partitions by hollow brick and gypsum plasterboard. After the refurbishment, the general feeling expressed by the householders was that the buildings worsened their performance in relation to the original situation. This highlights the idea that a careless or unconscious refurbishment made with inadequate materials can deteriorate the performance of traditional buildings.

From these results it can be affirmed that the surveyed traditional buildings in Oporto perform better than the expected in terms of energy consumption. The surveyed values were not only below the European and Portuguese averages for residential buildings, but they were also close to the values that have been verified for the most recently built buildings. The baseline data also reinforces the prevalence of electricity in Oporto, as the gas consumption in all cases was below the national average. The inverse can be observed for the electricity consumption, where only four cases present average values below the national rates.

In terms of the cost spent on the energy per dwelling, the average for the ten cases was €710.30 per year, which again is below the national average (€840.00), further confirming the identified consumption pattern (INE and DGEG, 2011).

By taking into account all the initial data, the energy consumption can generally be explained both by the building's thermal performance and by the low use of energy for space conditioning. The mild Portuguese climate and the cost involved may justify the usual absence of central systems, as demonstrated in the previous chapters. This explains the low energy consumption when compared with the standards promoted by the thermal regulations, which usually benchmark energy efficiency based on heating, cooling and DHW demands in relation to a theoretical pattern of use and a fixed model of comfort.

Comfort

It may be argued that the low income of these households could explain the low energy consumption, which may be achieved in at the cost of thermal comfort. However, the householders reported a reasonable overall comfort pattern, suggesting that the reasons for the identified consumption are not entirely related to socio-economic factors.

Comfort was overall reasonable in all the ten cases, with the mean PPD of the living areas remaining under the peak result of 35%. Naturally, this can be partially explained by the mild weather conditions of Oporto and concurrently by the buildings' performance in relation to the local climate. The results do not clearly point to an extraordinary high thermal performance of these buildings, but to a centennial symbiosis between a building's fabric and the local climate, which permits achieving a balance between the desired comfort (adaptive) and the space conditioning, which is then used to compensate the peak situations.

By cross referencing the data sources, it can be concluded that comfort was not identified as a major problem in the case studies, which consequently renders a higher investment in energy for heating and/or cooling unnecessary. This confirms the general tendency for Portugal and Oporto, where cooling was identified as irrelevant and heating represented around 20% of the global domestic sector energy consumption (AdEPorto *et al.*, 2008; INE and DGEG, 2011). This also is apparent in the surveyed case studies, and is further confirmed in the domestic energy surveys for Portugal and Oporto (AdEPorto *et al.*, 2008; AdEPorto and UCP, 2011; INE and DGEG, 2011), where cooling systems are inexpressive and heating is mostly performed by space-based individual devices instead of central heating systems.

The European statistics reinforce this framework, as they show that the household energy consumption by end-use in the EU-27 for space heating accounted for an average of almost 70% in 2009 (EEA, 2012). A survey undertaken in the UK domestic sector by Yohanis, revealed that of the 240 sampled homes, 99% have some form of central heating system, on which a third of them relies for heating entirely (2012). Moreover, in 72% of the sampled houses, the domestic hot water was provided by the central heating systems. These results also highlight the existing disparity between the domestic energy usage in the northern European and in the Mediterranean climates, as shown in the European energy statistics, where Spain and Cyprus were the countries with the lowest consumption of energy used for space heating[70] (EEA, 2012). This also points out that the use of centralised systems is efficient in colder climates with a greater number of heating degree days, while their effectiveness decreases in milder climates. In the case studies, the occasional use of portable heating devices, associated directly with the space occupation pattern, reveals to be much more flexible and consequently more adequate to satisfy the household's needs.

[70] - No data was available for Portugal and Malta.

Not many studies on energy efficiency upgrading of traditional buildings report on comfort improvements. Only partial aspects of comfort or generalised unspecific comfort perceptions are usually given. Draught-proofing and upgrading of glazed elements are generally stressed to be proven measures, to improve airtightness and consequently raises comfort levels (Changeworks, 2007; Changeworks, 2008; Energy Saving Trust, 2010). The most commonly used criteria for comfort in the reviewed literature was the improvement of the indoor temperature. Thus, improving comfort is generally related to the maintenance of temperatures in a fixed comfort range, ordinarily defined as values between 19°C and 25°C. These are the values which drive the calculation of heating and cooling demands on the steady state models. The dynamic models allow interacting with several complex variables in a flexible way, leading to more accurate results as with the simulations performed in the IES VE software.

Conclusively, it is possible to affirm that the low energy consumption detected in traditional buildings in Oporto reflects the balance between the actual levels of comfort and the low heating demand. The relatively favourable existing baseline also explains why the simulated design scenarios do not significantly influence the comfort level.

9.2.2 – Measures Simulations

The results obtained from the Oporto design scenarios simulation affirm the following: regarding the reduction of energy consumption, the DHW, equipment and lighting are effectively the major areas of potential and feasible improvement. Inversely, measures which focused on the retrofit of the construction systems revealed to be ineffective overall. This includes envelope insulation, which is widely established in the literature as the major focus of energy efficiency upgrades.

Behavioural Measures

The simulations addressing the behavioural approach showed a high efficiency, in particular for low-cost measures like the upgrade of lighting and stand-by nulling. The results from this last measure verify the outputs of similar studies that were performed either in Portugal (Antunes, 2008; Ferreira *et al.*, 2011) or at a European level (REMODECE, 2008; SELINA, 2011). The Portuguese studies identified a potential energy saving of 5.1% in the domestic sector simply by not leaving devices in stand-by mode, and 2.6% by adopting more efficient lighting.

The averages identified in the 10 case studies were slightly lower and revealed an inverse trend with lighting presenting a higher potential (3.76%) than stand-by avoidance (1.78%). The high cost involved in upgrading the major appliances decreases their cost-effectiveness. However, as previously pointed out, this can be effective over the long term by relying on the behavioural choice when replacing the old models.

Fabric Measures

The results from the dynamically simulated design scenarios confirm and reinforce the influence of the Portuguese domestic energy consumption pattern. The relatively low use of energy in heating and cooling lead to small gains obtained from the energy conservation measures addressing the envelope upgrade. The DWH improvements revealed to be effective because they are less dependent on the climate, as proven by the fact that most European countries present a similar share of consumption in the energy statistics (EEA, 2012).

The glazed elements in the 10 cases represent on average 40% of the total area of the main facade (ranging from 25% to 51%). This expressive area highlights the importance of considering the upgrading of these glazed elements. The small gains obtained from the draught proofing of external windows and doors (maximum of 1.39%), verify the laboratory tests carried out by Baker (2010), which showed that if these measures were applied to traditional sash and casement windows, their U-value was only upgraded from 4.5 to 4.2 W/m^2K which was pointed out to be statistically insignificant. Nonetheless, the comfort improvement obtained in most of the case studies' simulation, allows concluding that it justifies the use of these measures.

The introduction of double and secondary glazing in the traditional windows allowed reducing the average U-values from the initial 4.6 W/m^2K to 3 and 2.8 W/m^2K respectively. This highlights the fact that the introduction of secondary glazing is slightly more effective than upgrading to double glazing. This also confirms Baker's results that use a single glazed traditional window (5.4 W/m^2K) as a starting point and achieved a heat losses reduction of 55% (1.9 W/m^2K) and 63% (1.7 W/m^2K) respectively by introducing double and secondary glazing (2010). Additionally, the results are also in line with the ones obtained in the Oporto guidance for the historic centre, which reduced the original U-value of 4.3 W/m^2K to 3.3 and 2.0 W/m^2K, proving once more that secondary glazing produces better results than double glazing (AdEPorto *et al.*, 2010). Conclusively, it must be pointed out that the consistency of the results is transversal through the case studies.

The increase of the airtightness obtained through glazing improvements is also pointed out by Baker (2010). However, the energy reduction from the design scenarios was again very limited, reaching an improvement average of less than 1%. Inversely, the comfort increased, achieving a maximum improvement of 8.13% from the baseline. Unlike the draught-proofing measure, the cost involved in upgrading the frames renders it unattractive, even despite the comfort improvement.

These results from the upgrade of the glazed elements vary from the ones obtained from the simulation conducted in a nineteenth century Scottish villa, where this retrofit solution was one of the best performing scenarios (IES, 2009). However, this again reinforces the role space heating has on the results, as this case was simulated by taking into account the large heating loads required in the Scottish climate.

The use of insulation in the envelope is widely promoted in the literature and the thermal regulations as one of the most effective measures. However, this was not verified in the simulations, where the insulation of roofs and walls achieved relatively low reductions for the energy consumption. The top saving value reached 9.58%, but the majority of the cases presented insignificant savings. These results, in conjunction with the high cost involved in the implementation of the measures, the heritage limitations, and the relatively reduced area of walls in the facades lead to the conclusion that the insulation of the envelope of traditional buildings in Oporto is a measure which is surprisingly ineffective. This is in contrast with the results obtained in the Oporto guidance, which presented an energy consumption reduction of up to 60% from the baseline situation (AdEPorto *et al.*, 2010). These results may be explained by the use of the standard steady calculation method promoted by the thermal behaviour regulation, which is based on fixed heating and cooling loads, which are not in line with the real-life behaviour verified in the surveyed case studies.

Nevertheless, it is again necessary to separately stress the energy savings obtained from improving the thermal behaviour of the fabric. While the first measure is ineffective, this second one confirms the expected improvements widely disseminated in the literature. The improvement obtained from insulating the case studies' external walls allowed to achieve average U-values of *circa* 0.54 W/m^2K from the original 2.28 W/m^2K. These values are very similar to the typical U-value reduction obtained in the Oporto guidance of 0.6 W/m^2K from the original 2.9 W/m^2K (AdEPorto *et al.*, 2010). The research undertaken by Rye *et al.* in the UK showed an analogous reduction pattern, obtaining a value of 0.16 W/m^2K, down from the original 1.24 W/m^2K in a granite wall (2012). This reinforces once again the idea that, when focusing on the strict fabric parameters, the obtained results revealed a transversal improvement.

Another widely promoted measure, the introduction of solar thermal panels, also presented lower savings than expected, with an average reduction in the energy consumption of 7.9%. This result is consistent with the simulation performed in the Oporto guidance, which achieved a reduction of 6% in the energy consumption through the use solar collectors by addressing 40% of the total DHW demand (AdEPorto *et al.*, 2010). When comparing the cost savings with the required investment, solar thermal systems lose their efficiency and attractiveness. Moreover and as previously argued, the consequences to Oporto's roofscape image caused by the massive use of solar panels are highly disruptive for the WHS authenticity. Additionally, the multifamily occupation identified in the case studies would result in a high demand of solar panels for each roof[71]. When taking into account all these factors, it can be concluded that solar thermal scenarios are not a viable solutions for the Oporto World Heritage Site.

Overall, the results reached with the simulated design scenarios are far below the ones that were obtained in several similar case studies on the retrofits that had been performed in traditional buildings in England and Scotland[72] (table 47). In the refurbishment of Victorian houses in the UK, Yates achieved energy cuts of 67% to 75% and carbon emissions reductions of 63% to 85% (2006). Similar results were obtained in the Sheffield *EcoTerrace* refurbishment (Energy Saving Trust, 2010), cutting 76% in carbon emissions and 60% to 81% in energy consumption (electricity and gas respectively).

It must be stressed, however, that these refurbishment case studies were profound and also included the installation of renewables and efficient central heating systems, which were revealed to be cost-effective under the high heating demand in the UK. It is necessary to

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[71] - The Portuguese thermal regulation (RCCTE) requires the installation of $1m^2$ of panel for each resident, given that it does not occupy more than 50% of the roof slopes facing south, southeast or southwest. This area was reduced to 10% in the Oporto historic site guidance (AdEPorto et al., 2010, p.36).

[72] - These case studies and the specific improvements performed are listed in the Chapter Four.

reinforce that without the high energy consumptions associated with heating and/or cooling, the possible savings will never meet the reported levels. The energy efficiency upgrade of the Edinburgh Georgian tenements produced results that were closer to the ones obtained in the Oporto case studies, with yearly average energy savings of 18.45% and CO_2 emissions cuts of 16.92% per flat (Changeworks, 2008). Despite the similar percentage of improvement obtained in relation to the baseline situation, the Oporto energy consumption presented values which demonstrate a different reality. Each Scottish flat consumed an average of 26,971.0 kWh per year, while in Oporto the dwellings consumed on average five times less (4,945.1 kWh/year).

Case Studies	Yates, 2006		Rye *et al.* 2012		Changeworks, 2008	Restart, 2000	Energy Saving Trust, 2010
	The Flagship Home Project, London	**The Nottingham Ecohome (2000)**	**The Firs, Devon (2012)**	**Mill House, Devon (2012)**	**Lister Housing Co-operative, Edinburgh (2007-2008) - each flat**	**CRUARB Office, Oporto (1996)**	**Sheffield EcoTerrace (2009)**
Savings	energy - 67%/year; CO2 - 63%/year	energy cost - 75%; CO2 - 85%	4% improvement in U-value of external wall	87% improvement in U-value of external wall	energy - 5000kWh/year; cost - £175/year; CO2 - 1 tonne/year	Simulated: heating - 20%; Cooling - 20%, lighting - 40%	electricity - 60%; Gas - 81%; Cost - 67%; CO2 - 76%

Table 47 – Literature case studies savings

Overall these results reinforce the conclusion that the energy used for space conditioning highly influences savings, both in terms of energy consumption and carbon emissions. Oporto's traditional buildings are actually relatively low in energy consumption due to their use pattern of heating and cooling. Hence, upgrades that aim to improve heat losses in the existing fabric are revealed to be cost ineffective and present low savings for energy consumption and carbon dioxide emissions. At the same time, their lack of effectiveness is a positive outcome from the heritage perspective, as envelope approach measures are more intrusive to a building's appearance.

Nevertheless, it should be considered that, disregarding the differences between climate zones and energy loads for space conditioning, a pattern of potential improvement emerges that confirms the role that these buildings may play in achieving climate change mitigation. Furthermore, a better performance than expected seems constant in all studies concerning traditional buildings, confirming that the current methods of calculation and thermal regulations must be adapted to overcome such gaps. This approach must focus on the built structure itself and on the real behavioural data. Moreover, the social perspective which is usually absent from energy efficiency objectives has to be inserted in the process when dealing with traditional and historic buildings located in the old depressed quarters. In these areas the savings are much more than mere indicators; they are real improvements to the people's living conditions. It is then necessary to consider this factor and use it to promote awareness among the residents. Additionally, it is also possible to point out some additional gains obtainable from the reduction of the carbon dioxide emissions by using natural gas instead of LPG. From an overall perspective it is important to reinforce the idea of promoting district solutions which can embark tri-generation and/or strategically placed renewables to overcoming their visual impact on heritage (*e.g.* geothermal and heat pumps).

It is important to point out that the scenarios which presented the best results were obtained in the variants 3a, 3b and 4. These are the most common across the research area (78% of all buildings), representing mid-terraced houses with one or two façades. This fact highlights the potential savings obtainable from a large scale implementation of the most effective design scenarios.

9.2.3 - Short-term and long-term scenarios

The detailed analysis of each simulated scenario allowed for determining the most feasible measures by crossing energy and carbon savings, cost effectiveness and comfort improvement. In table 48, table 49 and table 50 the most effective potential gains identified in the equipment and dynamic simulations are summarised. The diverse scenarios are reported by variant, which further allows calculating the potential savings achievable in the total research area based on the representativeness of each variant.

The design scenarios were classified as 'short-term' and 'long-term', based on their cost-effectiveness and their feasibility of implementation, similar to the approach taken by Yates (2006). This is verifiable in table 48 and table 49, where 'long-term' refers to the total possible savings obtainable from the equipment simulation, including the replacement of all non-efficient equipment. The short-term scenario reduces the scope, isolating the low cost and immediately applicable measures from the previous.

A similar approach was taken for the dynamic simulation scenarios, which were based on the DHW improvement measures identified as the most effective, to which the upgrade of the inner shutters was added. However, the analysis of the two scenarios revealed that the gains achievable by the second are negligible, even reaching negative values in some cases. For this reason, the final potential gains obtainable by merging the two simulations did not account for this last scenario. The comfort indicators did not reveal to be conclusive, as they presented both better and worse results than the short-term scenario. Moreover, the short-term scenarios simulated for cases 8 and 9 (table 50) presented negative outcomes, hence they were only accounted for in terms of comfort.

		Short Term Scenario							
Variant	Cases	Lighting savings (kWh)	Lighting saving (%)	Carbon Savings (kgCO2)	saving (€/year)	Stand-by savings (kWh)	Stand-by savings (%)	Carbon Savings (kgCO2)	saving (€/year)
V1 mid	case 10	35.14	1.80	8.03	6.07	42.00	2.15	9.60	7.26
V1 top	case 8	251.33	5.17	57.46	43.43	83.28	1.71	19.04	14.39
V2 mid	case 7	141.96	4.14	32.45	24.53	67.90	1.98	15.52	11.73
V2 top	case 9	166.73	3.60	38.12	28.81	31.67	0.68	7.24	5.47
V3a mid	case 6	290.37	4.71	66.38	50.18	148.30	2.40	33.90	25.63
V3a top	case 3	245.28	4.16	56.07	42.38	79.28	1.35	18.12	13.70
V3b mid	case 1	78.84	1.79	18.02	13.62	70.22	1.60	16.05	12.13
V3b top	case 2	263.44	3.67	60.23	45.52	222.70	3.10	50.91	38.48
V4 mid	case 5	442.85	4.82	101.24	76.52	214.42	2.33	49.02	37.05
V4 top	case 4	0.00	0.00	0.00	0.00	22.38	0.48	5.12	3.87

Table 48 – Potential savings from the equipment simulation regarding the yearly total energy in short-term scenarios

		Long Term Scenario			
Variant	Cases	Total savings (kWh)	Total savings (%)	Carbon Savings (kgCO2)	saving (€/year)
V1 mid	case 10	328.68	16.81	75.14	56.80
V1 top	case 8	737.89	15.19	168.69	127.51
V2 mid	case 7	586.60	17.12	134.10	101.36
V2 top	case 9	455.96	9.85	104.24	78.79
V3a mid	case 6	1877.81	30.44	429.29	324.49
V3a top	case 3	726.05	12.32	165.98	125.46
V3b mid	case 1	404.58	9.20	92.49	69.91
V3b top	case 2	1152.62	16.05	263.50	199.17
V4 mid	case 5	1215.57	13.23	277.89	210.05
V4 top	case 4	322.93	6.86	73.83	55.80

Table 49 - Potential savings from the equipment simulation regarding the yearly total energy in long-term scenarios

In table 51 the final results obtained from joining the two previous tables are listed. The short-term scenario presented remarkable yearly savings, ranging from 4.28% to 16.73% for the consumed reference energy, which corresponded respectively to a decrease of 45.36kg and 257.10kg in CO_2 emissions. The long-term scenario approximately doubled or tripled these savings, registering reductions of 9.85% to 33.78% in the consumed energy, corresponding respectively to 104.25kg and 476.49kg of reduced CO_2 emissions per year. It is important to point out that in both scenarios the most expressive results were obtained in the variants 3a, 3b and 4, highlighting the potential savings which may be obtained from the implementation of any of these scenarios (table 51).

				Short Term Scenario			Long Term Scenario		
Variant	Case	Indicators	Baseline	Scenarios 1, 4 and 5	Savings (%)	saving (€/year)	Scenarios 1, 4, 5, and 3	savings (%)	saving (€/year)
V3b mid	Case 1	Energy (kWh/year)	5177.6	4925.90	4.86	43.49	4925.90	4.86	43.49
		CO2 (kgCO2)	1131	1073.00	5.13		1073.00	5.13	
		PPD (Mean %)	16.63	16.71	-0.51		16.71	-0.50	
V3b top	Case 2	Energy (kWh/year)	6412.6	5774.10	9.96	110.33	5702.70	11.07	122.67
		CO2 (kgCO2)	1440	1294.00	10.14		1277.00	11.32	
		PPD (Mean %)	27.49	28.10	-2.20		25.83	6.04	
V3a top	Case 3	Energy (kWh/year)	6632.9	6108.90	7.90	90.55	6077.00	8.38	96.06
		CO2 (kgCO2)	1437	1318.00	8.28		1310.00	8.84	
		PPD (Mean %)	26.49	25.92	2.12		24.87	6.12	
V4 top	Case 4	Energy (kWh/year)	4522.5	4211.10	6.89	53.81	4157.30	8.08	63.11
		CO2 (kgCO2)	1013	942.00	7.01		929.00	8.29	
		PPD (Mean %)	26.75	26.93	-0.67		27.78	-3.84	
V4 mid	Case 5	Energy (kWh/year)	8495.3	7847.00	7.63	112.03	7850.10	7.59	111.49
		CO2 (kgCO2)	1863	1715.00	7.94		1716.00	7.89	
		PPD (Mean %)	33.42	30.89	7.59		32.45	2.92	
V3a mid	Case 6	Energy (kWh/year)	6178.3	5971.80	3.34	35.68	5968.20	3.40	36.31
		CO2 (kgCO2)	1360	1313.00	3.46		1312.00	3.53	
		PPD (Mean %)	22.29	21.72	2.57		21.55	3.30	
V2 mid	Case 7	Energy (kWh/year)	2948.1	2884.50	2.16	10.99	2881.60	2.26	11.49
		CO2 (kgCO2)	650	635.00	2.31		635.00	2.31	
		PPD (Mean %)	26.29	26.34	-0.17		26.29	0.00	
V1 top	Case 8	Energy (kWh/year)	4433.7	4479.40	-1.03	-7.90	4479.40	-1.03	-7.90
		CO2 (kgCO2)	988	999.00	-1.11		999.00	-1.11	
		PPD (Mean %)	30.17	27.90	7.52		27.90	7.52	
V2 top	Case 9	Energy (kWh/year)	3229	3362.80	-4.14	-23.12	3362.80	-4.14	-23.12
		CO2 (kgCO2)	684	715.00	-4.53		715.00	-4.53	
		PPD (Mean %)	26.63	25.31	4.98		24.44	8.24	
V1 mid	Case 10	Energy (kWh/year)	2427.1	2301.80	5.16	21.65	2301.80	5.16	21.65
		CO2 (kgCO2)	555	526.00	5.23		526.00	5.23	
		PPD (Mean %)	17.43	17.42	0.06		16.68	4.28	

Table 50 - Potential savings from the dynamic simulation regarding the yearly total energy in short- and long-term scenarios

		Short Term Scenario				Long Term Scenario			
Variant	Cases	Total savings (kWh)	Total savings (%)	Carbon Savings (kgCO2)	saving (€/year)	Total savings (kWh)	Total savings (%)	Carbon Savings (kgCO2)	saving (€/year)
V1 mid	case 10	202.44	9.11	46.28	34.98	453.98	21.97	103.78	78.45
V1 top	case 8	334.61	6.88	76.50	57.82	737.89	15.19	168.69	127.51
V2 mid	case 7	273.46	8.28	62.52	47.25	650.20	19.28	148.64	112.35
V2 top	case 9	198.40	4.28	45.36	34.28	455.96	9.85	104.24	78.79
V3a mid	case 6	645.17	10.45	147.49	111.49	2084.31	33.78	476.49	360.17
V3a top	case 3	848.56	13.41	193.99	146.63	1250.05	20.22	285.77	216.01
V3b mid	case 1	400.76	8.25	91.62	69.25	656.28	14.06	150.03	113.41
V3b top	case 2	1124.64	16.73	257.10	194.34	1791.12	26.01	409.47	309.51
V4 mid	case 5	1305.57	14.78	298.47	225.60	1863.87	20.86	426.10	322.08
V4 top	case 4	333.78	7.37	76.31	57.68	634.33	13.75	145.01	109.61

Table 51 – Long and short term scenarios from the thermal and equipment simulations

Overall, it is possible to test the potential applicability of these savings to the total research area accordingly to the representativeness of each variant. Calculating with 191 buildings (665 dwellings), it will be possible to save 464.76 MWh (€80,309) each year with the short-term scenario and 914.65 MWh (€158,051) with the long-term scenario. It can be affirmed that the results present a valid potential for complying with the energy and carbon reduction targets established by the municipality for 2020 (AdEPorto, 2010). Referring to the yearly buildings' energy saving targets established for 2020, these two scenarios represent respectively the shares of 1.22% and 2.41%.

9.2.4 - Future-Proofing

The simulated future weather confirmed the predicted changes for Oporto[73] (Instituto de Meteorologia de Portugal and Instituto Dom Luiz da Universidade de Lisboa, 2008; Santos *et al.*, 2002; Santos and Miranda, 2006), which aggravate the tendency for overheating. Based on such a future scenario, the study conducted by Aguiar *et al.* predicted a reduction in the energy consumption associated with heating and the inverse for cooling (2002). In the specific case of the Portuguese north coast, the study pointed out a decrease of 473kWh/year for heating and an increase of 651kWh/year for cooling. However, the calculations were made using the static comfort model, with continuous heating and cooling when the temperatures fall outside of the defined bandwidth (20˚C and 25˚C).

The data output of the future weather simulations seems to support the arguments of Aguiar *et al.,* who associate the decrement in heating energy consumption with the temperature increase.(2002). Regarding the performance, it can be pointed out that Oporto's traditional buildings show that a decrease in comfort is mainly due to rising temperatures. Consequently, the predicted climate changes may lead to minor adaptation measures that, if not mitigated correctly, can impact on the heritage value of the buildings. The current increase of refurbishment trends may lead to a gentrification of the area and consequently bring residents who may have higher comfort standards, thus leading to an increased cooling demand. This could consequently produce negative impacts on heritage and energy consumption if external AC units are to be installed. Another possible future scenario arises from the current demographic trends, which show a growing ageing population. This may turn into a major

[73] - It is predicted a 3°C increase in the Portuguese mainland coastal area.

social issue, resulting in severe health problems if this low-income population has to deal with these overheated dwellings.

It can be affirmed that Oporto’s traditional buildings are not significantly affected by the predicted climate change. The reduction in the energy used for heating is a positive aspect. Hence, the future-viability of Oporto's traditional buildings has to be directed mainly towards decreasing comfort and the social and heritage problems arising from this. The solutions must take advantage of the buildings’ high thermal mass, which prevents overheating during the day. Again, the challenge is to enhance the natural ventilation during the evening and night time in order to dissipate the heat absorbed by the walls. This must be addressed by either raising the ventilation rates through the exterior frames or by enhancing the use of the central stair space through establishing a good ventilation rate between main door and skylight. Adapting these behaviours may be less intrusive to a building's appearance than changing the window frames. Still, the role of adaptive comfort and behaviour control must also be pointed out. Currently, some of the householders already use an adaptive approach by closing windows and shutters during the day in summer and leaving them open during the night. Based on their experience and respective simulated profile, this simple measure proves to be very effective in dealing with this problem. This highlights the role of adaptive behaviour in energy efficiency and confirms the positive performance of traditional windows and internal shutters as identified by Baker (2010) in relation to sash windows.

9.3 – Main Findings

Several points which must be highlighted emerge from the analysis of the results. Primarily, it can be stressed that the overall performance presented by the studied traditional buildings was higher than the installed vision which regards them as highly inefficient. This encompasses both energy and comfort converging to support the emerging literature which questions the established U-values used for these buildings. The Portuguese pattern of energy demand for space conditioning is directly linked to the mild climate which leads these buildings to perform better than the values which are being put out by calculation methods which are based on thermal regulations. Additionally, the dynamic simulation reveals to be the most adequate method for dealing with all the complex factors involved in the energy efficiency of traditional buildings, as the static calculation methods fail to fully encompass these. Furthermore, these buildings must be researched further instead of relying on the expected results from the steady calculations. This will allow achieving a more accurate understanding of their integral performance which is a recognised gap in the literature.

Regarding the performance, it can also be pointed out that Oporto's traditional buildings can face the predicted climate changes with minor adaptation measures that will not impact on their heritage value. These have to deal mainly with increasing the natural ventilation during the night in order to dissipate the heat accumulated by the high thermal mass of the solid walls.

Secondly, it must be stressed that from the simulation analysis it can be affirmed that the most effective solutions to improve the energy efficiency of Oporto's traditional buildings are a DHW upgrade and the efficient use of equipment. From the short- and long-term scenarios, yearly cuts on energy use and carbon emissions of 464.76 MWh and 106 tonnes of CO_2, and 914.65 MWh and 209 tonnes of CO_2 respectively, were identified. On average, each dwelling could respectively save €121 and €238 a year in the short- and long-term scenarios. The results present a valid and feasible potential to help achieving the energy and carbon reduction targets established in the 2020 strategy. At the same time, the cost savings are extremely relevant from the social perspective, as the population residing in the historic centre has a relatively low income, a factor which is further accentuated by the ageing trend among the population, which may lead to profound fuel poverty in the future.

Thirdly, it was verified that the role of upgrading the fabric is less important than usually pointed out in literature, which relieves the pressure on the heritage values of these traditional buildings. Surprisingly, envelope insulation was revealed to be ineffective overall, resulting in irrelevant energy savings and low comfort improvements. At the same time, these are high-cost measures and negatively impact on the building's heritage values. The measures which were identified as more effective are non-intrusive to the heritage values identified in Oporto's traditional buildings. Solar panels were revealed to be highly intrusive to the historic context and damaging for the World Heritage City integrity. They were economically ineffective and presented administrative and design constraints. These last constraints in conjunction with the heritage intrusiveness can be extended to the introduction of solar photovoltaic panels or micro-wind generation. The intrusiveness of the panels highlights the necessity of addressing heritage impact on traditional buildings at several scales: element, building and site. This supports an independent approach diverging from the envelope-centred upgrade and reinforces the role of the social dimension in energy efficiency. However, it must be stressed that the results are deeply influenced by the heating and cooling demands which characterise the Portuguese energy trends. Focusing strictly on the obtained fabric improvement thermal parameters, it is possible to verify that they follow the pattern expressed in the literature.

Finally, it must be underlined that a broad consensual approach towards the energy efficiency upgrade of traditional buildings and posed heritage constraints emerged from the scientific and technical literature (AdEPorto *et al.*, 2010; Changeworks, 2008; Energy Saving Trust, 2010; English Heritage, 2011; Ferguson, 2011; May and Rye, 2012; Restart Project, 2000; Yates, 2006). However, as stressed previously, these approaches do not reveal a clear process of weighting the energy efficiency parameters with heritage significance protection. To overpass this gap, several methods were amalgamated and applied to Oporto's traditional buildings case studies.

Chapter Ten: Conclusions and Future Research

Chapter Ten: Conclusions and Further Research

10.1 - Introduction

The purpose of this chapter is to summarise and connect the content of the thesis in order to highlight the significance of the findings. This includes establishing the connection with the aims of the thesis and answering the research questions. Furthermore, the implications for future policies aiming to improve the energy efficiency of traditional buildings in Oporto and similar cases are addressed. Finally, recommendations for further research are made.

10.2 – Main Conclusions

This dissertation covered the '*Investigation of energy efficiency measures in the traditional buildings in the Oporto World Heritage Site*', thus allowing revising and addressing the major questions which frame this subject. This included bringing together the fields of building energy efficiency with heritage conservation in traditional buildings, by using the Oporto World Heritage Site as a case study. The study was divided into two parts: the first comprised establishing the background and the literature review, concluding with the methodology definition; the second part focused on the case studies, including determining the typologies, the survey results from the research area with 191 buildings, and the thermal simulation of 10 case studies, representative of the identified variants. The second part concluded with determining the most effective measures to improve the energy efficiency of traditional buildings in Oporto, which also included a discussion of the obtained results in reference to the literature.

10.2.1 – Review of the Thesis Aims and Objectives

As established in Chapter One, the main aim of this research is to identify the means by which urban traditional residential buildings can be upgraded to improve their energy performance while at the same time preserving their heritage significance. Using Oporto's traditional buildings integrated in the World Heritage Site as research objects, the aim was addressed by identifying the most effective measures for improving energy efficiency to upgrade these buildings.

To achieve such an objective, a methodology to assess the improvement of energy efficiency of traditional buildings and their acceptable limit of change to the heritage was developed. The method crossed the fields of heritage significance of traditional buildings and management of change assessment with the improvement of their energy efficiency, while balancing cost, comfort, energy consumption and CO_2 emissions. By applying this method to the results of the dynamic and equipment simulations, it was possible to clearly identify the most feasible and effective measures applicable to the ten case studies and further and extrapolate the results to all traditional buildings located in the research area. The obtained findings are summarised in the next sub-section.

10.2.2 – Findings Summary

This sub-section highlights the main findings of the thesis, covering the performance of traditional buildings, most effective measures, social perspective, methodological approach and results extrapolation.

Traditional Buildings Performance

The analysis of the data regarding energy consumption for the case studies was obtained from the supplier and revealed the following:

- a low consumption for heating and cooling was identified, confirming previously established patterns for Oporto and Portugal;
- overall, one of the most intensive energy consumptions is related to the domestic hot water (DHW); the average yearly consumption calculated from the actual data for all the case studies was lower than the Portuguese and European shares for the most recently built buildings.

From the analysis of the case study questionnaires, it was possible to conclude that the majority of the households are satisfied with the overall comfort of the dwelling, namely, with temperature, air quality, light and noise.

The monitored temperatures during summer in four of the cases highlighted the relevant role of the thermal mass of these buildings. The pattern of temperature variation in the dwellings showed that the heat which had accumulated in the solid granite external walls was slowly released during the night. In these cases, night ventilation should be improved to avoid overheating. The simulation with future weather scenarios reinforces this, pointing it out to be a major problem that needs addressing. The adopted behavioural controls in some dwellings, like closing the windows and shutters during summer days and opening them at night, revealed positive results.

During the research process, doubts arouse due to recent literature about the established calculation methods which reported a lower performance of traditional buildings than what was actually observed. Recent fieldwork regarding thermal performance analysis of traditional buildings proves exactly this knowledge gap (Baker, 2010; Baker, 2011; Rye, 2011; Rye *et al.*, 2012). This point to the inadequacy of applying current standards and static energy calculation methods to traditional buildings. These calculations define abstract comfort levels which have to be continuously met throughout the year and serve as a basis for calculating the energy demand necessary to fulfil them.

The Most Effective Measures

The analysis of the design scenarios simulation results showed that the most effective measures are related to the DHW system retrofit and behavioural approach towards equipment use (lighting and stand-by nulling). This confirms the literature framework identified and is regardless of the buildings age. Simultaneously, these low-cost measures are also compatible with traditional buildings fabric and heritage values, which reinforces their feasibility.

Surprisingly, envelope improvements resulted in negligible energy savings, which together with their high implementation costs rendered them ineffective due to very long pay-back periods. This ineffective fabric approach differs from the results reported in the literature, which presented significant energy savings achieved through envelope retrofit, with special relevance to insulation (Changeworks, 2008; Energy Saving Trust, 2010; Rye *et al.*, 2012; Yates, 2006). However, as previously pointed out, the influence of the low heating and cooling demands and the mild climate background in Portugal can explain the differing results. This is confirmed by the heat loss reduction that was achieved in the simulations, which also confirmed the literature results. The results were obtained at the dwellings retrofit scale and if a profound refurbishment of the entire building occurs, the cost-effectiveness of the solutions may raise and increase their effectiveness. Nevertheless, based on the achieved negligible savings, it is extremely unlikely that they may become feasible. Moreover, even in this situation the management of change process remains valid as only the cost parameter changes.

The comfort improvements achieved through envelope retrofit are also negligible, which reinforces their inadequacy for upgrading energy efficiency in Oporto's traditional buildings. The improvement of the glazed elements is the exception, especially for low cost draught-proofing. While the energy savings are insignificant, these measures do increase the comfort levels of the inhabitants. The medium cost of introducing double or secondary glazing, in conjunction with the traditional internal shutters, may turn these solutions feasible should a scenario of increased heating and/or cooling loads occur. The changes on the traditional external frames must be performed with care in order to preserve the overall significance of the building. In the literature similar solutions were identified, which achieved a successful design compatibility with the original frames, leading to affirm that these solutions are perfectly viable to be implemented in Oporto.

The use of solar thermal panels for water heating, although presented to be relatively cost-effective, has a relevant negative impact on the significance of the World Heritage Site (‘visual noise’), resulting in a reluctance of using them in historic urban landscapes. This highlights the necessity to assess the heritage impact of the solutions at several levels: element, building and site. This is particularly relevant in traditional buildings, whose individual change may produce cumulative negative impacts on the site.

In Oporto, the detected tenure framework additionally influences the concretisation of the measures. The feasibility of implementing general refurbishment is then highly compromised, regardless of cost. As opposed to this, all solutions which can be executed at the individual home (apartment) level reveal to be potentially practicable. In the literature it is pointed out that when measures are executed on a ‘do-it-yourself’ (DIY) basis, it is possible to cut the payback periods by half (Changeworks, 2008; Edinburgh World Heritage, 2012). The use of other forgotten traditional solutions, like ‘draught excluders’ or heavy curtains for draught-proofing, is also pointed out (English Heritage, 2008). This could be a viable strategy to overcome the high payback periods of some retrofit solutions, specifically taking into account that the inhabitants of Oporto's historic centre usually have a low income.

The Social Perspective

In the context of the research development it was possible to understand the relevance of the social perspective in the energy efficiency of traditional buildings. This covers two independent scopes; one is related to the role of the households' behaviour in promoting energy efficiency, and the other one to the advantages which can be achieved for the inhabitants of the historic centre with the energy efficiency savings.

The advantages of the first aspect were already patent in the obtained results and confirm the general trends in energy efficiency improvement for buildings, which are transversally pointed out in the literature (Energy Saving Trust and DEFRA, 2012), including in Portugal (Ferreira *et al.*, 2008; Ferreira *et al.*, 2011; Quercus, 2008). Combined behavioural and technological approaches can be more effective leading to potential electricity savings of up to 48% in the European residential sector (2011). In parallel, another possible behavioural approach in traditional dwellings was detected. The use of traditional methods to achieve comfort was shown to be effective. The control of windows and shutters is a good example of how to improve thermal, acoustic and visual comfort and save energy. So, the occupants behaviour in relation to energy use in their homes and how they can operate them so that less energy is needed for mechanical cooling, heating and electrical lighting, is a critical aspect of energy efficiency in the traditional buildings studied, encompassing a high saving potential. Moreover, the climate change trends point to increasing temperatures and possible overheating scenario. The control of natural ventilation by the occupants will likely be critical, both to improve comfort and avoid increasing the energy consumption.

The relevance of the economic savings must be particularly highlighted in the detected social context. In accordance with the framework identified in the literature, the households participating in the study mostly had a low income. Additionally, the current context of an economic crisis, continuous raises of energy prices and the ageing population trends, aggravate this scenario leading to fuel poverty. The potential economic savings also have to be considered from this social perspective, going beyond the usual energy and carbon metrics, as they may actually improve the households' living conditions.

The Methodological Approach

A broad consensual approach towards energy efficiency upgrade for traditional buildings and consequent heritage constraints emerged from the scientific and technical literature.

However, these approaches do not reveal a clear process of weighting the energy efficiency parameters with heritage significance protection. To overpass this gap, several existing methods were crossed and applied to the case studies of traditional buildings in Oporto. The method rests on the traditional process of measuring energy efficiency improvements and is crossed with a cyclical process of heritage impact assessment. The first compares the baseline with the simulated design scenarios in order to measure the diverse parameters of energy efficiency. The heritage assessment evaluates the impacts caused by these solutions in several instances. A limit of change for each measure was then identified in order to benchmark and avoid any adverse impact on Oporto's traditional buildings and on the significance of the World Heritage Site.

The measurement of this impact integrated in the methodological process was not identified in the reviewed case studies, which addressed it as a complement of the technical perspective. Yates addresses the question by discussing the ‘conservation limit’ which corresponds to the ‘limit of change’ expressed in the previous section (2011). However, this methodology was never clearly expressed in the literature and reviewed case studies. This gap is pointed out by May and Rye, who stress the necessity of developing a “systemic approach (…) regarding the assessment and retrofit of traditional buildings” (2012, p.7).

The research or guidance identified for Oporto mainly relies on technically driven approaches, which range from methods where energy is the most relevant aspect (Cupido, 2000) to methods which are based mainly on a common sense approach for avoiding damaging the buildings appearance (AdEPorto *et al.*, 2010; Restart Project, 2000).

The most delicate step in the process is to define the ‘limit of change’ regarding the heritage, which will drive the process of measuring the impact. Moreover, the heritage impact assessment on several levels, element, building, site, was used. In traditional buildings it is essential to consider the management of change from the perspective of these levels. Since their heritage is related mainly to group values and not to individual exceptional significance. As a consequence, it is necessary to assess how individual change may affect the group as a whole.

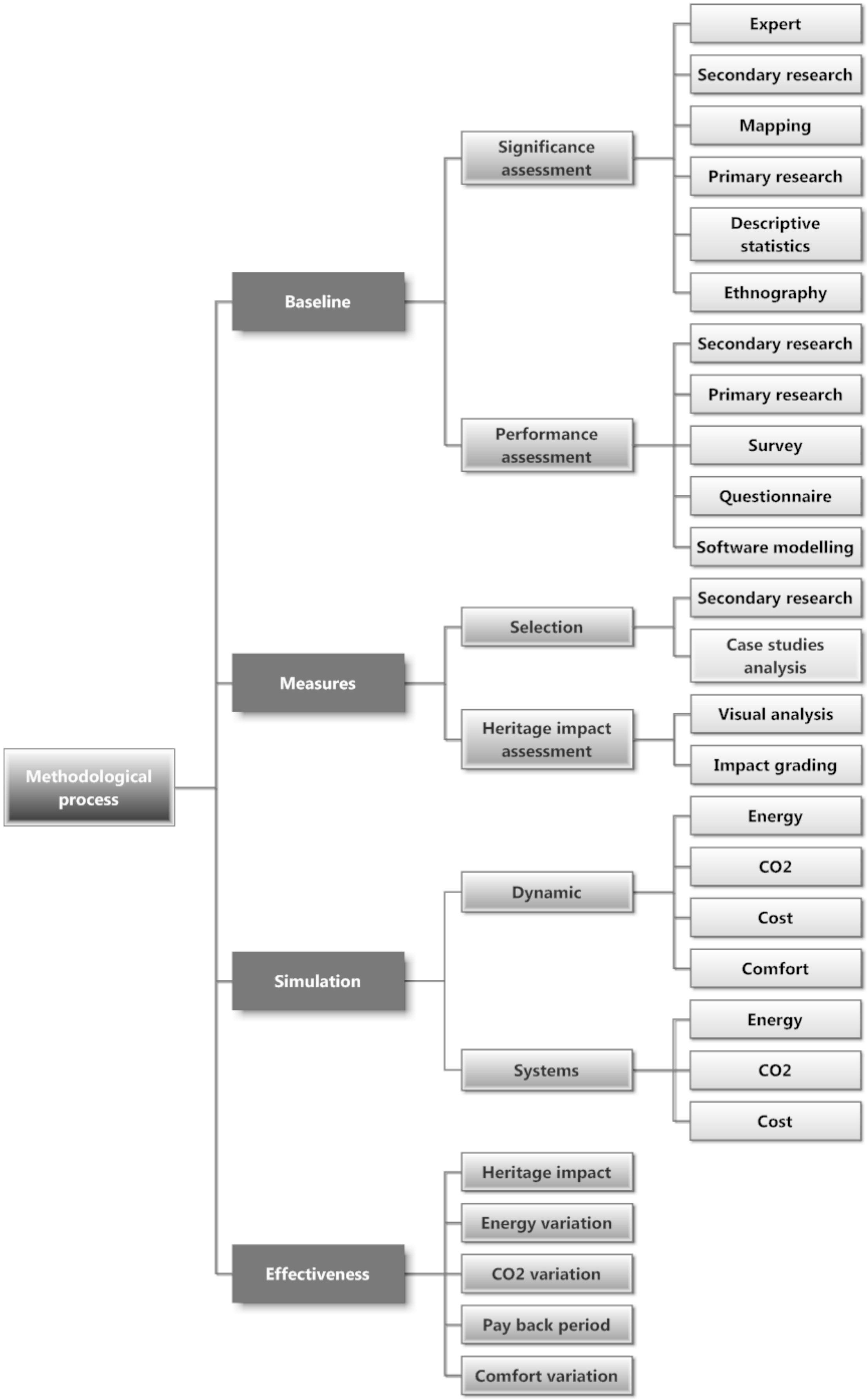

Figure 79 – Detailed methodological process

Results Extrapolation

In the previous chapter, the results obtained from the short and long-term scenarios were extrapolated to the 191 traditional buildings of the research area. Even if the overall results are not expressive, they contribute to climate change mitigation policies. Moreover, if the results are extended to all the 7,891 pre-1919 buildings of Oporto it will be possible to achieve yearly energy consumption reductions of up to 11.32 GWh and 20.46 GWh, for short and long-term scenarios respectively. These are reduction shares which impressively correspond to 29.81% and 53.88% of the annual reduction target established by the municipality to comply with the 2020 strategy. Moreover, it is important to stress that such promising energy efficiency achievements were obtained with solutions that did not interfere with the buildings' heritage significance. This proves that it is possible to reach expressive cumulative results without compromising the historic site.

Further extrapolations of the results are possible, but not without losing accuracy. The obtained results are linked to the construction technologies, building typologies, patterns of energy use and local climate. The terraced typology identified in Oporto is relatively common among traditional urban buildings across Europe and the former colonies of European nations around the world. The other factors are site specific and pose limitations to extending the findings. However, it is possible to hypothesise that similar results could be obtainable in the traditional buildings of the European Mediterranean region, which share some similarities with the traditional buildings of Oporto. From these, the energy consumption by end-use values for Spain and Cyprus resemble the Portuguese trend the most (EEA, 2012), which increases the potential to verify similar results.

10.3 – Contribution to Knowledge

The study’s key contribution to knowledge is based on the results from the simulations. Contrary to expectation, they highlighted the inefficiency of envelope insulation for upgrading the energy efficiency of traditional buildings in Oporto, independently of the heritage value impacts they may have. This result has not been previously described in the literature, which stresses the high efficiency of these measures in retrofitting all types of existing buildings. As mentioned in the results extrapolation, this output may also be valid for traditional and historic buildings of the European Mediterranean region. This finding has important implications for providing a new understanding on how to approach energy efficiency improvements for these buildings. The thermal regulations and established policy and practice are based mainly on these upgrading solutions. By proving their inefficiency, the scope must be orientated towards new approaches, relieving traditional buildings of the heavy heritage impact that these solutions may bring.

Other of the main contributions to knowledge made by this research is based on the development of an integrated methodology to address the scopes of heritage and energy efficiency in traditional buildings. As explained in the previous section, this method addresses the gap found in literature for jointly assessing energy efficiency improvement and heritage preservation of traditional or historic buildings, which are usually approached separately or by focusing on one of the fields, with prevalence to the technical perspective. No existing research was identified using a complete method crossing the variables addressing the two perspectives: energy, CO_2, cost, comfort and heritage impact. Although their application was performed in the Oporto context, the method can be used for approaching any historic or traditional building independently of its geographical location, climate and construction system or heritage value. All the parameters can be changed inside the method to address local specificities and obtain the most feasible energy efficiency measures for each context.

Another contribution of this thesis refers to the first application of a dynamic simulation for Southern European traditional or historic buildings, inserted in a methodology for putting out results and pointing out the most feasible measures. Despite the methodological approach, similar dynamic simulations were identified in Northern European countries, in particular in the UK case studies. The identified literature focusing on the Mediterranean or Southern European region is based on the study of partial components of traditional buildings, lacking a complete integration of all aspects for dealing with an occupied dwelling.

10.4 – Policy Recommendations

Built heritage is a strategic resource for a sustainable Europe and must be part of the contemporary life. At the same time, the reduction of the CO_2 emissions from the residential sector is a strategic action to mitigate worldwide climate change. This second aspect must be achieved without compromising the first, even if this means giving up more substantial savings. The balance between these two aspects is the core philosophy subjacent to this study, aiming to promote the refurbishment and re-use of the traditional as a strategy for a sustainable urban environment. The concept of ‘traditiovation’ exposed by Cannarella and Piccioni (2011) is an exact illustration of how to combine the advantages of traditional knowledge with the requirements of contemporary life. The ‘traditiovations’ are defined “as the practices and techniques deriving from historical or past traditional knowledge or re-invented practices and techniques, however, linked to traditional knowledge, showing, thanks also to the support of science and research, a capability to operate as innovation, despite their apparently obsolete and out-of-date features, in production and management” (2011, p.691).

Overall, the necessity to promote more integrated approaches to address energy efficiency in traditional buildings is beginning to emerge in the literature. At the same time, these approaches must be less rigid and address the specificities of these buildings. The research findings reinforce this vision and allow providing policy recommendations to improve the energy efficiency of traditional buildings.

Main Recommendations:

- The energy efficiency calculations for traditional buildings must allow the use of dynamic simulation, instead of relying exclusively on steady calculation methods promoting theoretical comfort models.
- The retrofit of traditional buildings should assess insulation-orientated regulations critically, verifying their impact and feasibility for each case.
- The role of thermal mass in the traditional buildings' performance renders it necessary to devise natural ventilation design strategies that help dissipating the heat accumulated in the solid walls.
- The retrofit of the traditional frames should also be encouraged as it improves the inner comfort of the homes. Like insulation, improvements to the frames must also be assessed according to their impact and feasibility in each case.
- The measures have to be based on design solutions that are compatible with the existing fabric; *e.g.* ‘breathability’ or hygrothermal behaviour. The simulations showed that the buildings which had been profoundly refurbished without considering compatibility, performed worse that the ones where the original fabric had been kept.

- The widely promoted use of solar thermal panels must be discouraged in historic environments, due to their visual impact. This recommendation is also valid for other renewable technologies which may produce similarly grave visual impacts. On the other hand, the introduction of non-intrusive renewables, like use of geothermal measures, should be encouraged.
- The promotion of district heating and cooling can also be an alternative to solar systems. The traditional urban block can be a natural unit for these systems' energy distribution and/or transformation. A heritage assessment which considers the cumulative impacts on the historic site, rather than on the individual building only, should be introduced.
- Based on the most effective solutions identified, the development of awareness campaigns for behavioural changes, focusing on DHW improvement, stand-by nulling, upgrade of equipment efficiency and enhancement of internal shutters and traditional windows use, is suggested.

10.5 – Research Limitations

The major limitation was the use of a small sample of ten cases. The limitation is mainly reflected in the incertitude of extrapolating the results. Further, the dwelling-limited approach instead of an entire building one could bring bias to the overall energy efficiency results. However, a whole-building approach would mainly focus on the fabric, which due to its low gains is unlikely to reveal a dramatic change in the results and lead to diverse conclusions. In the future, the comparison between the overall building and the dwellings performance must be explored, in order to compare the results. All limitations mentioned can also be pointed out as future research topics.

Another limitation is the incertitude of the data accuracy used in the study. This is related to the U-values, which were taken from existing literature or simulated in the software when addressing the composite layers which are not fully accepted by IES VE software. The gap between calculated and in-situ measured values is widely pointed out in the literature. Thus, in-situ measurements are needed in the Portuguese and Oporto context to validate the results. The impossibility of accessing the adequate survey equipment turned unviable to integrate such component on the research, but it is undoubtedly a point to be explored in future research. The accuracy of the information reported by the householders regarding their perception about energy consumption and behavioural control can also be pointed out as a limitation of this research. These limitations can provoke bias in the results, but they are constant in the performed simulations and are unlikely to affect the comparison between the results obtained.

10.6 – Suggestions for further research

The uncertainty of the heat transfer behaviour of traditional materials is widely pointed out in the literature and was also felt during this research. To perform *in-situ* measurements to obtain accurate U-values of traditional buildings systems is a suggestion for future research.

Further work should also verify if the pay-back of the fabric approach reveals to be effective in profound refurbishment operations in Oporto that cover the entire building. The role of some emerging technologies should be explored in the energy efficiency improvement of traditional buildings. This includes the use of super-insulating materials, PCM insulation incorporated in the plaster, and slim glazing for retrofitting traditional frames.

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Appendices

Appendix A

Protocols

Fieldwork

Questionnaire

Database Tables

Terminology

street survey-Infante Porto

BD_ID (objectid)

building identification

sru id	ine id	building id	building id in lot
130	131213		

name

building localization

	street names	numbers
main street		
back street		
side street one		
side street two		

main façade solar orientation		urban typhology	

building characterization

age	conservation	heritage	intervention	date	typhology

number of floors	number facades	number fronts	gable facades	number of openning rows	roof type	roof window

Building type

building geometry

main facade front width	building long	main façade elevation	floor height	building area	building volume	exterior wall thickness

building materials

main façade structure	main facade	main facade color	roof	windows frame	windows color	glass type

light control		main façade insulation	

building function

global function	street function	upper floors function

Building ocuppation

households

Observation

Age	Age of Buildings
bef_18	Before XVIII
18	XVIII
19	XIX
1_XX	1st Half of XX
2_XX	2nd Half of XX
21	XXI
const	In Construction

Conservation	Conservation of Buildings
g	Good
r	Reasonable
b	Bad
const	In Construction
refurb	In Refurbishment

Functions	Functions of Buildings
res	Residential
man_res	Mainly Residential
com	Commercial
serv	Services
pub_serv	Public Services
rel	Religious
war	Warehouse
gar	Garage
healt	Health
edu	Education
emp	Empty
cult	Culture

Heritage	Heritage Value of Buildings
li	Listed
exc	Exceptional
hi	High
gr	Group
di	Dissonant
not	Not Applicable

Solar_Orient	Main Facade Solar Orientation
N	North
NE	Northeast
E	East
SE	Southeast
S	South
SW	Southwest
W	West
NW	Northwest

Fac_St_Mat	Main Facade Structure Materials
st	Stone
con	Concrete
wo	Wood
ir	Iron
br	Brick
not	Not Identificable

Fac_Mat	Main Facade Material
ti	Traditional Tile
nti	Non Traditional Tile
pl	Plaster
fa	Fasquio
ta	Tabique

Colors	Colors of Materials
w	White
y	Yellow
r	Rose
g	Grey
b	Blue
d	Dark
gr	Green
br	Brown

Facade_Insul	Main Facade Insulation
0	No Insulation
1	Insulation 1 cm
2	Insulation 2 cm
3	Insulation 3 cm
4	Insulation 4 cm
5	Insulation 5 cm
6	Insulation 6 cm

Roof Type	Roof Type
4_slop	Traditional 4 Slopes
3_slop	Traditional 3 Slopes
2_slop	Traditional 2 Slopes
1_slop	Traditional 1 Slope
terr	Terrace

Roof_Wind	Roof Window
trad_roof	Traditional Roof Window
non_trad	Non Traditional Roof Window
no_roof	No Roof Window

Main_Window	Main Facade Window
trad_wood	Traditional Wood Frame
non_trad_wood	Non Traditional Wood Frame
alum	Aluminum Frame
pvc	PVC Frame
iron	Iron Frame

Glass	Main Façade Glass Type
sing	Single Glazed
doub	Double Glazed

Solar_Prot	Main Facade Solar Protection
in_shut	Inner Shutters
venet	Venetians
curt	Curtains
Brise_sol	Brise Soleil

HOUSING QUESTIONNAIRE

OXFORD BROOKES UNIVERSITY

The survey is being conducted to help with the refurbishment of your house in an energy efficient manner. All responses will be anonymous and the information collected will be treated as completely confidential by the survey team.

Name ______________________________ **Sex** M F

Date ______________ **Time** ______________ **Age** __________

Are you a: Tenant __________ Owner __________

Section A - Occupancy

1. Number of Occupants <18 __________ 18-64 __________ >65 __________

2. Number of persons that are normally at home:

	07-08,30h	08,30-10h	10-12,30h	12,30-14h	14-16h	16-18h	18-20h	20-22h	22-24h	24-07h
Mon										
Tue										
Wed										
Thu										
Fri										
Sat										
Sun										

3. Does this type of occupancy changes in holidays and how: ______________________________

Section B - Comfort

4. How do you feel the temperature at this time?

- Much to warm
- Too warm
- Comfortably warm
- Comfortably neither warm nor cool
- Comfortably cool
- Too cool
- Much too cool

5. I would prefer to be:

- Much cooler
- A bit cooler
- No change
- A bit warmer
- Much warmer

6. How do you find the air movement in your house at this time?

- Very high
- High
- Slightly high
- Neither high nor low
- Low
- Very low

7. How do you find the daylight levelat your house at this time?

- Very bright
- Bright
- Slightly bright
- Neither bright nor dim
- Slightly dim
- Dim
- Very dim

8. How do you find the noise in the surronding areas?

- Very noisy
- Noisy
- Slighly noisy
- Neither noisy nor quiet
- Slightly quiet
- Quiet
- Very quiet

9. How would you describe the air quality in your house at this time?

- Very bad
- Bad
- Slightly bad
- Neither bad nor good
- Slightly good
- Good
- excellent

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HOUSING QUESTIONNAIRE

Section B - Comfort (continuation)

10. At this time, how would you rate your overall comfort? in your house? Considering all the above factors

Very bad	
Bad	
Slightly bad	
Neither bad nor good	
Slightly good	
Good	
excellent	

11. Clothing you are using at this time - tick all that apply

Short sleeve/blouse	
Long sleeve shirt/blouse	
Vest	
Trousers/short skirt	
Dress	
Pullover	
Jacket	
Long socks	
Tights	
Tie	
Boots	
Shoes	
Sandals	

12. Activity level - What have you been doing in the last 15 min

Sitting (passive work)	
Sitting (active work)	
Standing relaxed	
Walking indoors	
Walking outdoors	
Other (specify)	

13. Controls - tick all that apply	**How**	**How long**
Internal door open		
External door open		
Window(s) open		
Blind/curtains down		
Internal shutters closed		
General lighting on		
Localised lighting on		
General heating on		
Localised heater on		
Air condition on		
Fan on		

14. Measurements

Air temperature (C°)	
Relative Humidity %	
Lighting level (lux)	
Background noise level (dbA)	

Section C - Equipments

15. Specify the equipments in use and how they are used:

Room	Equipment	Power rating	Average usage hours (day)

THANK YOU FOR YOUR HELP

If you have any queries, please contact Joaquim Flores - jflores@brookes.ac.uk or +351962339320

QUESTIONÁRIO

Este inquérito está ser conduzido de modo a permitir uma maior eficiência no uso da energia em futuros processos de reabilitação da sua casa e de casas semelhantes. Todas as resposta serão anónimas e a informação recolhida será tratada de modo completamente confidencial pela equipa de investigação.

Nome ____________________ **Sexo** M ____ F ____

data __________ **Hora** __________ **Idade** __________

É: inquilino __________ Proprietário __________

Secção A - Occupação

1. Número de ocupantes/idades <18 ______ 18-64 ______ >65 ______

2. Número de pessoas que está habitualmente em casa:

	07-08,30h	08,30-10h	10-12,30h	12,30-14h	14-16h	16-18h	18-20h	20-22h	22-24h	24-07h
Segunda										
terça										
Quarta										
Quinta										
Sexta										
Sábado										
Domingo										

3. Este tipo de ocupação muda nas férias e como: ____________________

Secção B - Conforto

4. Como é que sente a temperatura neste momento?

- Demasiado quente ☐
- Quente ☐
- Confortalvelmente quente ☐
- Confortável, nem quente, nem fria ☐
- Confortavelmente fria ☐
- Fria ☐
- Demasiado fria ☐

5. Eu preferia que fosse:

- Muito mais fresca ☐
- Mais fresca ☐
- Igual ☐
- Um pouco mais quente ☐
- Muito mais quente ☐

6. Como acha a ventilação na sua casa neste momento?

- Muito elevada ☐
- Elevada ☐
- Ligeiramente elevada ☐
- nem elevada nem baixa ☐
- Baixa ☐
- Muito baixa ☐

7. Como sente a iluminação natural na sua casa neste momento?

- Muito luminosa ☐
- Luminosa ☐
- ligeiramente luminosa ☐
- Nem luminosa nem escura ☐
- Ligeiramente escura ☐
- Escura ☐
- Muito escura ☐

8. Como sente o ruído exterior?

- Muito ruidoso ☐
- Ruidoso ☐
- Ligeiramente ruidoso ☐
- nem ruidoso nem silencioso ☐
- Ligeiramente silencioso ☐
- Silencioso ☐
- Muito silencioso ☐

9. Como descreveria a qualidade do ar na sua casa neste momento?

- Muito má ☐
- Má ☐
- Ligeiramente má ☐
- Nem boa nem má ☐
- Ligeiramente boa ☐
- Boa ☐
- excelente ☐

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QUESTIONÁRIO

Secção B - Conforto (continuação)

10. Neste momento, como classificaria o confortona sua casa?
tendo em consideração o global dos factores acima referidos

Muito mau	
Mau	
Ligeiramente mau	
Nem bom nem mau	
Ligeiramente bom	
Bom	
excelente	

11. Roupa que está a usar neste momento - assinale o necessário

camisa/blusa de manga curta	
camisa/blusa de manga comprida	
Camisola	
calças/saia curta	
vestido	
pullover	
casaco	
meias altas	
collants	
gravata	
Botas	
Sapatos	
Sandálias	

12. Nível de actividade - O que esteve a fazer nos últimos 15 m

sentado (trabalho passivo)	
Sentado (trabalho activo)	
de pé relaxado	
a andar em casa	
a andar no exterior	
Outro (especifique)	

13. Controles - assinale os aplicáveis	**Como**	**Tempo**
Porta interior aberta		
Porta exterior aberta		
Janela(s) aberta		
Estores/cortinas fechadas		
Portadas interiores fachadas		
Luz geral acesa		
Luz localizada acesa		
Aquecimento geral ligado		
Aquecedor localizado ligado		
Ar condicionado ligado		
Ventoinha ligada		

14. Medições

Temperatura do ar (C°)	
Humidade relativa %	
Intensidade luminosa (lux)	
Nível de ruído de fundo (dbA)	

Secção C - Equipamentos

15. Especifique os equipamentos que usa e como são usados:

Compartimento	Equipamento	Potência de consumo	Média de horas de uso (por dia)

MUITO OBRIGADO PELA SUA COLABORAÇÃO

Se tiver alguma questão por favor contacte Joaquim Flores - jflores@brookes.ac.uk ou +351962339320

Grades - English Portuguese Conversion

4	
Much to warm	Demasiado quente
Too warm	Quente
Comfortably warm	Confortalvelmente quente
Comfortably neither warm nor cool	Confortável, nem quente, nem fria
Comfortably cool	Confortavelmente fria
Too cool	Fria
Much too cool	Demasiado fria

5	
Much cooler	Muito mais fresca
A bit cooler	Mais fresca
No change	Igual
A bit warmer	Um pouco mais quente
Much warmer	Muito mais quente

6	
Very high	Muito elevada
High	Elevada
Slightly high	Ligeiramente elevada
Neither high nor low	nem elevada nem baixa
Low	Baixa
Very low	Muito baixa

7	
Very bright	Muito luminosa
Bright	Luminosa
Slightly bright	ligeiramente luminosa
Neither bright nor dim	Nem luminosa nem escura
Slightly dim	Ligeiramente escura
Dim	Escura
Very dim	Muito escura

8	
Very noisy	Muito ruidoso
Noisy	Ruidoso
Slighly noisy	Ligeiramente ruidoso
Neither noisy nor quiet	nem ruidoso nem silencioso
Slightly quiet	Ligeiramente silencioso
Quiet	Silencioso
Very quiet	Muito silencioso

9	
Very bad	Muito má
Bad	Má
Slightly bad	Ligeiramente má
Neither bad nor good	Nem boa nem má
Slightly good	Ligeiramente boa
Good	Boa
excellent	excelente

10	
Very bad	Muito mau
Bad	Mau
Slightly bad	Ligeiramente mau
Neither bad nor good	Nem bom nem mau
Slightly good	Ligeiramente bom
Good	Bom
excellent	excelente

	A	B
1	**English Terminology**	**Portuguese Terminology**
2	Architrave (door)	Padieira
3	Ashlar mansonry	pedra aparelhada
4	Balcony	Varanda ou Sacada
5	Beams	Traves, Vigas
6	Canopy	Cobertura de terraços e marquises
7	Carpet	Alcatifa
8	Casement Window	Janela de Abrir (1 ou 2 folhas)
9	Cast iron	Ferro fundido
10	Ceiling height	pé direito
11	Ceramic tile	Azulejo cerâmico
12	Ceramic tile flooring	Mosaico cerâmico
13	Chestnut wood	Madeira de castanho
14	Cladding	Revestimento
15	Clay	Barro, argila
16	Concrete slab	laje de betão
17	Corbels	Cachorros
18	Cornice	Cornija
19	Corrugated iron cladding	Chapa ondulada de ferro
20	Crank	Dobradiça
21	Detached house	Edifício isolado
22	Dormer Window	Janela Trapeira (sotão)
23	Eave	Beiral
24	Ell	Vara
25	End Terrace	Edifícios que rematam a banda
26	Extensions	Acrescentos
27	Exterior walls	Paredes exteriores
28	Fanlight window	Bandeira (porta ou janela)
29	Finish	Acabamento
30	Flat Roof	Cobertura Plana
31	Floorboarding	Tábuas do soalho
32	Flues	Condutas
33	Forged iron	Ferro forjado
34	Frame	Caixilho
35	French Window	Janela/Porta de Abrir (porta envidraçada)
36	Gable	Empena
37	Gable Roof	Telhado de 2 Águas com acentuada inclinação
38	Gargoyle	Gárgula
39	Georgian wrought iron fanlight window	Gradeamento em ferro da bandeira (porta ou janela)
40	Glazed balcony	Marquise
41	Granite	Granito
42	Grit	Saibro
43	Groove	Ranhura, entalhe, sulco
44	Gypsum plaster	Gesso
45	Gypsum skim	Barramento de gesso
46	half-timbering or timber framing	Taipa de Rodízio
47	Hip Roof	Telhado de 4 Águas
48	Hydraulic lime	Cal hidráulica
49	Indoor shutter, inner shutter	Portada interior
50	Ironmongery	Ferragens (puxadores, fechaduras, etc..)
51	Jalousie	Veneziana, Gelosia, Rótula de Pau
52	Jamb	Ombreira da Porta ou Janela
53	Joinst	Juntas
54	Joists	Barrotes
55	Landing	Patamar da escada
56	Lath	Ripa do fasquio
57	Lath and plaster	Tabique/fasquio
58	Lath and plaster ceiling	Tecto de estuque com base de tabique
59	Lattice or lattice-work	Entrelaçado de ripas para fasquio
60	Lean-to Roof	Telhado de 1 Água (normalmente telheiro)
61	lesbian and polygonal masonry	Estereotomia entre pedra irregular e aparelhada
62	Lime	Cal

	A	B
1	**English Terminology**	**Portuguese Terminology**
63	Lime mortar	Reboco
64	Lime plaster	Reboco de cal
65	Limestone	Calcário
66	Linoleum	Linóleo
67	Lintel	Lintel, padieira
68	Mansart Roof	Mansarda
69	Merlons	Merlões
70	Mid Terrace	Edifícios do meio da banda
71	Mortar	Argamassa
72	Moulding	Perfil de um elemento (cornija, por exemplo)
73	Noggin	Tarugos
74	Oak wood	Madeira de carvalho
75	Overhang	Ressalto
76	Parapet wall	platibanda
77	Partition walls	Paredes interiores
78	Party wall	Paredes de meação entre casas
79	Pediment	Frontão
80	Pine wood	Madeira de pinho
81	Pitched Roof	Telhado de 2 Águas com inclinação variável
82	Plaster	Reboco
83	Purlin	Terça (telhado)
84	Rafters	Caibros (telhado)
85	Ridge	Viga de cumeeira
86	Riga pine wood	Madeira de Pinho Riga
87	Roller blind(s)	Estore(s)
88	Roof battens	Ripas do telhado
89	Roof Ridge	Cumeeira
90	Roof Tile	Telha
91	Roof Truss	Asna
92	Rubble masonry	Pedra irregular
93	Sash Window	Janela de Guilhotina
94	Sashes	Caixilhos (folhas)
95	Scots Pine (or European Redwood, but less common)	Madeira de casquinha
96	Semi-detached house	Edifício geminado
97	Shutter	Portada
98	Side hung	Porta ou janela de abrir lateralmente
99	Sill	Peitoril
100	Skylight	Clarabóia
101	Slate	Lousa
102	Sole plate	Travessa soleira
103	Solid hardwood floor	Soalho
104	Span	Palmo
105	span	vão (espaço entre)
106	Stairs landing	patamar das escadas
107	Stone	Pedra
108	Stone Masonry	Alvenaria de pedra
109	Stone Mouldings	Trabalho de Cantaria
110	Stonemasonry	Cantaria
111	Stucco or plaster	Estuque
112	Stud	Prumo
113	Tallow	Sebo
114	Tenement	Edifícios de apartamentos
115	Terraced house	Edifício urbano em banda
116	Timber stud partition wall	Paredes interiores de tabique (madeira e reboco)
117	Top plate	Travessa topo
118	Wall base	Rodapé
119	Wall panelling	Lambrim

	A	B
1	**English Terminology**	**Portuguese Terminology**
120	Wallpaper	Papel de parede
121	Weatherstripped	Calaftada
122	Wood plank	Tábua de madeira do soalho
123	Wood slats	Ripado
124	Wrought	Gradeamento
125	Wrought Iron Balconies - Georgian, Regency, Victorian, Art Deco	Gradeamento em ferro das varandas

Appendix B

Case Studies

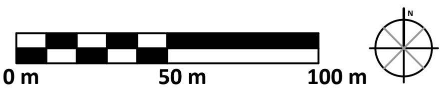
Drawings

Construction Systems

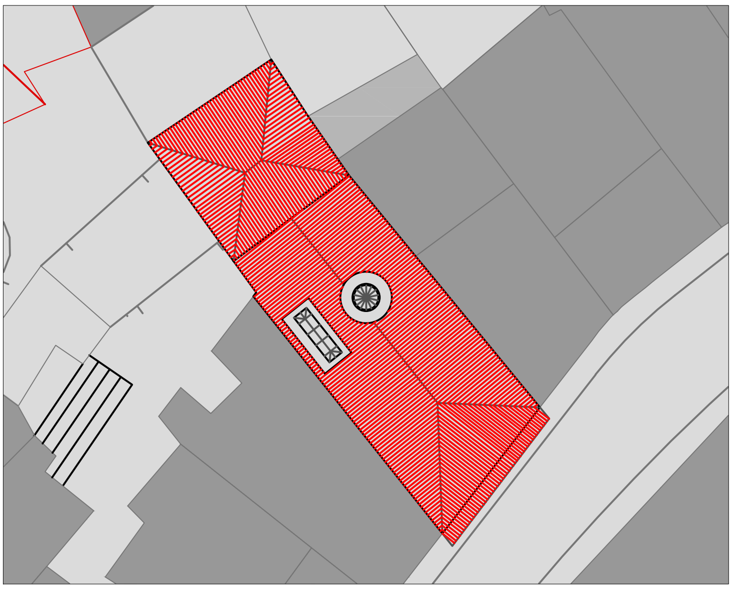
Equipment

Profiles

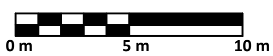
Case Study 1
Study Area Location Plan



Study area

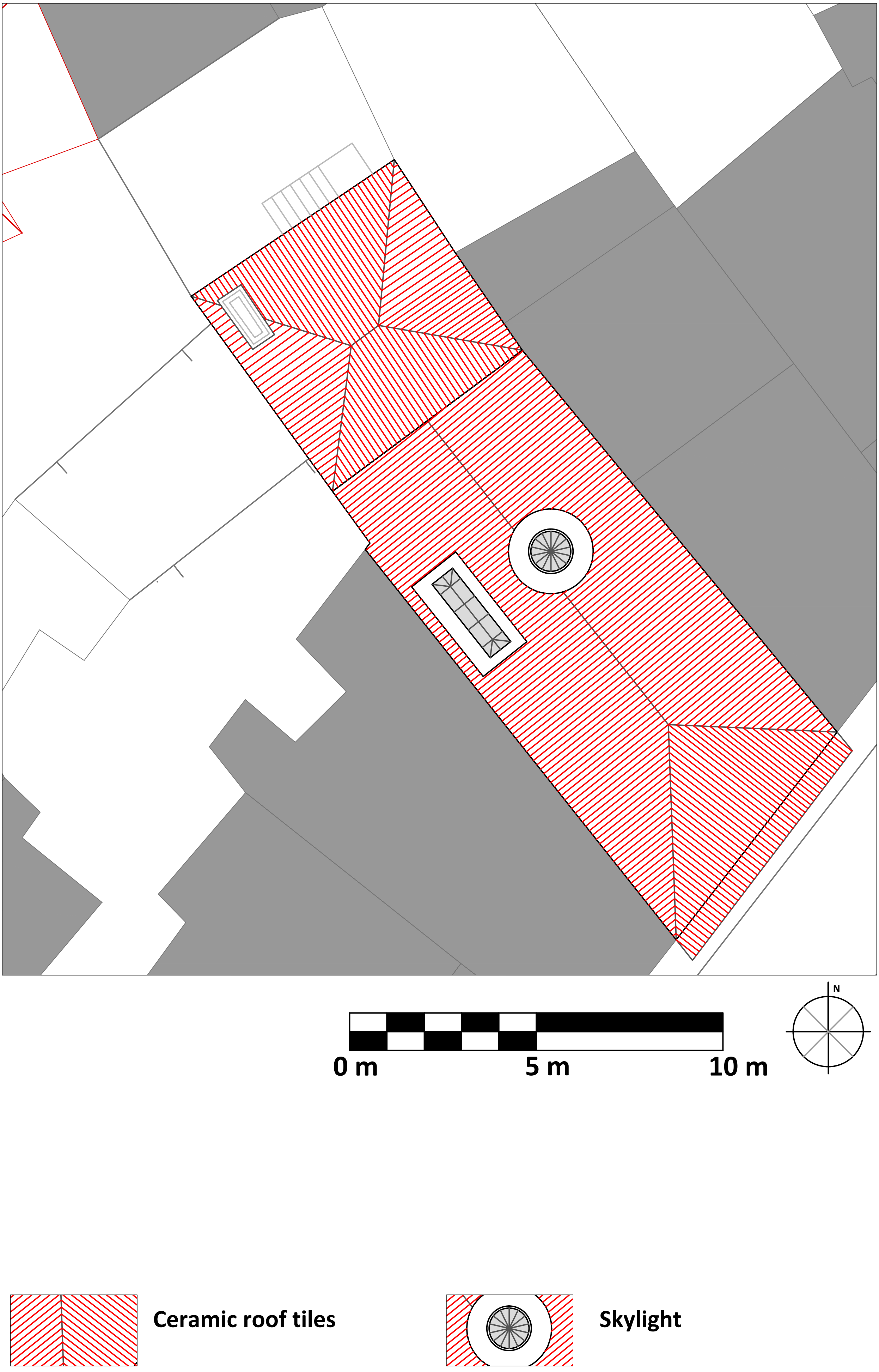


Case 1 site plan



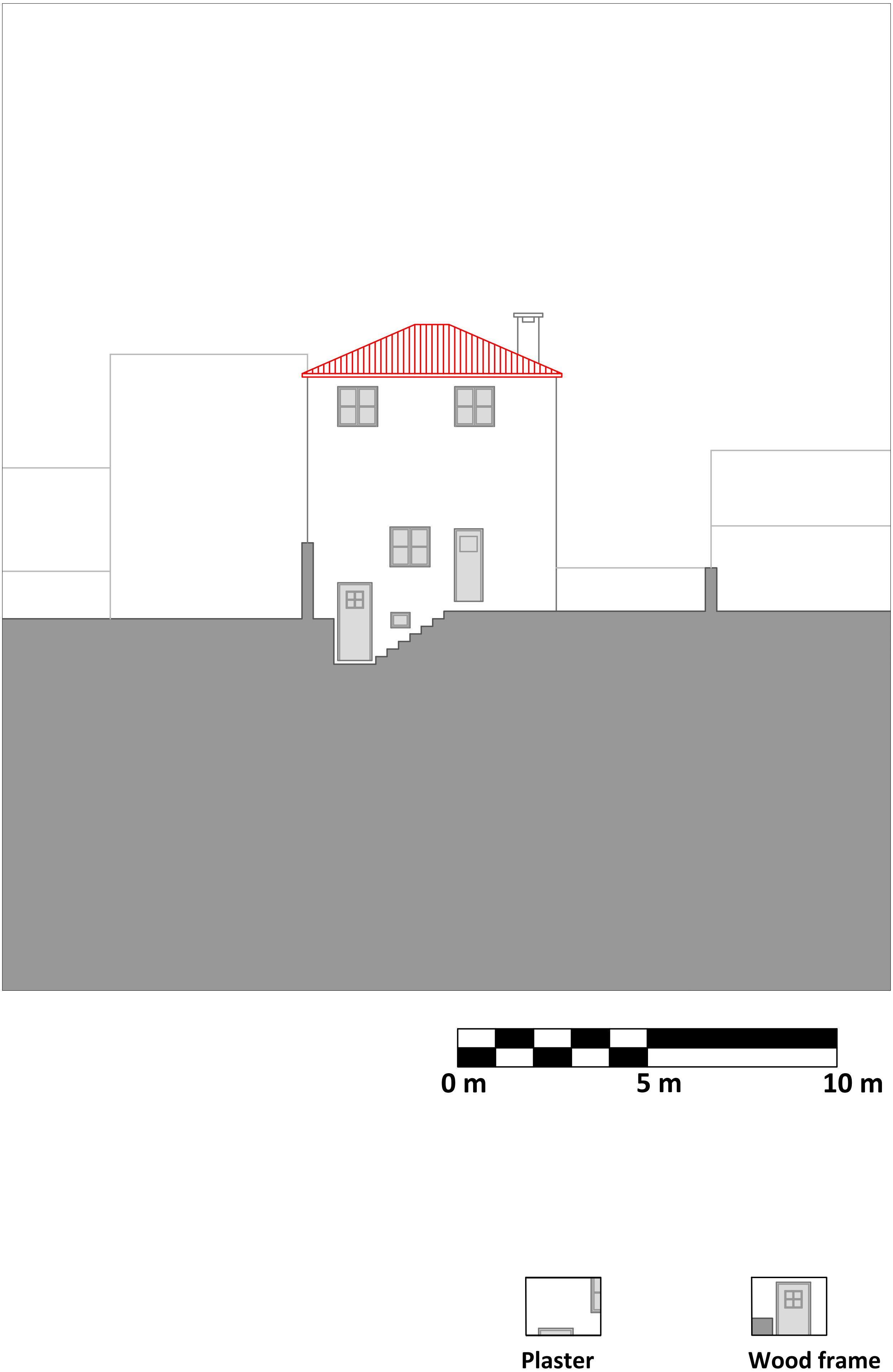
Case Study 1
Variant 3b middle floor plan (2nd floor)

Case Study 1
Variant 3b roof plan



Case Study 1
Variant 3b front facade (street)

Case Study 1
Variant 3b rear facade (courtyard)



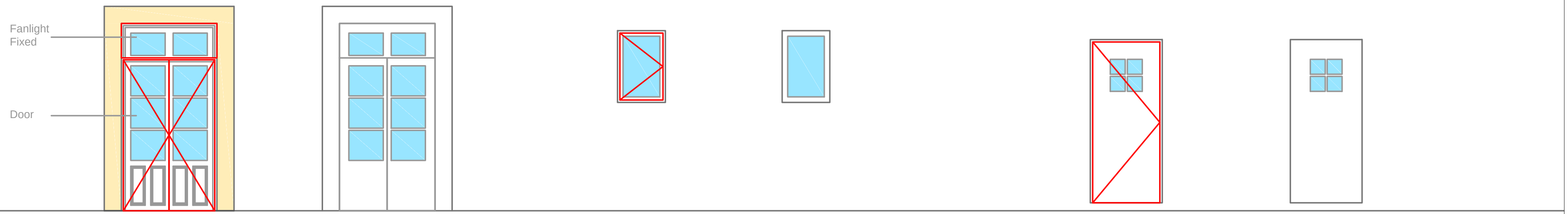
Case Study 1
Variant 3b Section

Case Study 1
Variant 3b - middle floor - Openings

Front (SE) 2th floor x 3

Side (SW) 2th floor x 1

Back (NW) 2th floor x 1



1.09 m2

94.78% max.
opening area

Fanlight 0.52m2
0.12m2
0.24 m2
46.15% of
glazed area

Door 1.15m2
0.16m2
0.16m2
0.16m2

0.48 m2

41.74% of
glazed area

0.45 m2

83.33% max.
opening area

0.54m2
0.35m2
64.8% of
glazed area

1.70 m2

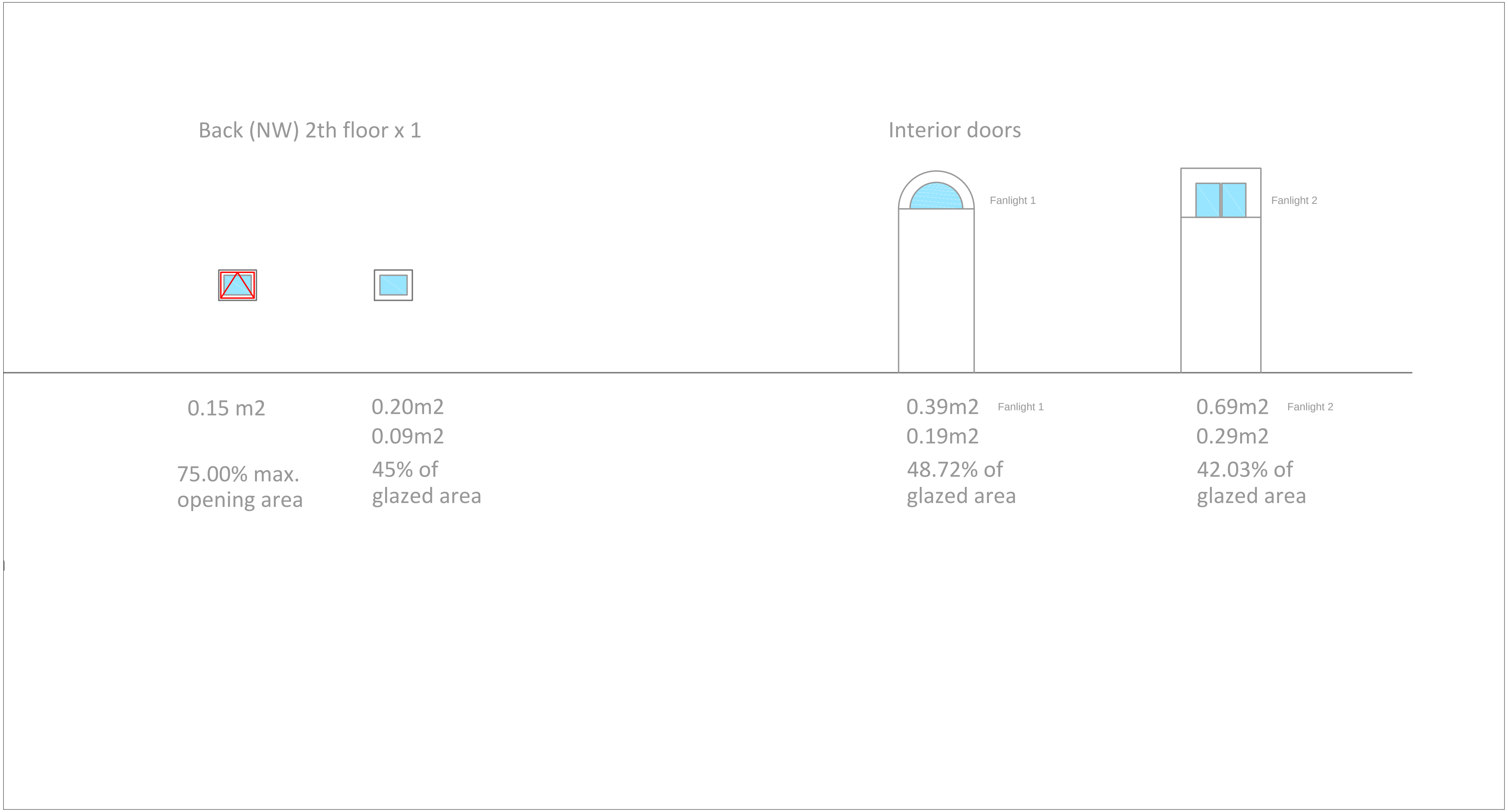
91.89% max.
opening area

1.85m2
0.04m2

0.16 m2

8.65% of
glazed area

Case Study 1
Variant 3b - middle floor - Openings



	type 1	type 2	type 2	type 3	type 4	type 5	type 6
exterior wall	front (SE)	Side (SW)	Side (NE)	Back (NW)	front (SE) back (NW)	Side (SW) Kitchen	Back (NW) WC
Total Thickness	0.55	0.75	0.75	0.72	0.24	0.75	0.72
ext layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	granite	plaster (0.025)	plaster (0.025)
layer 1	granite (0.50)	granite (0.70)	granite (0.70)	granite (0.67)	granite (0.24)	granite (0.70)	granite (0.67)
layer 2							
layer 3							
layer 4							
int layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	granite	tile (0.025)	tile (0.025)

	type 1	type 2	type 2				
partition wall		WC - Kitchen					
Total Thickness	0.13	0.14	0.13				
ext layer	plaster (0.025)	plaster (0.015)	plaster (0.025)				
layer 1	wood+mortar (0.08)	brick (0.11)	wood+mortar (0.08)				
layer 2							
layer 3							
layer 4		mortar (0.01)	mortar (0.02)				
int layer	plaster (0.025)	tile (0.005)	tile (0.005)				

	type 1 (Floor)	type 2 (ceiling)					
Horizontal separation							
Total Thickness	0.30	0.30					
floor layer	hardwood (0.03)	tile (0.005)					
layer 1	wood beams (0.245)	mortar (0.005)					
layer 2		hardwood (0.03)					
layer 3		wood beams (0.235)					
layer 4	timber framing (0.01)	timber framing (0.01)					
ceiling layer	gypsum (0.015)	gypsum (0.015)					

Front (SE) - 3 doors	3 fanlight	6 sashes		3 sets of shutters		3 sets of curtais	
Ext. Window (balcony door)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	0.52	1.15	allways closed except with hot temperature	2.82	open day /closed night	2.82	closed continuously
glazed area (m2)	0.24	0.48					
frame area (m2)	0.28	0.67					
percentage of glazed (%)	46.15	41.74					
percentage of frame (%)	53.85	58.26					
max. Opening area (m2)	0.00	1.09					
percentage of max. Opening area (%)	0.00	94.78					
Frame material	wood (3cm)	wood (3cm)		wood (3cm)		light tissue	
Type of glass	single (3mm)	single (3mm)					

Side (SW)	1 casement window						
Ext. Window (Kitchen)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.54	open continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.35		no		no	
frame area (m2)	no	0.19		no		no	
percentage of glazed (%)	no	64.81		no		no	
percentage of frame (%)	no	35.19		no		no	
max. Opening area (m2)	no	0.45		no		no	
percentage of max. Opening area (%)	no	83.33		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Back (NW)	1 door						
Ext. Door (backyard)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.85	closed continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.16		no		no	
frame area (m2)	no	1.69		no		no	
percentage of glazed (%)	no	8.65		no		no	
percentage of frame (%)	no	91.35		no		no	
max. Opening area (m2)	no	1.70		no		no	
percentage of max. Opening area (%)	no	91.89		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Back (NW) 1 casement

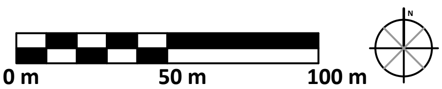
Ext. Window (WC)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.20	open continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.09		no		no	
frame area (m2)	no	0.11		no		no	
percentage of glazed (%)	no	45.00		no		no	
percentage of frame (%)	no	55.00		no		no	
max. Opening area (m2)	no	0.15		no		no	
percentage of max. Opening area (%)	no	75.00		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Int. Door	Fanlight window	Door	use profiles	Fanlight window 1	Fanlight window 2
total area (m2)	no	not applicable	allways closed (bedrooms)	0.39	0.69
glazed area (m2)	no	no	when in opened (others)	0.19	0.29
frame area (m2)	no			0.20	0.40
percentage of glazed (%)	no			48.72	42.03
percentage of frame (%)	no			51.28	57.97
max. Opening area (m2)	no			0.00	0.00
percentage of max. Opening area (%)	no			0.00	0.00
Frame material	no	wood (3cm)		wood (3cm)	wood (3cm)
Type of glass	no	no		single (3mm)	single (3mm)

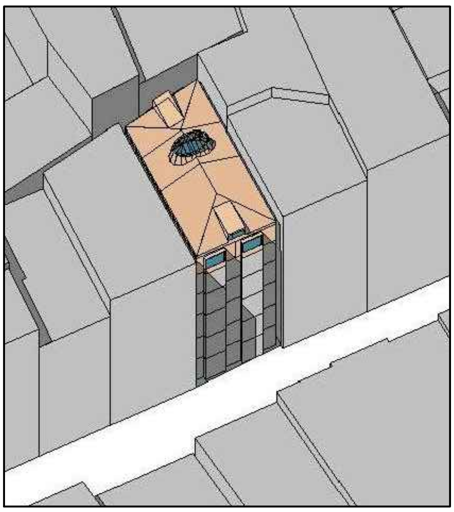
Int. Window	Fanlight window	sash	use profiles
total area (m2)	no	not applicable	allways closed
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

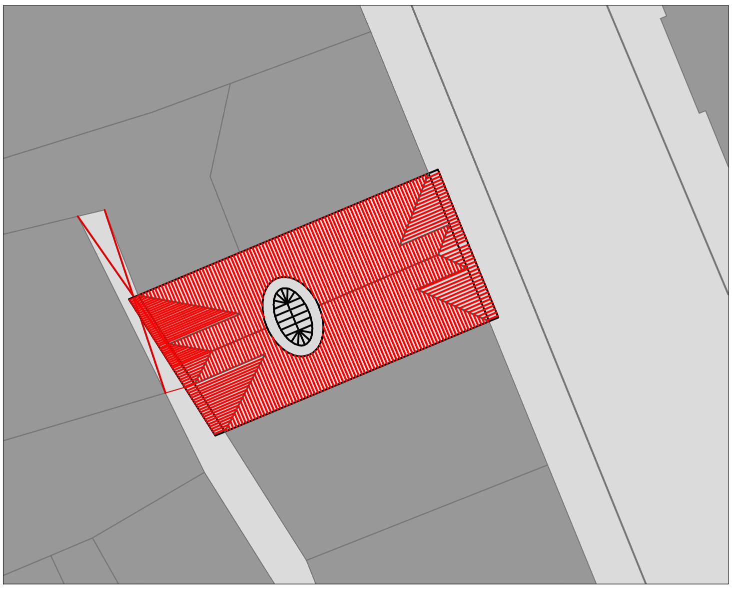
							Operation profile assumed	Hours per year		
IES VE code	Room	Category	Equipment	model	brand	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Source
FLR20010	Hall	lighting	3 halogen lamps			0.1050	1 hour/day	365	38.33	ERSE (35w)
FLR20024	Corridor	lighting	1 compact fluorescent lamp			0.0110	0.5 hours/day	182.5	2.01	ERSE (11w)
FLR20018	Living Room	lighting	1 compact fluorescent lamp			0.0110	4 hours/day	1460	16.06	ERSE (11w)
FLR20018	Living Room	entertainment	1 TV		Philips	0.0900	3 hours/day	1095	98.55	ERSE (90w)
FLR20018	Living Room	entertainment	1 TV in standby		Philips	0.0025	21 hours/day	7665	18.86	Deco Proteste Internet simulator
FLR20018	Living Room	entertainment	1 DVD player			0.2400	0.5 hours/day	182.5	43.80	ERSE (240w)
FLR20018	Living Room	entertainment	1 DVD player in standby			0.0014	23.5 hours day	8577.5	11.84	Deco Proteste Internet simulator
FLR20019	Bedroom 3	lighting	1 compact fluorescent lamp			0.0110	0.5 hours/day	182.5	2.01	ERSE (11w)
FLR20013	Bedroom 2	lighting	1 compact fluorescent lamp			0.0110	1 hour/day	365	4.02	ERSE (11w)
FLR20013	Bedroom 2	entertainment	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR20013	Bedroom 2	entertainment	1 TV in standby			0.0025	23 hours/day	8395	20.66	Deco Proteste Internet simulator
FLR20013	Bedroom 2	entertainment	1 Desktop computer			0.3000	1 hour/day	365	109.50	ERSE (300w)
FLR20009	Bedroom 1	lighting	3 halogen lamps			0.1050	2 hours/day	730	76.65	ERSE (35w)
FLR20025	Kitchen	lighting	2 compact fluorescent lamps			0.0220	3 hours/day	1095	24.09	ERSE (11w)
FLR20025	Kitchen	appliance	1 Washing machine	J853	Samsung	2.0000	2 washes (1.5h)/week	78	156.00	ERSE (2000w) - ver net
FLR20025	Kitchen	appliance	1 Dish washer	ZDF211	Zanuzzi	2.0000	1.5 hours/week	78	156.00	ERSE (2000w) - ver net
FLR20025	Kitchen	appliance	1 fridge / freezer	Class A	Whirlpool	0.0392	On continuously	8760	343.39	model WTE 3111 W (internet manual) - 0.94w/day
FLR20025	Kitchen	appliance	1 Microwave	CRS	Worten	0.9000	0.5 hours/day	182.5	164.25	ERSE (900w)
FLR20025	Kitchen	appliance	1 Microwave in standby	CRS	Worten	0.0043	23.5 hours day	8577.5	37.28	Deco Proteste Internet simulator
FLR20025	Kitchen	appliance	1 Electric frying pan	DF 30AW	Electric	2.0000	1 hour /week	52	104.00	in situ
FLR20025	Kitchen	appliance	1 Iron			1.6000	7 hours /week	364	582.40	ERSE (1600w)
FLR20025	Kitchen	entertainment	1 TV	Trinitron	Sony	0.0900	3 hours /day	1095	98.55	ERSE (90w)
FLR20025	Kitchen	entertainment	1 TV in stand-by	Trinitron	Sony	0.0025	21 hours/day	7665	18.86	Deco Proteste Internet simulator
FLR20025	Kitchen	environment	1 Electric hot water cylinder	75 RI	Aparici	2.0000	On continuously	8760	448.95	AKI - 1.23kWh/Day
FLR20025	Kitchen	appliance	1 Gas stove/oven				2 hours/day (1 bottle /month)		0.00	Households
FLR20004	WC	lighting	1 fluorescent lamp			0.0360	2 hours/day	730	26.28	ERSE (36w)
								TOTAL	**2635.17**	
									3641.00	EDP (kWh/Year)

Case Study 2
Study Area Location Plan

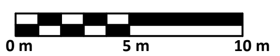


Study area

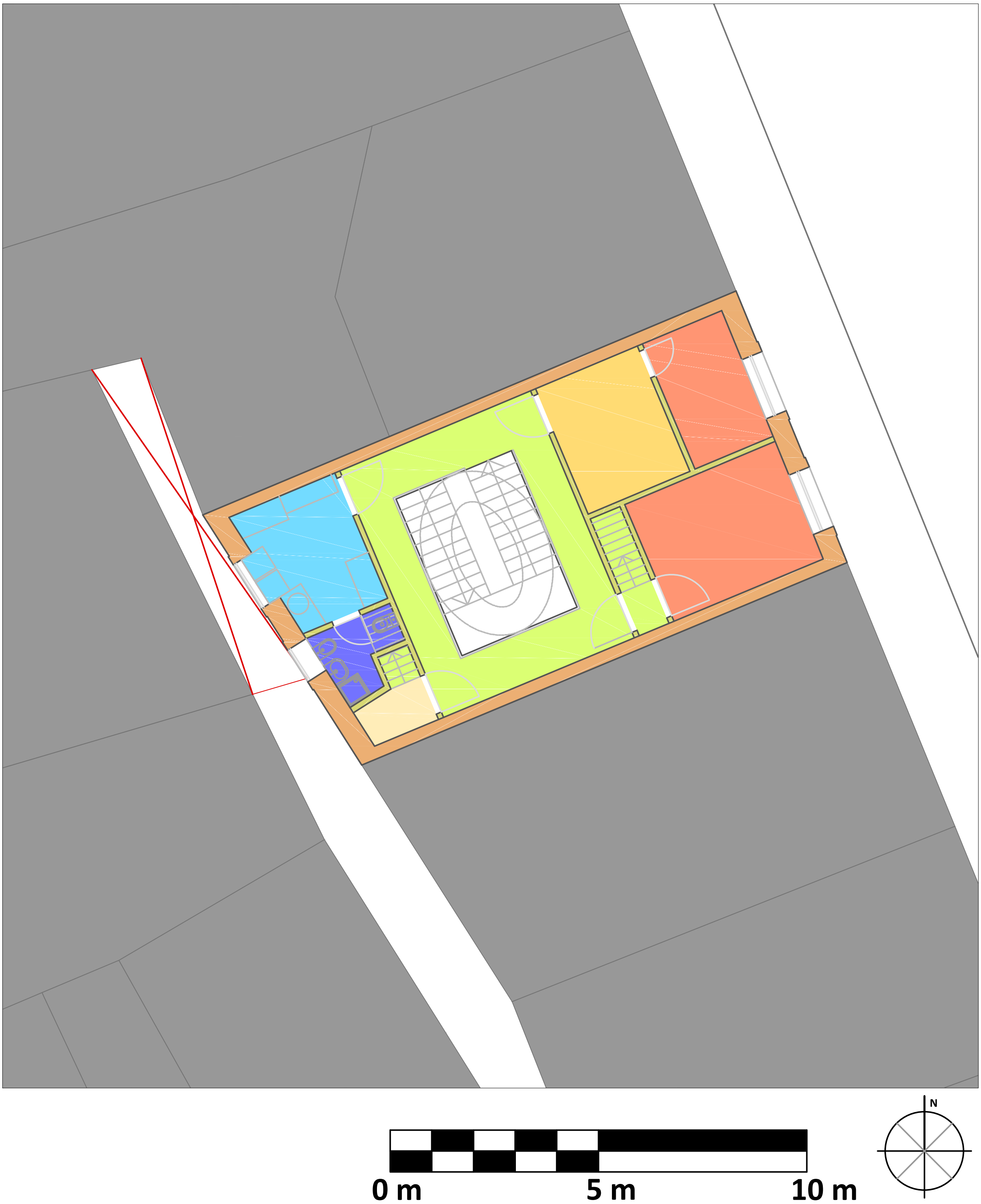


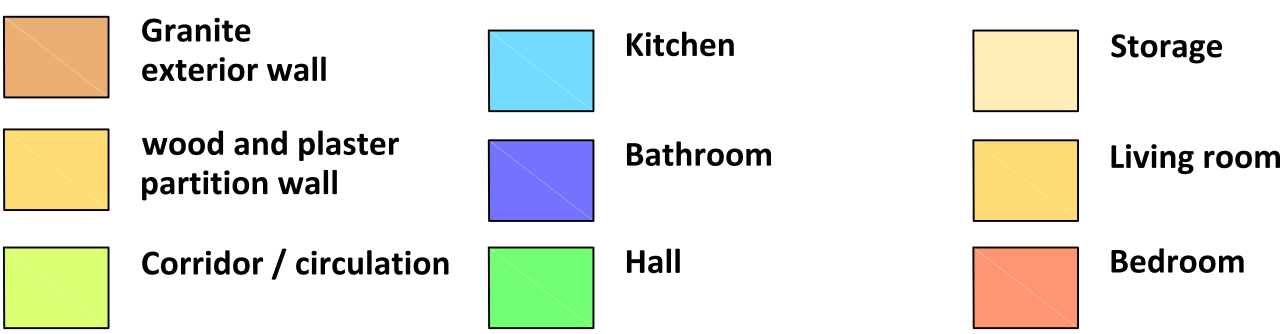


Case 2 site plan

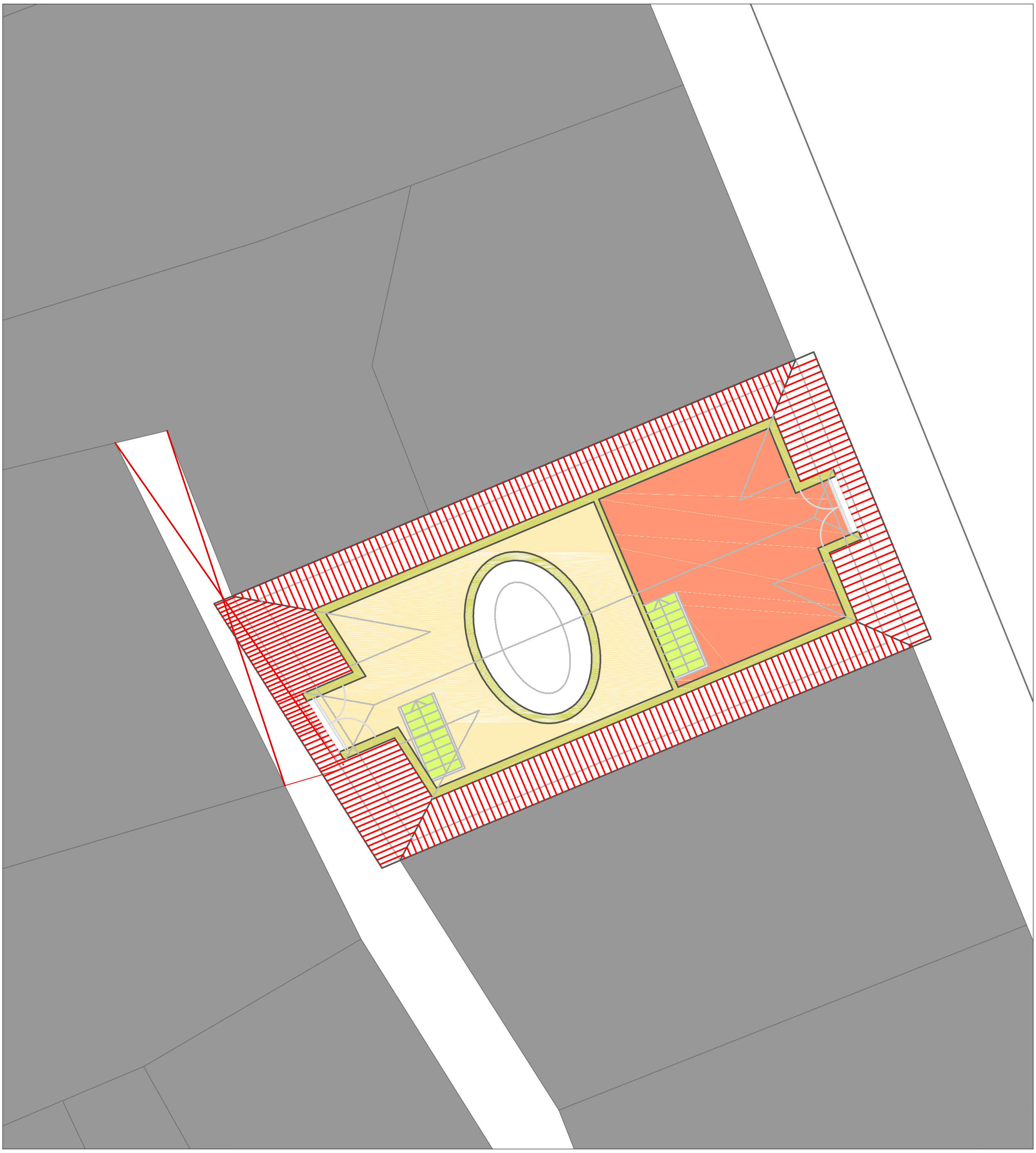


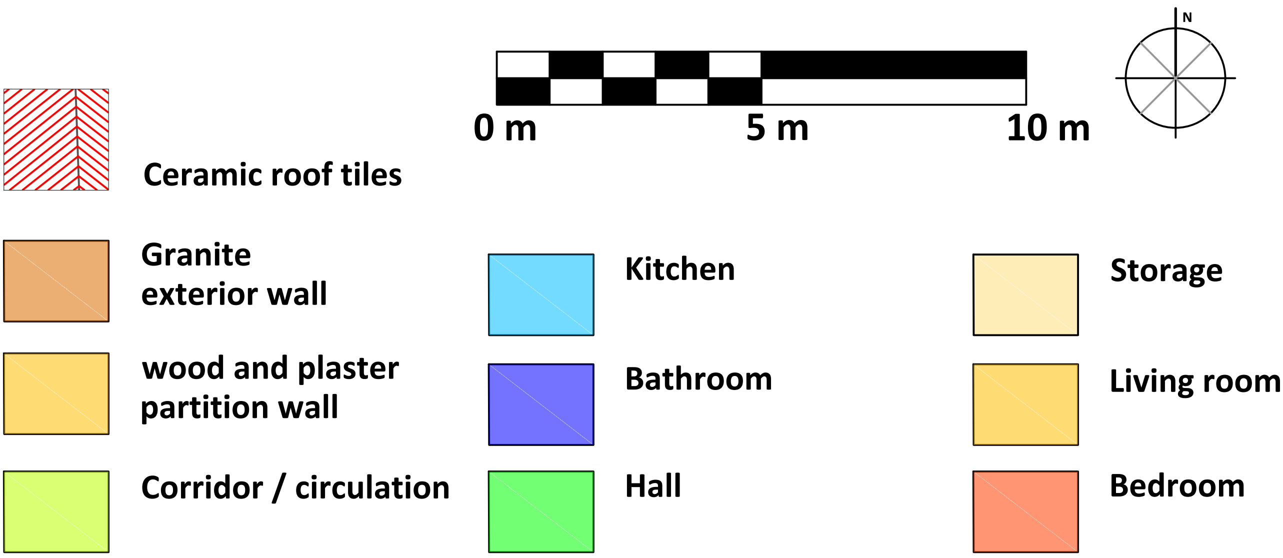
Case Study 2
Variant 3b top - 5th floor plan



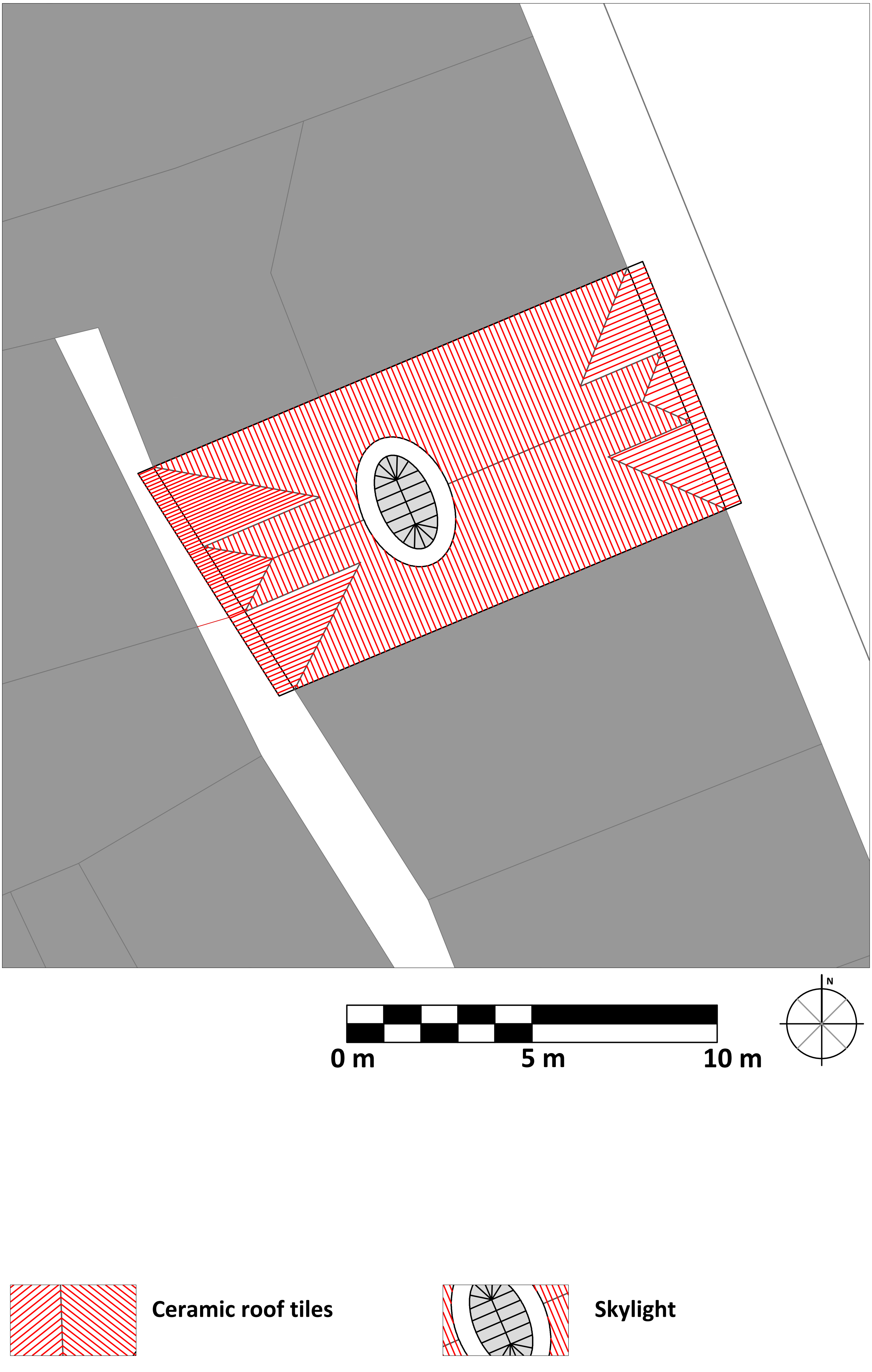


Case Study 2
Variant 3b top - 6th floor plan



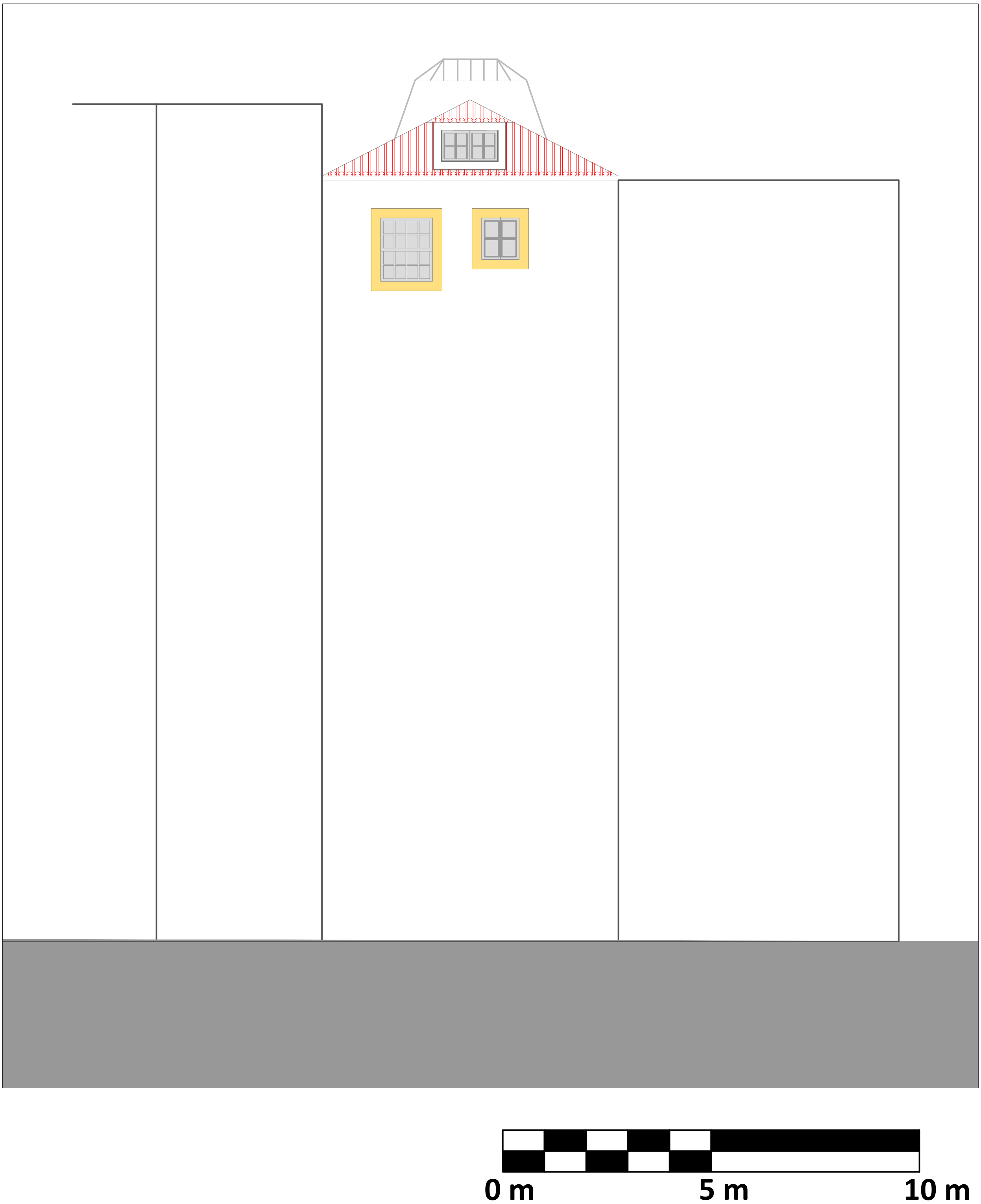


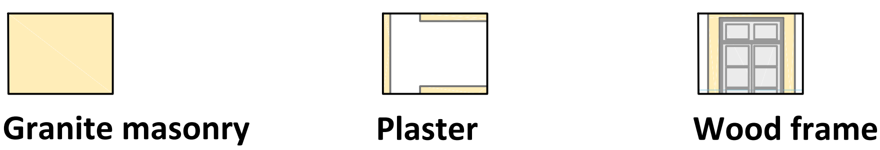
Case Study 2
Variant 3b top - roof plan



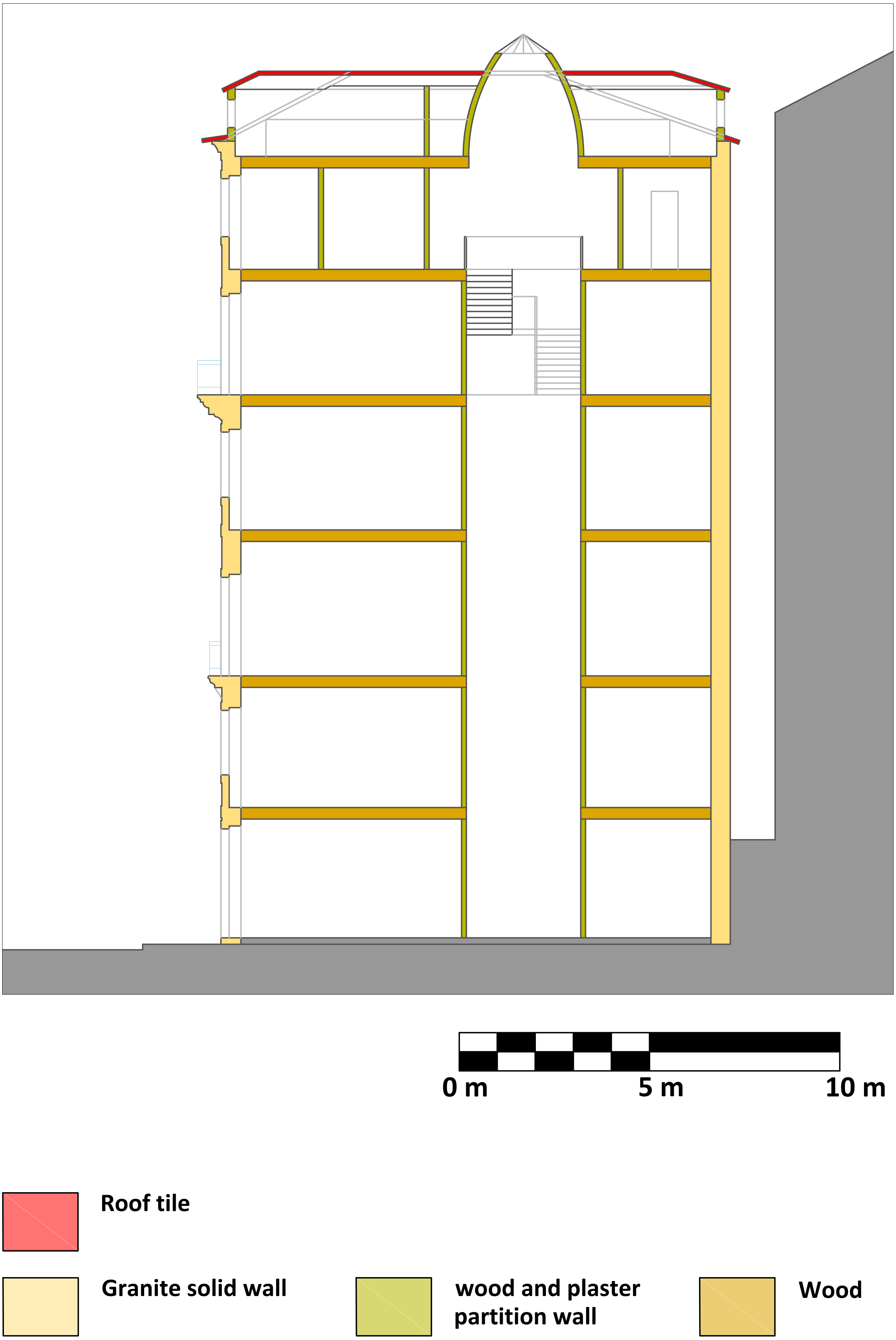
Case Study 2
Variant 3b top - front facade (street)

Case Study 2
Variant 3b top - rear facade (courtyard)



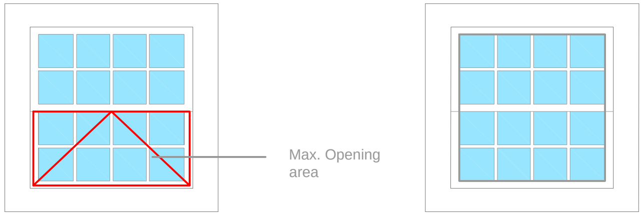


Case Study 2
Variant 3b top - Section



Case Study 2
Variant 3b - top floor - Openings

Front (E) 5th floor x 2



1.03 m2

44.02% max. opening area

2.34 m2
0.10m2 x 16

1.60 m2

68.38% of glazed area

31.62% of frame area

Back (SW) 5th floor x 1

0.83 m2

43.46% max. opening area

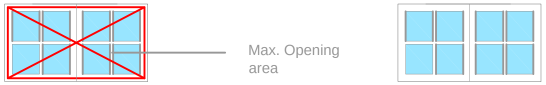
1.91m2
0.08m2 x 16

1.28 m2

67.02% of glazed area

32.98% of frame area

Case Study 2
Variant 3b - top floor - Openings

Back (SW) 5th floor x 1		Front/Back (E/SW) 5th floor x 2	
		 	
0.79 m2	0.90m2 0.14m2 x 4	0.87 m2	0.99m2 0.07m2 x8
	0.56 m2		0.56 m2
87.78% max. opening area	62.22% of glazed area	87.88% max. opening area	56.57% of glazed area
	37.78% of frame area		43.43% of frame area

	type 1	type 2	type 1	type 2	type 3	type 4	type 4
exterior wall	front (E) 5th floor	front (E) 6th floor	Back (SW) 5th floor	Back (SW) 6th floor	front, Back (E, SW)	Side (S) party wall	Side (N) party wall
Total Thickness	0.50	0.20	0.50	0.20	0.22	0.60	0.60
ext layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	granite	plaster (0.025)	plaster (0.025)
layer 1	granite (0.45)	wood+mortar (0.15)	granite (0.45)	wood+mortar (0.15)	granite (0.22)	granite (0.55)	granite (0.55)
layer 2							
layer 3							
layer 4							
int layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	granite	plaster (0.025)	plaster (0.025)

	type 1	type 2	type 3	type 4			
partition wall		new room/livingroom	Kitchen/WC				
Total Thickness	0.13	0.14	0.13	0.13			
ext layer	plaster (0.025)	plaster (0.015)	tile (0.005)	plaster (0.025)			
layer 1	wood+mortar (0.08)	brick (0.11)	mortar (0.02)	wood+mortar (0.08)			
layer 2			wood+mortar (0.08)				
layer 3							
layer 4			mortar (0.02)	mortar (0.02)			
int layer	plaster (0.025)	plaster (0.015)	tile (0.005)	tile (0.005)			

	type 1	type 2	type 3				
Horizontal separation			roof				
Total Thickness	0.30	0.30	0.21				
floor layer	hardwood (0.03)	tile (0.005)	ceramic tile (0.015)				
layer 1	wood beams (0.245)	mortar (0.005)	wood (0.18)				
layer 2		hardwood (0.03)					
layer 3		wood beams (0.235)					
layer 4	timber framing (0.01)	timber framing (0.01)					
ceiling layer	gypsum (0.015)	gypsum (0.015)	wood (0.015)				

Front (E) 5th floor — 2 sash windows

Ext. Window (Rooms)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	2.34	open 1 h day /moorning	2.34	open continuously	2.34	closed continuously
glazed area (m2)	no	1.6					
frame area (m2)	no	0.74					
percentage of glazed (%)	no	68.38					
percentage of frame (%)	no	31.62					
max. Opening area (m2)	no	1.03					
percentage of max. Opening area (%)	no	44.02					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (3mm)					

Front (E) 6th floor — 1 casement window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.99	open 1 h day/moorning	no	not applicable	0.99	closed continuously
glazed area (m2)	no	0.56		no			
frame area (m2)	no	0.43		no			
percentage of glazed (%)	no	56.57		no			
percentage of frame (%)	no	43.43		no			
max. Opening area (m2)	no	0.87		no			
percentage of max. Opening area (%)	no	87.88		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (0.3cm)		no			

Back (SW) 5th floor — 1 sash window

Ext. Window (Kitchen)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.91	open 1 h day/moorning	no	not applicable	no	not applicable
glazed area (m2)	no	1.28		no		no	
frame area (m2)	no	0.63		no		no	
percentage of glazed (%)	no	67.02		no		no	
percentage of frame (%)	no	32.98		no		no	
max. Opening area (m2)	no	0.83		no		no	
percentage of max. Opening area (%)	no	43.46		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (0.3cm)		no		no	

Back (SW) 5th floor — 1 casement

Ext. Window (WC)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.90	open 1 h day/moorning	no	not applicable	0.90	closed continuously
glazed area (m2)	no	0.56		no			
frame area (m2)	no	0.34		no			
percentage of glazed (%)	no	62.22		no			
percentage of frame (%)	no	37.78		no			
max. Opening area (m2)	no	0.79		no			
percentage of max. Opening area (%)	no	87.78		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (0.3cm)		no			

Back (SW) 6th floor — 1 casement window

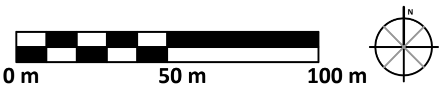
Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.99	open 1 h day/moorning	no	not applicable	0.99	closed continuously
glazed area (m2)	no	0.56		no			
frame area (m2)	no	0.43		no			
percentage of glazed (%)	no	56.57		no			
percentage of frame (%)	no	43.43		no			
max. Opening area (m2)	no	0.87		no			
percentage of max. Opening area (%)	no	87.88		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (0.3cm)		no			

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	excepted bedrooms
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

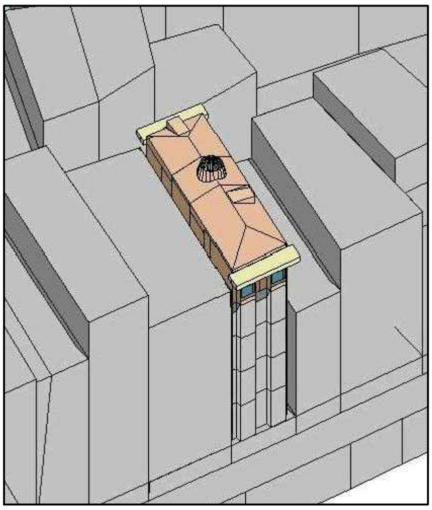
Int. Window	Fanlight window	Door	use profiles
total area (m2)	no	no	not applicable
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

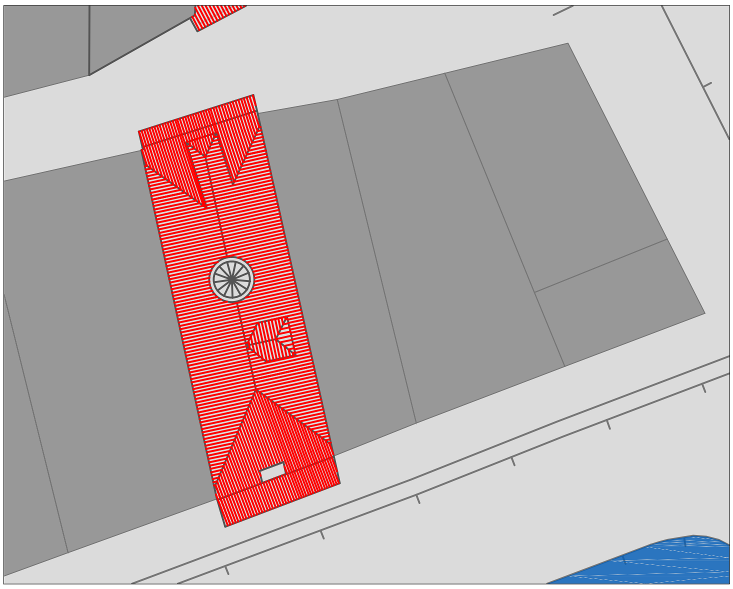
IES VE code	Room	Category	Equipment	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
FLR50016	Bedroom Hall	lighting	1 lamp			0.0600	0.5 hours/day	182.5	10.95	ERSE (60w)
FLR50004	Stairs hall	lighting	2 compact fluorescent lamps			0.0220	3 hours/day	1095	24.09	ERSE (11w)
FLR50015	Living room	lighting	3 halogen lamps			0.1050	3 hours/day	1095	114.98	ERSE (35w)
FLR50015	Living room	entertainment	1 TV		Tecnimagem	0.0900	3 hours/day	1095	98.55	ERSE (90w)
FLR50015	Living room	entertainment	1 TV in standby		Tecnimagem	0.0025	21 hours/day	7665	18.86	Deco Proteste Internet simulator
FLR50015	Living room	entertainment	1 Cable TV box decoder		Meo Box	0.0162	3 hours/day	1095	17.74	EDP (8w) / **Quercus (16.2w)**
FLR50015	Living room	entertainment	1 Cable TV box decoder in standby		Meo Box	0.0094	21 hours/day	7665	72.05	Quercus (9.4w)
FLR50023	Bedroom 1	lighting	3 halogen lamps			0.1050	1.5 hours/day	547.5	57.49	ERSE (35w)
FLR50023	Bedroom 1	lighting	2 lamps (table lamps)			0.0800	1.5 hours/day	547.5	43.80	ERSE (40w)
FLR50023	Bedroom 1	entertainment	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR50023	Bedroom 1	entertainment	1 TV in stand-by			0.0025	23 hours/day	8395	20.66	Deco Proteste Internet simulator
FLR50023	Bedroom 1	entertainment	1 DVD Player		Nustic or Mustic ?	0.2400	0.5 hours/day	182.5	43.80	ERSE (240w)
FLR50023	Bedroom 1	entertainment	1 DVD Player in standby			0.0014	23.5 hours/day	8577.5	12.01	Deco Proteste Internet simulator
FLR50023	Bedroom 1	entertainment	1 Cable TV box decoder		Meo Box	0.0162	1 hour/day	365	5.91	EDP (8w) / Quercus (16.2w)
FLR50023	Bedroom 1	entertainment	1 Cable TV box decoder in standby		Meo Box	0.0094	23 hours/day	8395	78.91	Quercus (9.4w)
FLR50023	Bedroom 1	environment	1 Electric Fan			0.1000	all night in summer		0.00	LG (100w)
FLR50024	Bedroom 2	lighting	3 halogen lamps			0.1050	1.5 hours/day	547.5	57.49	ERSE (35w)
FLR50020	Kitchen	lighting	1 fluorescent lamp			0.0580	4 hours/day	1460	84.68	ERSE (58w)
FLR50020	Kitchen	lighting	1 compact fluorescent lamp			0.0110	2 hours/day	730	8.03	ERSE (11w)
FLR50020	Kitchen	appliance	1 Washing machine	HE605 TX	Haier	1.9500	1.5 hours/day	547.5	416.10	1 washing/day. Manual in internet
FLR50020	Kitchen	appliance	1 fridge	Predilect	Fagor	0.1500	On continuously	8760	223.00	ERSE (150w) Topten (223 kWh/year)
FLR50020	Kitchen	appliance	1 freezer		Ariston	0.2500	On continuously	8760	296.00	ERSE (250w) Topten (296 kWh/year)
FLR50020	Kitchen	appliance	1 Microwave			0.9000	0.5 hours/day	182.5	164.25	ERSE (900w)
FLR50020	Kitchen	appliance	1 Microwave in standby			0.0043	23.5 hours/day	8577.5	36.88	Deco Proteste Internet simulator
FLR50020	Kitchen	appliance	1 Iron			1.6000	0.5 hour/day	182.5	292.00	ERSE (1600w)
FLR50020	Kitchen	appliance	1 Extractor hood		Airlux	0.1400	2 hours/day	730	102.20	ERSE (140w)
FLR50020	Kitchen	appliance	1 Toaster			1.0000	0.25 hours/day	91.25	91.25	ERSE (1000w)
FLR50020	Kitchen	environment	electric hot water cylinder		Spersil	1.0000	On continuously	8760	321.20	50 l - in situ; AKI - 0.88kWh/Day
FLR50020	Kitchen	appliance	1 Gas stove/oven				0.5 bottles/month		0.00	Households
FLR50032	WC	lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
FLR50019	Storage	lighting	1 lamp			0.0600	0.25 hours/day	91.25	5.48	ERSE (60w)
FLR60034	Bedroom 3 (Floor 7)	lighting	3 halogen lamps			0.1050	1.5 hours/day	547.5	57.49	ERSE (35w)
FLR60034	Bedroom 3 (Floor 7)	entertainment	1 TV			0.0900	1.5 hours/day	547.5	49.28	ERSE (90w)
FLR60034	Bedroom 3 (Floor 7)	entertainment	1 TV in standby			0.0025	22.5 hours/day	8212.5	20.21	Deco Proteste Internet simulator
FLR60034	Bedroom 3 (Floor 7)	entertainment	1 DVD Player			0.2400	1 hour/day	365	87.60	ERSE (240w)
FLR60034	Bedroom 3 (Floor 7)	entertainment	1 DVD Player in stand-by			0.0014	23 hours/day	8395	11.75	Deco Proteste Internet simulator
FLR60034	Bedroom 3 (Floor 7)	environment	1 Electric oil-filled radiator heater			2.0000	1 h when cold (less 19)		0.00	ERSE (2000w)
FLR60039	Storage (Floor 7)	lighting	3 halogen lamps			0.1050	0.125 hours/day	45.625	4.79	ERSE (35w)
								TOTAL	**3004.21**	
									5978.26	EDP (kWh/Year)

Case Study 3
Study Area Location Plan

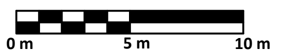


Study area

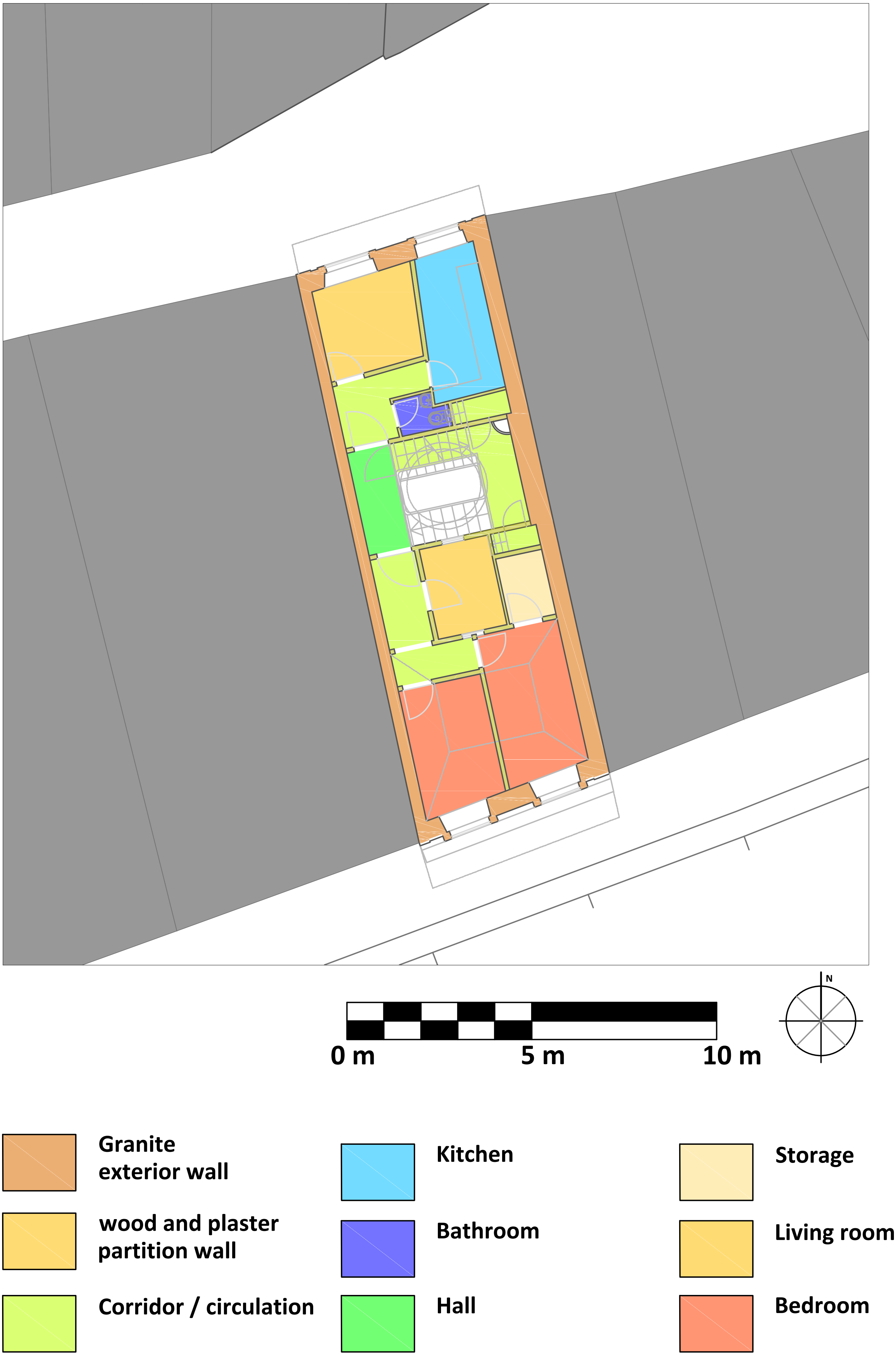




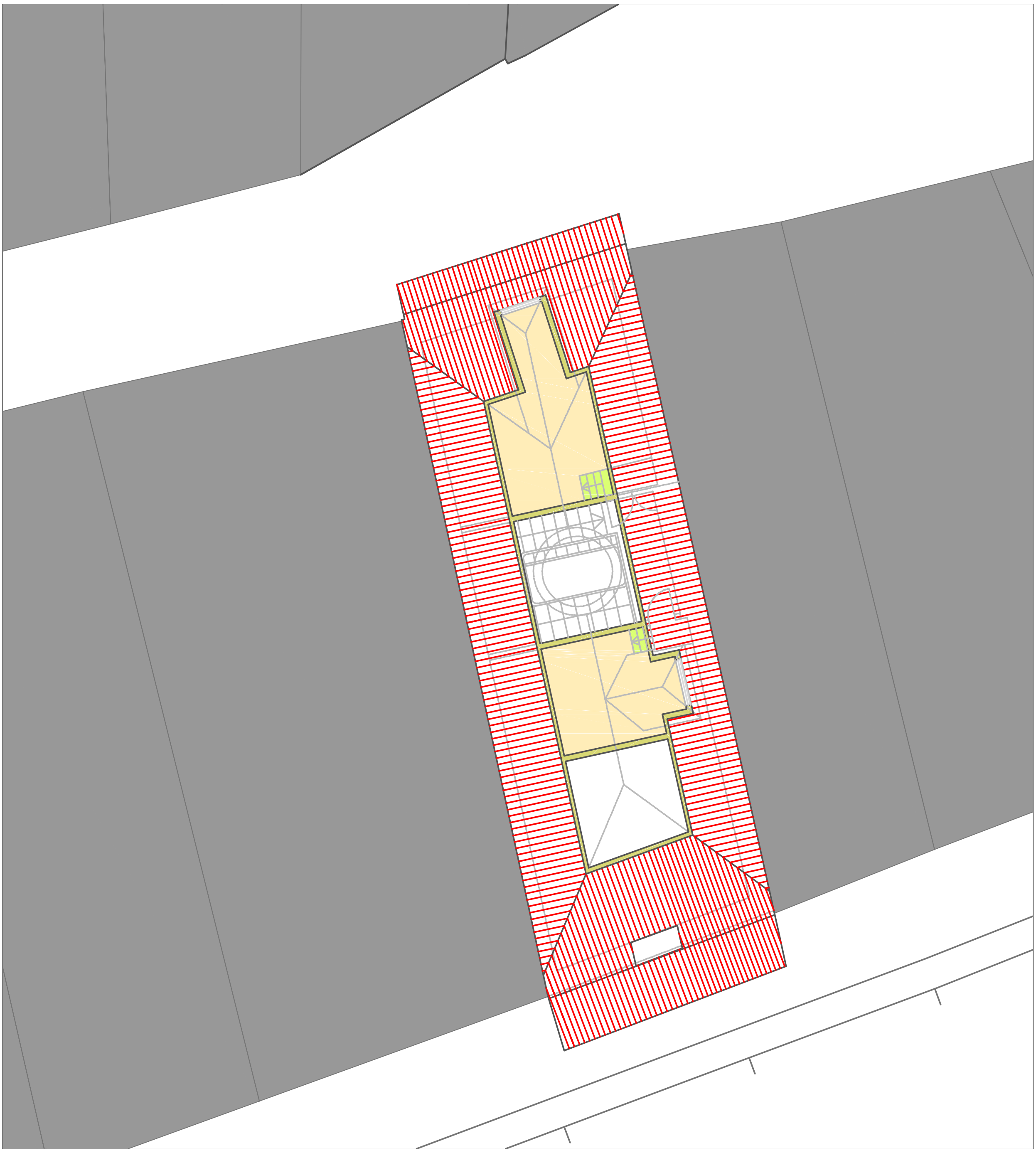
Case 3 site plan



Case Study 3
Variant 3a top - 4th floor plan



Case Study 3
Variant 3a top - 5th floor plan



Ceramic roof tiles

Granite exterior wall

wood and plaster partition wall

Corridor / circulation

Kitchen

Bathroom

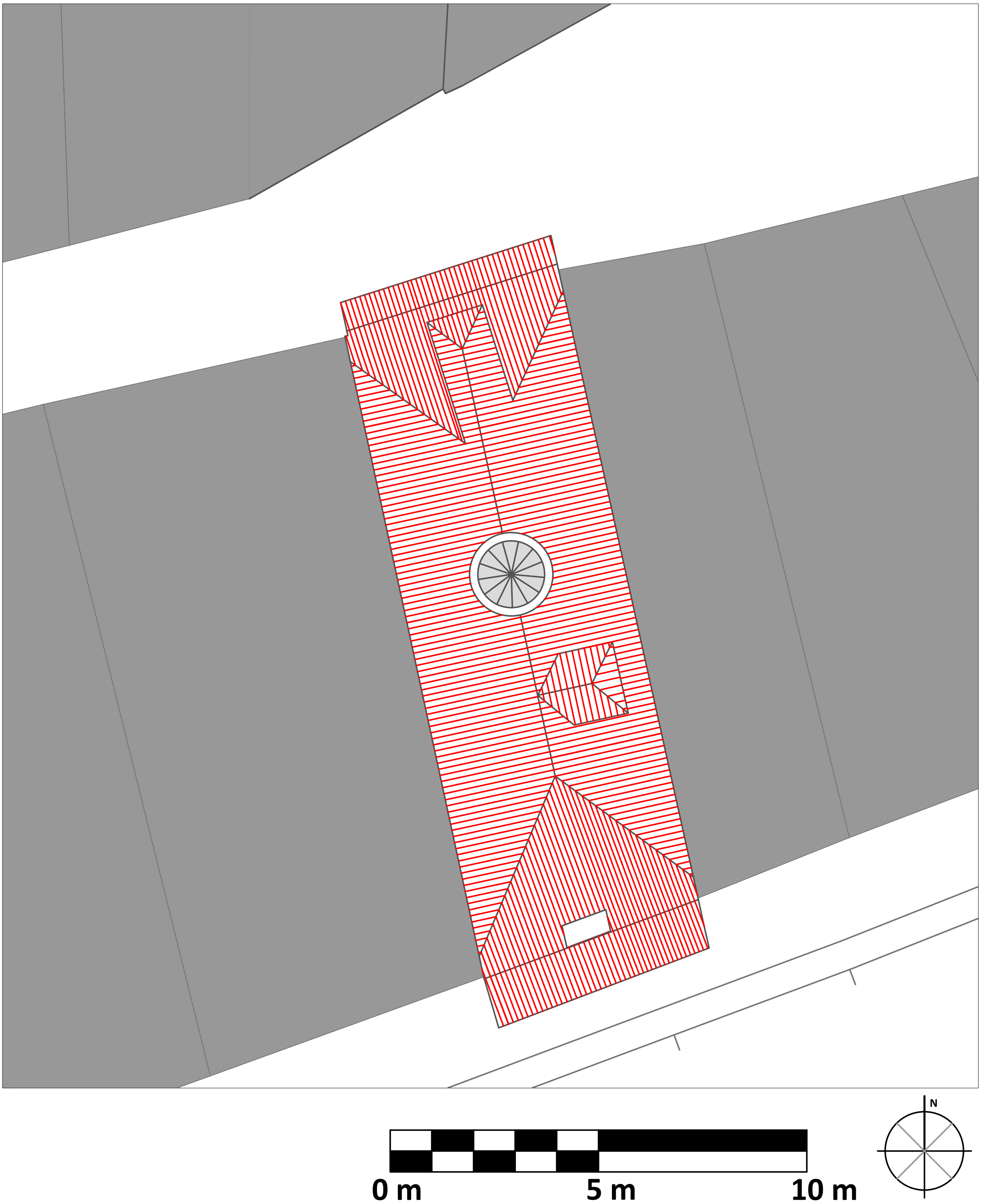
Hall

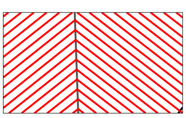
Storage

Living room

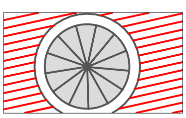
Bedroom

Case Study 3
Variant 3a top - roof plan



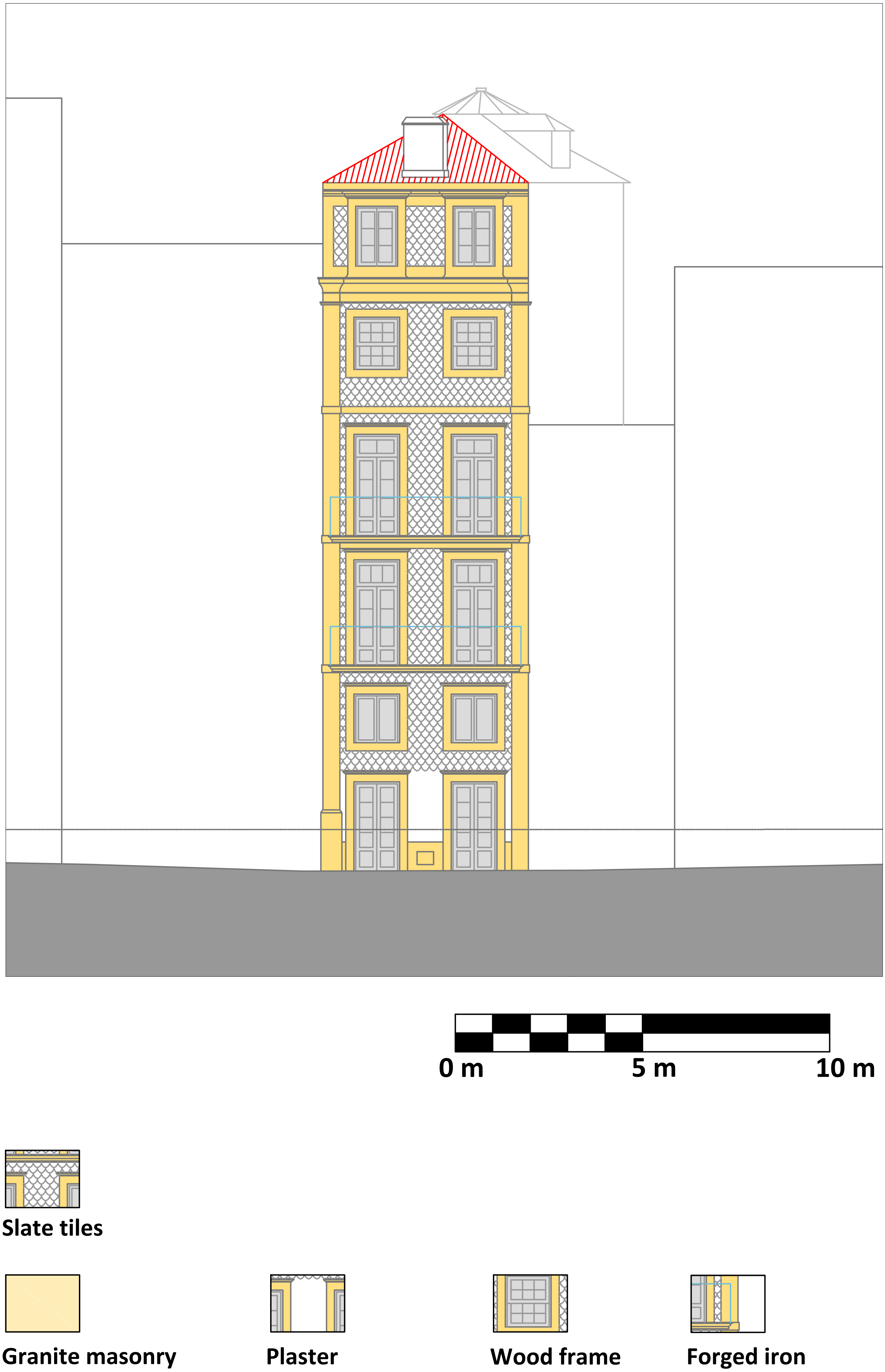


Ceramic roof tiles

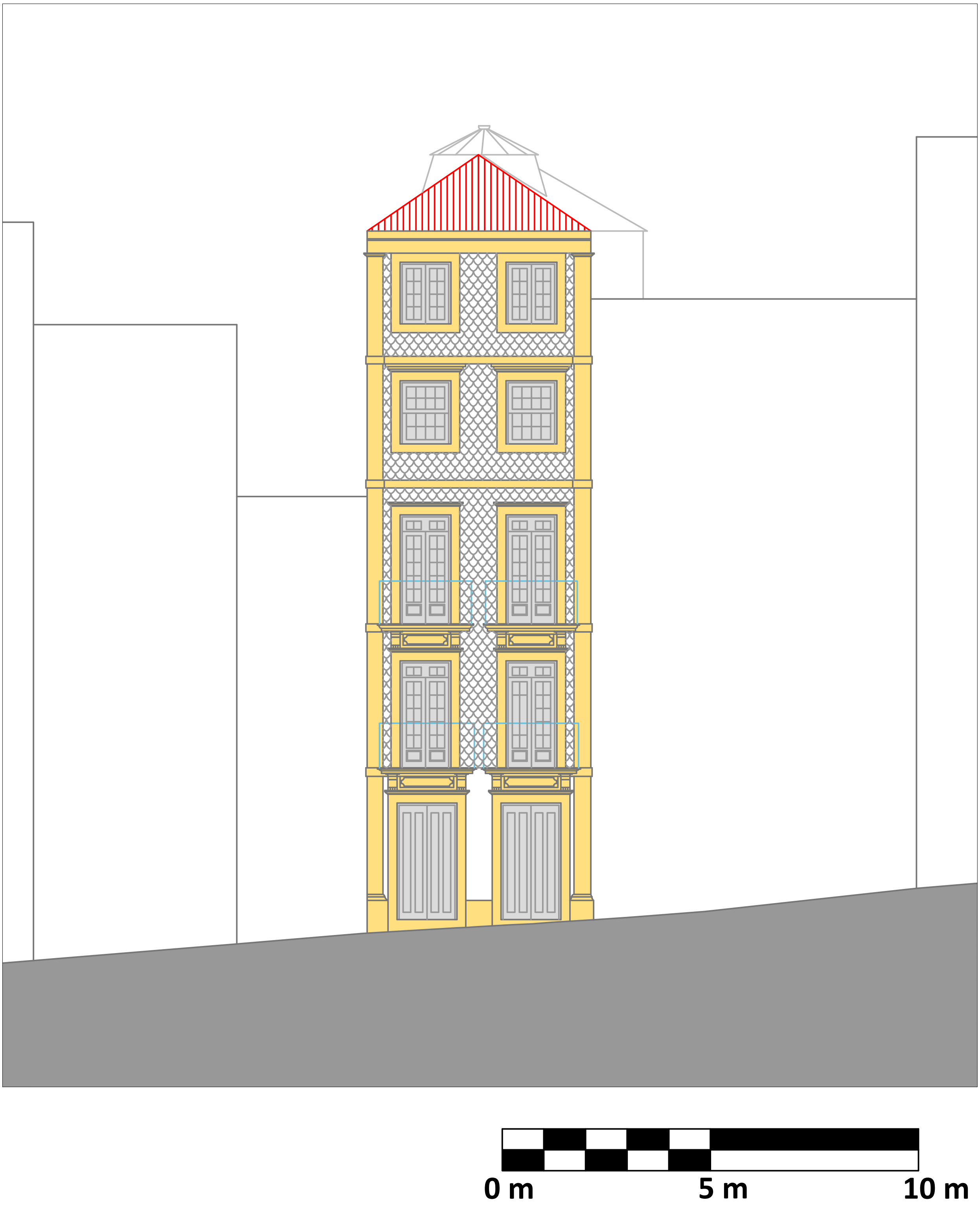


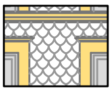
Skylight

Case Study 3
Variant 3a top - front facade (river)

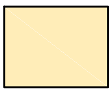


Case Study 3
Variant 3a top - rear facade (street)

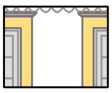




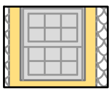
Slate tiles



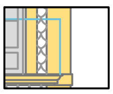
Granite masonry



Plaster



Wood frame



Forged iron

Case Study 3 **Variant 3a top - Section**

Case Study 3
Variant 3a - top floor - Openings

Front (S) 5th floor x 2

Back (N) 5th floor x 2

1.55 m2

86.59% max.
opening area

1.79 m2
0.16 m2 x6

0.96 m2

53.63% of glazed area

1.81 m2
0.05 m2 x 16

0.80 m2

44.20% of glazed area

1.57 m2

86.74% max.
opening area

Case Study 3
Variant 3a - top floor - Openings

Side (E) 6th floor x1

Back (N) 6th floor x1

0.76 m2
0.05 m2 x 8

0.40 m2

52.63% of glazed area

0.61 m2

80.26% max.
opening area

0.64 m2
0.04 m2 x 8

0.32 m2

50.00% of glazed area

0.50 m2

78.13% max.
opening area

	type 1 (bedrooms)	type 1 (livingroom)	type 2 (Kitchen)	type 3	type 4	type 5	
exterior wall	front (S) 5th floor	Back (N) 5th floor	Back (N) 5th floor	front, Back (S, N)	Side (E) party wall	Side (W) party wall	
Total Thickness	0.550	0.550	0.550	0.215	0.480	0.320	
ext layer	slate+wood (0.05)	slate+wood (0.05)	slate+wood (0.05)	granite	plaster (0.025)	plaster (0.025)	
layer 1	granite (0.475)	granite (0.475)	granite (0.475)	granite (0.215)	granite (0.43)	granite (0.27)	
layer 2							
layer 3							
layer 4							
int layer	plaster (0.025)	plaster (0.025)	tile (0.215)	granite	plaster (0.025)	plaster (0.025)	

	type 1	type 2	type 2				
partition wall							
Total Thickness	0.13	0.13	0.13				
ext layer	plaster (0.025)	plaster (0.025)	tile (0.005)				
layer 1	wood+mortar (0.08)	wood+mortar (0.08)	mortar (0.02)				
layer 2			'wood+mortar (0.08)				
layer 3							
layer 4		mortar (0.02)	mortar (0.02)				
int layer	plaster (0.025)	tile (0.005)	tile (0.005)				

	type 1	type 2	type 3				
Horizontal separation			roof				
Total Thickness	0.30	0.30	0.21				
floor layer	hardwood (0.03)	tile (0.005)	ceramic tile (0.015)				
layer 1	wood beams (0.245)	mortar (0.005)	wood (0.18)				
layer 2		hardwood (0.03)					
layer 3		wood beams (0.235)					
layer 4	timber framing (0.01)	timber framing (0.01)					
ceiling layer	gypsum (0.015)	gypsum (0.015)	wood (0.015)				

Front (S) 5th floor — 2 casement windows

Ext. Window (Rooms)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile	Exterior blinders	use profile
total area (m2)	no	1.79	open 2 h day /summer	no	not applicable	1.79	closed continuously	1.79	75% open during day
glazed area (m2)	no	0.96	closed continuously in winter	no					closed during night and away
frame area (m2)	no	0.83		no					
percentage of glazed (%)	no	53.63		no					
percentage of frame (%)	no	46.37		no					
max. Opening area (m2)	no	1.55		no					
percentage of max. Opening area (%)	no	86.59		no					
Frame material	no	wood (3cm)		no		light tissue		plastic (0.01)	
Type of glass	no	single (3mm)		no					

Back (N) 5th floor — 2 casement windows

Ext. Window (Kitchen; Livingroom)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.81	open 2 h day /summer	no	not applicable	1.81	closed continuously
glazed area (m2)	no	0.8	closed continuously in winter	no			
frame area (m2)	no	1.01		no			
percentage of glazed (%)	no	44.20		no			
percentage of frame (%)	no	55.80		no			
max. Opening area (m2)	no	1.57		no			
percentage of max. Opening area (%)	no	86.74		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (0.3cm)		no			

Back (N) 6th floor — 1 casement

Ext. Dormer Window	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.64	closed continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.32		no		no	
frame area (m2)	no	0.32		no		no	
percentage of glazed (%)	no	50.00		no		no	
percentage of frame (%)	no	50.00		no		no	
max. Opening area (m2)	no	0.50		no		no	
percentage of max. Opening area (%)	no	78.13		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (0.3cm)		no		no	

Side (E) 6th floor — 1 casement

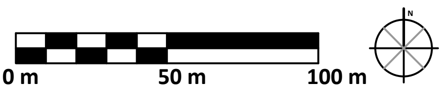
Ext. Dormer Window	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.76	closed continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.4		no		no	
frame area (m2)	no	0.36		no		no	
percentage of glazed (%)	no	52.63		no		no	
percentage of frame (%)	no	47.37		no		no	
max. Opening area (m2)	no	0.61		no		no	
percentage of max. Opening area (%)	no	80.26		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (0.3cm)		no		no	

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	excepted bedrooms
frame area (m2)	no		and acess to 6th floor
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

Int. Window	Fanlight window	sash	use profiles
total area (m2)	no		closed continuously
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no	0.65	
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
FLR40064	Stairs	Lighting	2 compact fluorescent lamps			0.0220	0.5 hours/day	182.5	4.02	ERSE (11w)
FLR40064	Stairs	Lighting	1 lamp			0.0400	0.5 hours/day	182.5	7.30	ERSE (40w)
FLR40037	Corridor 1	Lighting	1 compact fluorescent lamp			0.0110	0.5 hours/day	182.5	2.01	ERSE (11w)
FLR40009	Corridor 2	Lighting	1 compact fluorescent lamp			0.0110	0.5 hours/day	182.5	2.01	ERSE (11w)
FLR40088	Corridor 3	Lighting	1 lamp			0.0400	0.5 hours/day	182.5	7.30	ERSE (40w)
FLR40022	Livingroom 1	Lighting	5 lamps			0.2000	2 hours/day	730	146.00	ERSE (40w)
FLR40022	Livingroom 1	Entertainment	1 Hi-Fi			0.0600	0.125 hours/day	45.625	2.74	ERSE (60w)
FLR40022	Livingroom 1	Entertainment	1 HI-Fi standby			0.0010	23.875 hours/day	8714.375	8.76	Deco Proteste Internet simulator
FLR40008	Living Room	Lighting	2 compact fluorescent lamps			0.2200	2 hours/day	730	160.60	ERSE (11w)
FLR40008	Living Room	Entertainment	1 Plasma TV			0.3000	2 hours/day	730	219.00	ERSE (300w)
FLR40008	Living Room	Entertainment	1 Plasma TV in standby			0.0009	22 hours/day	8030	7.55	SELINA
FLR40091	Bedroom 1	Lighting	2 lamps			0.0800	1 hour/day	365	29.20	ERSE (40w)
FLR40091	Bedroom 1	Entertainment	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR40091	Bedroom 1	Entertainment	1 TV in standby			0.0025	23 hours/day	8395	20.99	Deco Proteste Internet simulator
FLR40091	Bedroom 1	Environment	1 Electric oil-filled radiator heater				**1h/day with cold (less 19)**		0.00	
FLR40092	Bedroom2	Lighting	4 lamps			0.1600	2 hours/day	730	116.80	ERSE (40w)
FLR40092	Bedroom2	Entertainment	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR40092	Bedroom2	Entertainment	1 TV in standby			0.0025	23 hours/day	8395	20.99	Deco Proteste Internet simulator
FLR40041	Kitchen	Lighting	2 fluorescent lamps			0.0720	3 hours/day	1095	78.84	ERSE (36w)
FLR40041	Kitchen	Appliance	1 Microwave		Taurus	0.8000	0.25 hours/day	91.25	73.00	in situ
FLR40041	Kitchen	Appliance	1 Microwave in standby		Taurus	0.0043	23.75 hours/day	8668.75	37.28	Deco Proteste Internet simulator
FLR40041	Kitchen	Appliance	1 Fridge / freezer		Balay	0.3000	On continuously	8760	293.00	ERSE (300w) Balay internet (293KWh/year)
FLR40041	Kitchen	Appliance	1 Extractor hood			0.1400	1 hour/day	365	51.10	ERSE (140w)
FLR40041	Kitchen	Appliance	1 Washing machine	Maxx 7	Bosch	1.1900	2/3 washes week (2.58 hours each)	335.4	399.13	Catalog internet
FLR40041	Kitchen	Entertainment	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR40041	Kitchen	Entertainment	1 TV in standby			0.0025	23 hours/day	8395	20.99	Deco Proteste Internet simulator
FLR40041	Kitchen	Environment	1 electric hot water cylinder		Spersil	1.0000	On continuously	8760	321.20	50 l in situ; AKI - 0.88kWh/Day
FLR40041	Kitchen	Appliance	1 Gas stove/oven				1.5 bottles/month		0.00	Households
FLR40038	WC	Lighting	1 compact fluorescent lamp			0.0110	1 hour/day	365	4.02	ERSE (11w)
FLR40011	Storage	Lighting	1 lamp			0.0400	0.25 hours/day	13	0.52	ERSE (40w)
FLR50021	Floor 5 Front Storage	Lighting	1 lamp			0.0400	0.25 hours/week	13	0.52	ERSE (40w)
FLR50018	Floor 5 Back Storage	Lighting	1 lamp			0.0400	0.25 hours/week	13	0.52	ERSE (40w)
								TOTAL	**2133.90**	
									2950.27	EDP (kWh/Year)

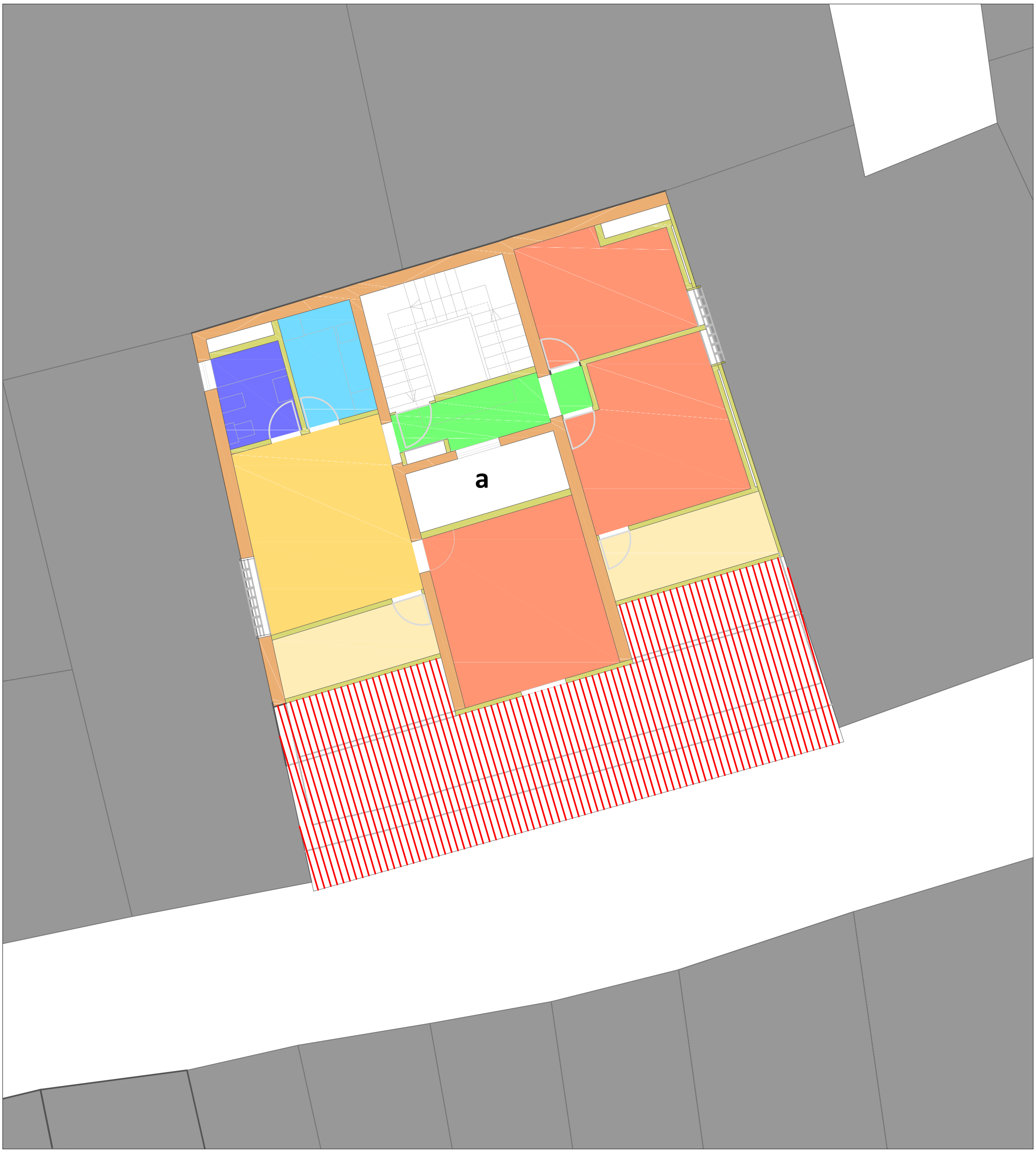
Case Study 4
Study Area Location Plan



Study area

Case 4 site plan

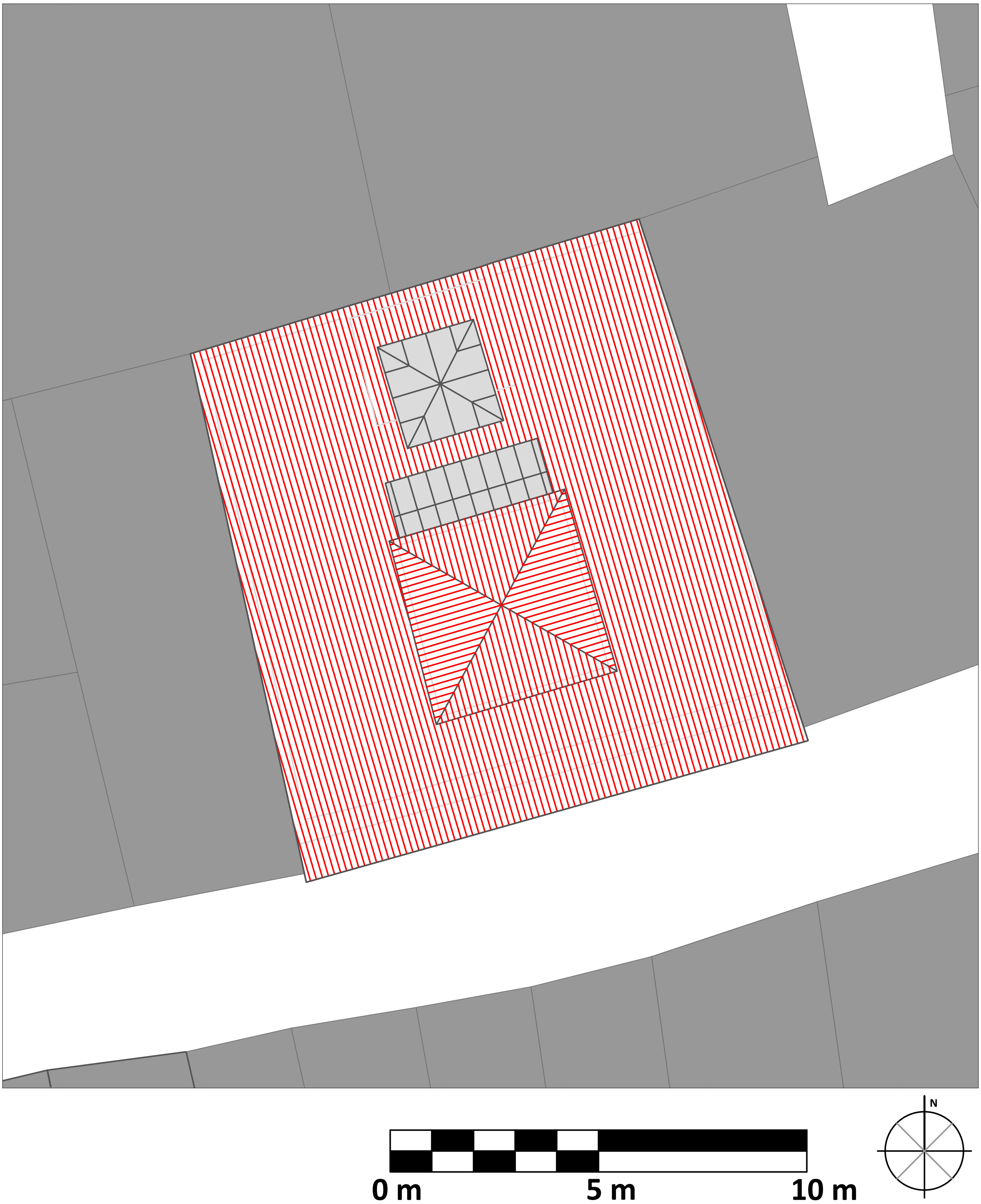
Case Study 4
Variant 4 top - 4th floor plan

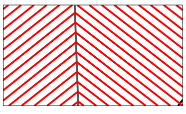


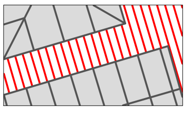
a - Inner courtyard

	Ceramic roof tiles				
	Granite exterior wall		Kitchen		Storage
	brick and plaster partition wall		Bathroom		Living room
	Corridor / circulation		Hall		Bedroom

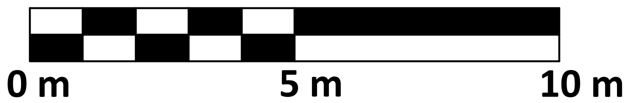
Case Study 4
Variant 4 top - roof plan




Ceramic roof tiles


Skylights

Case Study 4
Variant 4 top - front facade (street)



Granite masonry | Plaster | Wood frame | Forged iron

Case Study 4
Variant 4 top - Section

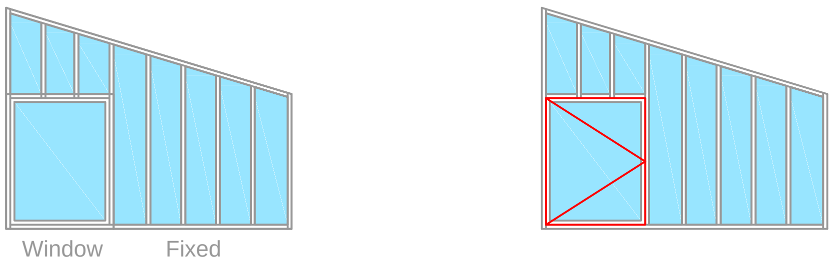
Roof tile

Granite solid wall

brick and plaster partition wall

Concrete

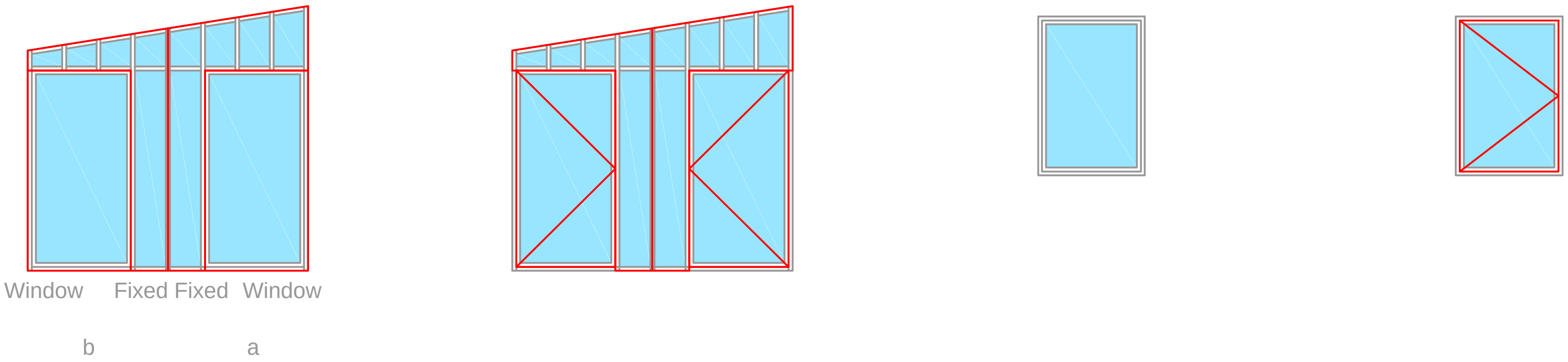
Case Study 4
Variant 4 - top floor - Openings

Side (W) 4th floor x 1			Front (S) 4th floor x 1	
				
0.55m2 0.41m2	1.37m2	0.48m2	1.64 m2 0.08m2 x12	0.70m2
0.41 m2	1.145 m2		0.96 m2	
74.55% of glazed area	83.58% of glazed area	87.27% max. opening area	58.54% of glazed area	42.68% max. opening area

Case Study 4
Variant 4 - top floor - Openings

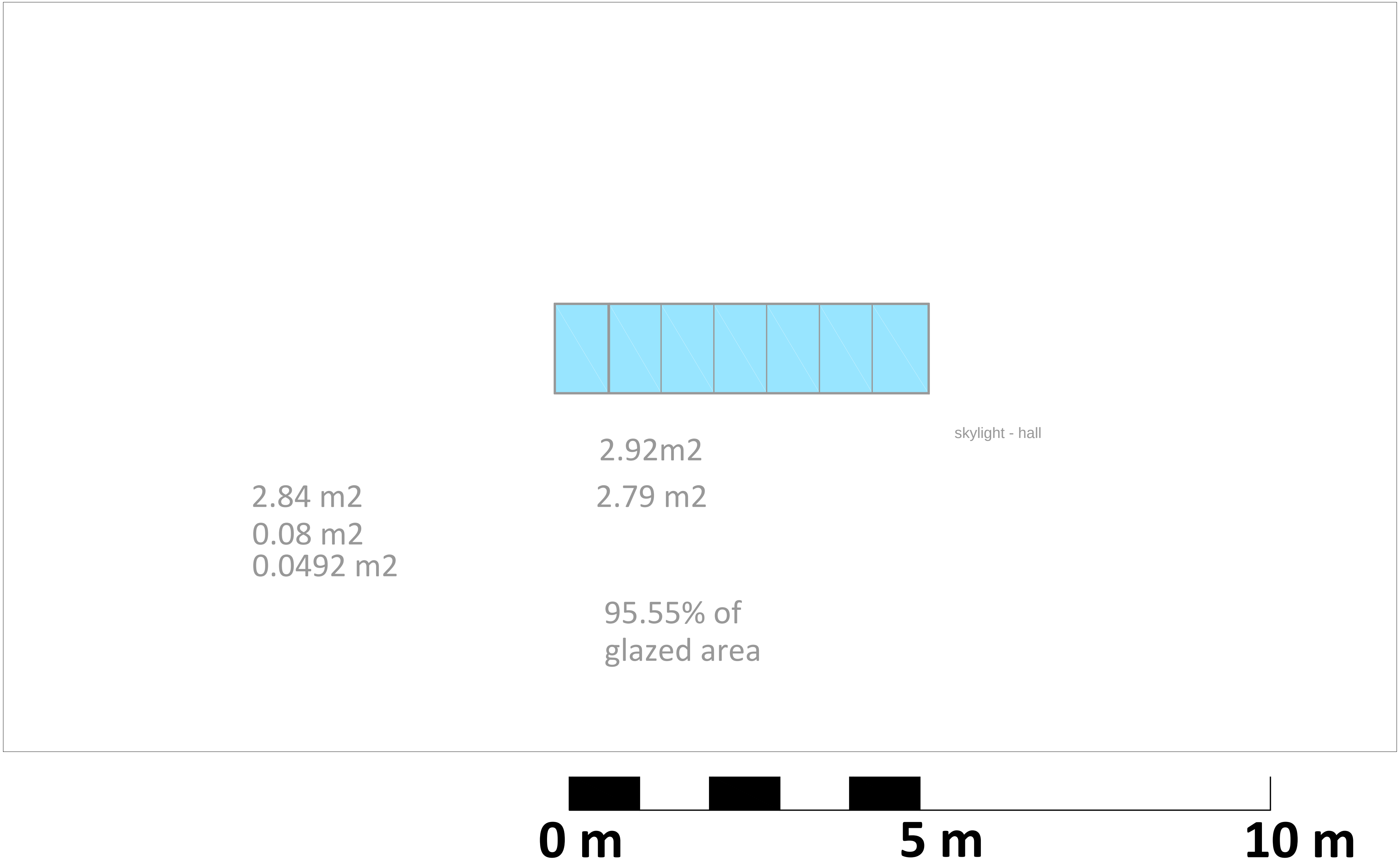
Side (E) 4th floor (2 parts)

Side (W) 4th floor x 1



0.82m2 a / b 0.68m2	0.59m2 a	0.46m2 a	0.77m2	0.67m2 0.51m2	0.59m2
0.68 m2	0.4575 m2	0.352 m2		0.51 m2	
82.93% of glazed area	77.97% of glazed area	76.09% of glazed area	93.90% max. opening area	76.12% of glazed area	88.06% max. opening area

Case Study 4
Variant 4 - top floor - Openings



	type 1	type 2	type 3	type 4	type 5	type 6	type 7
exterior wall	Side (S) 4th floor (room)	side (W) 4th floor (room)	side (E) 4th floor (room)	side (W) 4th floor (livingroom)	side (W) 4th floor (WC)	Stair / Kitchen	back house
Total Thickness	0.200	0.245	0.275	0.300	0.300	0.250	0.300
ext layer	corrugated metal sheet (5 mm)	corrugated metal sheet (5 mm)	corrugated metal sheet (5 mm)	corrugated metal sheet (5 mm)	corrugated metal sheet (5 mm)	plaster (0.015)	
layer 1	wood / cavity (0.02)	wood / cavity (0.02)	wood / cavity (0.02)	wood / cavity (0.02)	wood / cavity (0.02)	granite (0.22)	granite (0.285)
layer 2	brick (0.15)	granite (0.205)	granite (0.235)	granite (0.26)	granite (0.26)		
layer 3							
layer 4						mortar (0.01)	
int layer	plaster (0.015)	plaster (0.015)	plaster (0.015)	plaster (0.015)	Tile (0.015)	tile (0.005)	plaster (0.015)

	type 8	type 9	type 10	type 11	type 12
exterior wall	Side (E) 4th floor	4th floor (courtyard/livingroom)	4th floor (courtyard / bedroom3)	4th floor (courtyard / bedroom1)	4th floor (courtyard / Hall)
Total Thickness	0.150	0.235	0.265	0.140	0.265
ext layer	corrugated metal sheet (5 mm)	plaster (0.015)	plaster (0.015)	plaster (0.015)	plaster (0.015)
layer 1	wood / cavity (0.02)	granite (0.205)	granite (0.235)	brick (0.11)	granite (0.235)
layer 2	brick (0.11)				
layer 3					
layer 4					
int layer	plaster (0.015)	plaster (0.015)	plaster (0.015)	plaster (0.015)	plaster (0.015)

	type 1	type 2	type 2	type 3			
partition wall							
Total Thickness	0.11	0.11	0.11	0.285			
ext layer	plaster (0.02)	plaster (0.02)	tile (0.005)	plaster (0.015)			
layer 1	brick (0.07)	brick (0.07)	mortar (0.015)	granite (0.25)			
layer 2			brick (0.07)				
layer 3							
layer 4		mortar (0.015)	mortar (0.015)	mortar (0.015)			
int layer	plaster (0.02)	tile (0.005)	tile (0.005)	tile (0.005)			

	type 1 (all compartments)	type 2 (kitchen, wc)					
Horizontal separation							
Total Thickness	0.25	0.25					
floor layer	linoleum (0.001)	tile (0.005)					
layer 1	wood (0.014)	mortar (0.01)					
layer 2	concrete (0.22)	concrete (0.22)					
layer 3							
layer 4							
ceiling layer	gypsum (0.015)	gypsum (0.015)					

	type 1	type 2					
Horizontal separation (roof)							
Total Thickness	0.21	0.21					
roof layer	ceramic tile (0.015)	ceramic tile (0.015)					
layer 1	wood (0.18)	wood (0.18)					
layer 2							
layer 3							
layer 4		cavity (variable)					
ceiling layer	gypsum (0.015)	gypsum board (0.015)					

Front (S) 4th floor — 1 sash windows

Ext. Window (Rooms)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.64	open 3 h day /with sun	no	not applicable	1.64	closed continuously
glazed area (m2)	no	0.96		no			
frame area (m2)	no	0.68		no			
percentage of glazed (%)	no	58.54		no			
percentage of frame (%)	no	41.46		no			
max. Opening area (m2)	no	0.70		no			
percentage of max. Opening area (%)	no	42.68		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (W) 4th floor (livingroom) — 1 casement window

Ext. Window (room)	Fanlight window	Sash (1 window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.55	open 3 h day /with sun	no	not applicable	0.55	closed continuously
glazed area (m2)	no	0.41		no			
frame area (m2)	no	0.14		no			
percentage of glazed (%)	no	74.55		no			
percentage of frame (%)	no	25.45		no			
max. Opening area (m2)	no	0.48		no			
percentage of max. Opening area (%)	no	87.27		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (W) 4th floor (livingroom) — fixed window

Ext. Window (Kitchen)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.37	closed continuously	no	not applicable	1.37	closed continuously
glazed area (m2)	no	1.145		no			
frame area (m2)	no	0.23		no			
percentage of glazed (%)	no	83.58		no			
percentage of frame (%)	no	16.42		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (W) 4th floor (Kitchen) — 1 casement

Ext. Window (WC)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.67	open 8 h day	no	not applicable	0.67	closed continuously
glazed area (m2)	no	0.51		no			
frame area (m2)	no	0.16		no			
percentage of glazed (%)	no	76.12		no			
percentage of frame (%)	no	23.88		no			
max. Opening area (m2)	no	0.59		no			
percentage of max. Opening area (%)	no	88.06		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (E) 4th floor — casement window x2 (a, b)

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.82	open 3 h day /with sun	no	not applicable	0.82	closed continuously
glazed area (m2)	no	0.68		no			
frame area (m2)	no	0.14		no			
percentage of glazed (%)	no	82.93		no			
percentage of frame (%)	no	17.07		no			
max. Opening area (m2)	no	0.77		no			
percentage of max. Opening area (%)	no	93.90		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (E) 4th floor — fixed window x1 (a)

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.59	closed continuously	no	not applicable	0.59	closed continuously
glazed area (m2)	no	0.46		no			
frame area (m2)	no	0.13		no			
percentage of glazed (%)	no	77.97		no			
percentage of frame (%)	no	22.03		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Side (E) 4th floor — fixed window x1 (b)

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.46	closed continuously	no	not applicable	0.46	closed continuously
glazed area (m2)	no	0.35		no			
frame area (m2)	no	0.11		no			
percentage of glazed (%)	no	76.09		no			
percentage of frame (%)	no	23.91		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	wood (1.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

Courtyard 4th floor — fixed window x1

Ext. Window (hall)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.31	closed continuously	no	not applicable	1.31	closed continuously
glazed area (m2)	no	1.08		no			
frame area (m2)	no	0.23		no			
percentage of glazed (%)	no	82.44		no			
percentage of frame (%)	no	17.56		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		light tissue	
Type of glass	no	single (2mm)		no			

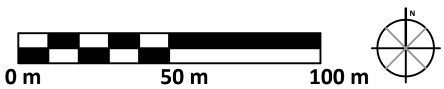
Shylight 4th floor — fixed window x1

Ext. Window (hall)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	2.92	closed continuously	no	not applicable	no	not applicable
glazed area (m2)	no	2.79		no		no	
frame area (m2)	no	0.13		no		no	
percentage of glazed (%)	no	95.55		no		no	
percentage of frame (%)	no	4.45		no		no	
max. Opening area (m2)	no	0.00		no		no	
percentage of max. Opening area (%)	no	0.00		no		no	
Frame material	no	iron (0.1cm)		no		no	
Type of glass	no	single (2mm)		no		no	

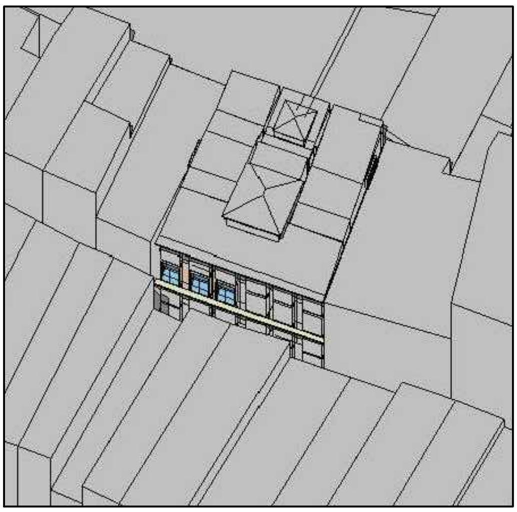
Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways closed
glazed area (m2)	no	no	except Kitchen
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
FLR40045	Entrance Hall	Lighting	1 compact fluorescent lamp			0.011	1 hour /day	365	4.02	ERSE (11w)
FLR40007	Bedroom Hall	Lighting	1 compact fluorescent lamp			0.011	0.25 hours/day	91.25	1.00	ERSE (11w)
FLR40023	Living Room	Lighting	4 compact fluorescent lamps			0.044	4 hours/day	1460	64.24	ERSE (11w)
FLR40023	Living Room	Entertainment	1 TV	HD TV Digital Plus	Samsung	0.058	3hours/day	1095	63.51	Samsung internet
FLR40023	Living Room	Entertainment	1 TV in standby	HD TV Digital Plus	Samsung	0.0003	21 hours/day	7665	2.30	Samsung internet
FLR40023	Living Room	Environment	1 electric resistance heater			1.5	with cold 3/4 electric resistences		0.00	ERSE (1500w) WC heater high
FLR40000	Bedroom 1	Lighting	3 compact fluorescent lamps			0.033	1 hour /day	365	12.05	ERSE (11w)
FLR40048	Bedroom 2	Lighting	3 compact fluorescent lamps			0.033	1 hour /day	365	12.05	ERSE (11w)
FLR40047	Bedroom 3	Lighting	3 compact fluorescent lamps			0.033	1 hour /day	365	12.05	ERSE (11w)
FLR40003	Kitchen	Lighting	1 fluorescent lamp			0.058	10 hours/day	3650	211.70	ERSE (58w)
FLR40003	Kitchen	Appliance	1 Washing machine	Fuzzy Logic 7Kg	LG	1.19	3 times/week (2 hours)	312	371.28	LG internet
FLR40003	Kitchen	Appliance	1 Dish washer	Top dispaner	Ocean	2	1 time /day (2 hours)	730	383.25	ERSE (2000w); TopTen (1.05 Kwh each wash)
FLR40003	Kitchen	Appliance	1 Fridge / freezer	Green Fresh	Balay	0.3	On continuously	8760	293.00	ERSE (300w) Balay internet (293KWh/year)
FLR40003	Kitchen	Appliance	1 Microwave	Techno Star		0.9	0.5 hours/day	182.5	164.25	ERSE (900w)
FLR40003	Kitchen	Appliance	1 Microwave in standby	Techno Star		0.0043	23.5 hours/day	8577.5	36.88	Deco Proteste Internet simulator
FLR40003	Kitchen	Appliance	1 Electric Oven			2.4	0.25 hours/day	91.25	219.00	ERSE (2400w)
FLR40003	Kitchen	Appliance	1 Extractor hood		Ocean	0.14	1 hour /day	365	51.10	ERSE (140w)
FLR40003	Kitchen	Entertainment	1 Mini-TV			0.09	2 hours/day	730	65.70	ERSE (90w)
FLR40003	Kitchen	Entertainment	1 Mini-TV in standby			0.0025	22 hours/day	8030	20.08	Deco Proteste Internet simulator
FLR40003	Kitchen	Environment	1 electric hot water cylinder		Jucomel	1.5	allways on	8760	467.20	50 l in situ; AKI - 1.28kWh/Day
FLR40003	Kitchen	Appliance	1 Gas stove		Ocean		1 bottle/2.5 months (0.4/month)		0.00	Households
FLR40002	WC	Lighting	1 compact fluorescent lamp			0.011	1.5 hours/day	547.5	6.02	ERSE (11w)
FLR40019	Storage 1	Lighting	1 compact fluorescent lamp			0.011	0.25 hours/week	13	0.14	ERSE (11w)
FLR40021	Storage 2	Lighting	1 compact fluorescent lamp			0.011	0.25 hours/week	13	0.14	ERSE (11w)
								TOTAL	**2460.95**	
									3896.90	EDP (kWh/Year)

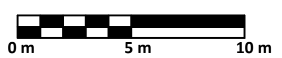
Case Study 5
Study Area Location Plan



Study area



Case 5 site plan

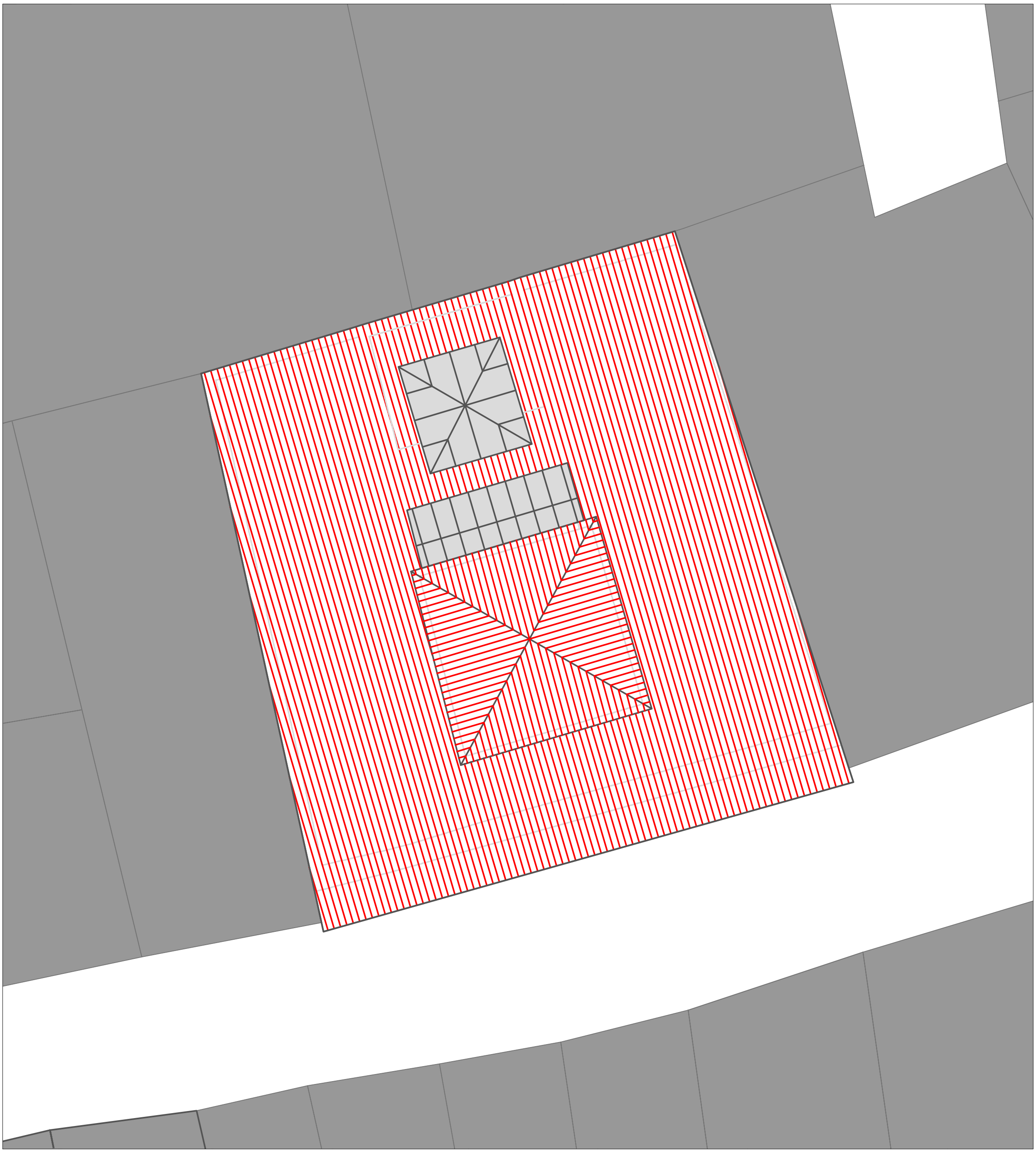


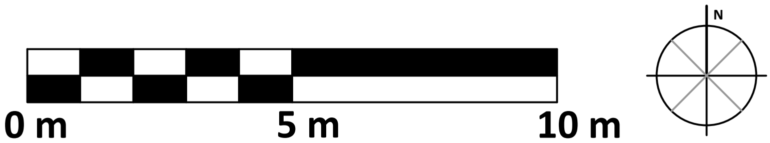
Case Study 5
Variant 4 middle - 2nd floor plan

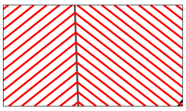
a - Inner courtyard

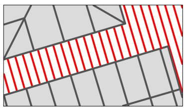
Granite exterior wall	Kitchen	Storage
brick and plaster partition wall	Bathroom	Living room
Corridor / circulation	Hall	Bedroom

Case Study 5
Variant 4 middle - roof plan

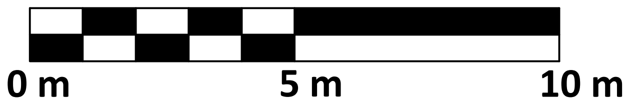




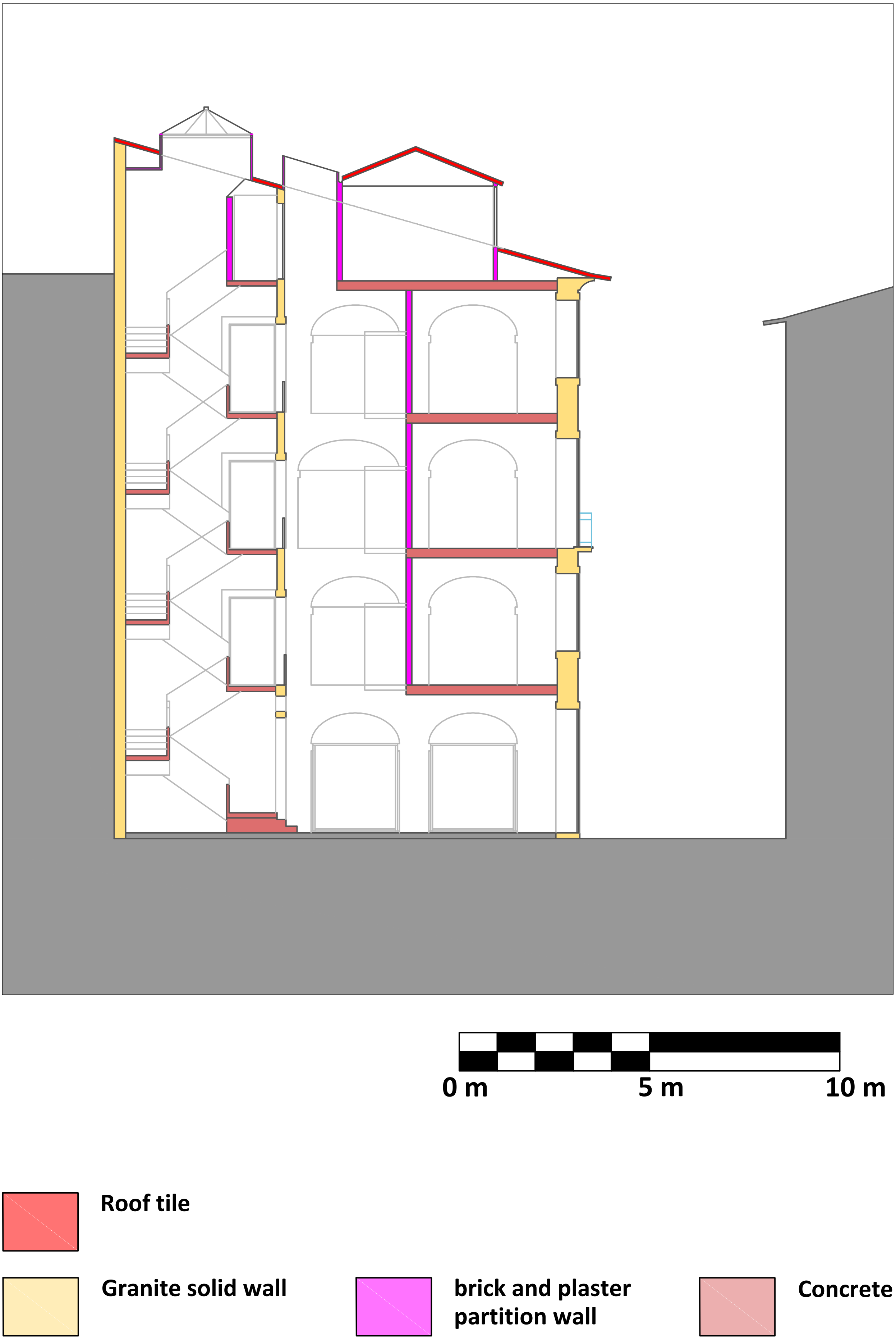




Case Study 5
Variant 4 middle - front facade (street)

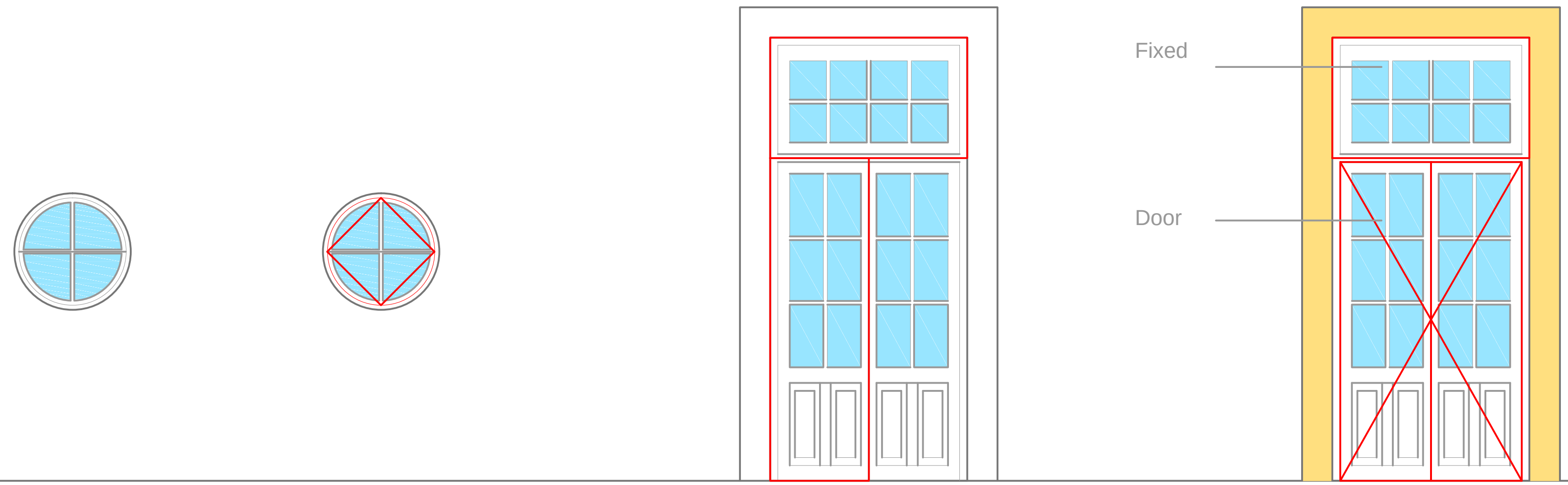


Case Study 5
Variant 4 middle - Section



Case Study 5
Variant 4 - middle floor - Openings

Front (S) 2nd floor x 3



Fanlight

0.44m2
0.07m2 x4

0.37m2

0.98 m2
0.06 m2 x8

1.20 m2

1

0.28 m2

63.64% of glazed area

84.09% max. opening area

0.48 m2

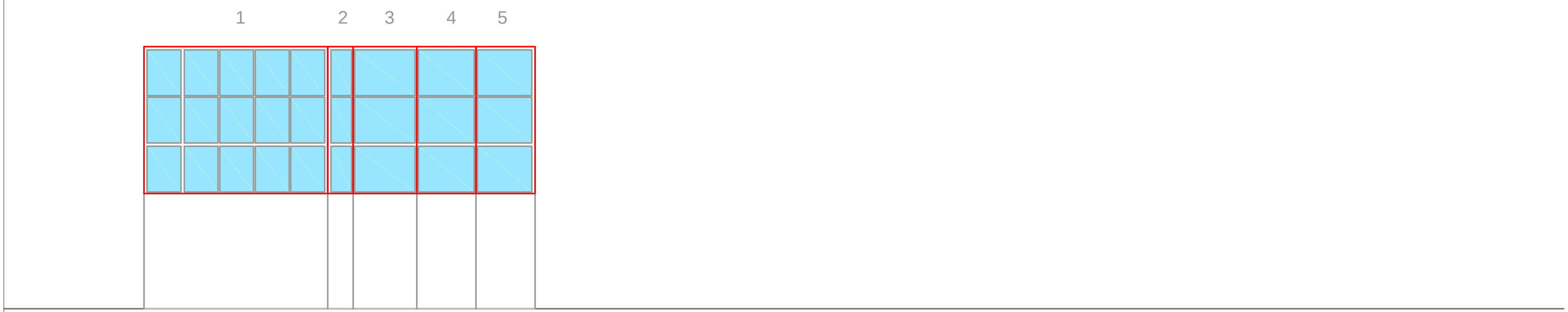
48.98% of glazed area

90.91% max. opening area

0 m 5 m 10 m

Case Study 5
Variant 4 - middle floor - Openings

Courtyard 2nd floor



1 1.65 m2
0.09m2 x 15

1.35 m2

81.82% of glazed area

2 0.23 m2
0.06m2 x3

0.18 m2

78.26% of glazed area

3 0.57 m2
0.17 m2 x3

0.51 m2

89.47% of glazed area

4 0.53m2
0.16 m2

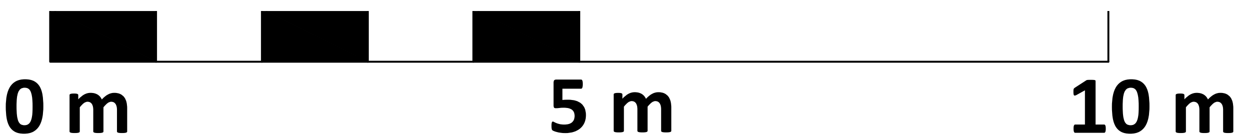
0.48 m2

90.57% of glazed area

5 0.53m2
0.15m2 x3

0.45 m2

84.91% of glazed area



	type 1	type 2	type 2	type 3	type 4	type 5	type 6
exterior wall	front (S) 2nd floor	side (N) 2nd floor	side (W) 2nd floor	side (W) 2nd floor	courtyard /livingroom	Stair / Kitchen	courtyard /side house
Total Thickness	0.55	0.30	0.30	0.30	0.30	0.30	0.15
ext layer	plaster (0.025)				plaster (0.025)	plaster (0.025)	plaster (0.02)
layer 1	granite (0.50)	granite (0.275)	granite (0.275)	granite (0.285)	granite (0.25)	granite (0.26)	brick (0.11)
layer 2							
layer 3							
layer 4				mortar (0.01)		mortar (0.01)	
int layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	tile (0.005)	plaster (0.025)	tile (0.005)	plaster (0.02)

	type 1	type 2	type 2	type 3			
partition wall							
Total Thickness	0.11	0.11	0.11	0.285			
ext layer	plaster (0.02)	plaster (0.02)	tile (0.005)	plaster (0.015)			
layer 1	brick (0.07)	brick (0.07)	mortar (0.015)	granite (0.25)			
layer 2			brick (0.07)				
layer 3							
layer 4		mortar (0.015)	mortar (0.015)	mortar (0.015)			
int layer	plaster (0.02)	tile (0.005)	tile (0.005)	tile (0.005)			

	type 1 (all compartments)	type 2 (kitchen, wc)					
Horizontal separation							
Total Thickness	0.25	0.25					
floor layer	linoleum (0.001)	tile (0.005)					
layer 1	wood (0.14)	mortar (0.01)					
layer 2	concrete (0.22)	concrete (0.22)					
layer 3							
layer 4							
ceiling layer	gypsum (0.015)	gypsum (0.015)					

Front (S) 2nd floor - 3 doors | 3 fanlight | 6 sashes

Ext. Window (balcony door)	Fanlight window (each)	Sashes (each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	0.98	1.32	winter - 30 min / day	3.62	winter - open all day, closed in the night	3.62	closed continuously
glazed area (m2)	0.48	0.54	summer - open all night closed all day		summer - open all night closed all day		
frame area (m2)	0.50	0.78					
percentage of glazed (%)	48.98	40.91					
percentage of frame (%)	51.02	59.09					
max. Opening area (m2)	0.00	1.20					
percentage of max. Opening area (%)	0.00	90.91					
Frame material	wood (3cm)	wood (3cm)		wood (3cm)		light tissue	
Type of glass	single (2mm)	single (2mm)					

courtyard 1 - 2nd floor | 1 fixed window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.65	closed continuously	no	not applicable	1.65	closed continuously
glazed area (m2)	no	1.35		no			
frame area (m2)	no	0.30		no			
percentage of glazed (%)	no	81.82		no			
percentage of frame (%)	no	18.18		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		heavy tissue	
Type of glass	no	single (2mm)		no			

courtyard 2 - 2nd floor | 1 fixed window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.23	closed continuously	no	not applicable	0.23	closed continuously
glazed area (m2)	no	0.18		no			
frame area (m2)	no	0.05		no			
percentage of glazed (%)	no	78.26		no			
percentage of frame (%)	no	21.74		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		heavy tissue	
Type of glass	no	single2mm)		no			

courtyard 3 - 2nd floor | 1 fixed window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.57	closed continuously	no	not applicable	0.57	closed continuously
glazed area (m2)	no	0.51		no			
frame area (m2)	no	0.06		no			
percentage of glazed (%)	no	89.47		no			
percentage of frame (%)	no	10.53		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		heavy tissue	
Type of glass	no	single (2mm)		no			

courtyard 4 - 2nd floor | 1 fixed window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.53	closed continuously	no	not applicable	0.53	closed continuously
glazed area (m2)	no	0.48		no			
frame area (m2)	no	0.05		no			
percentage of glazed (%)	no	90.57		no			
percentage of frame (%)	no	9.43		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		heavy tissue	
Type of glass	no	single (2mm)		no			

courtyard 5 - 2nd floor | 1 fixed window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.53	closed continuously	no	not applicable	0.53	closed continuously
glazed area (m2)	no	0.45		no			
frame area (m2)	no	0.08		no			
percentage of glazed (%)	no	84.91		no			
percentage of frame (%)	no	15.09		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	iron (0.5cm)		no		heavy tissue	
Type of glass	no	single (2mm)		no			

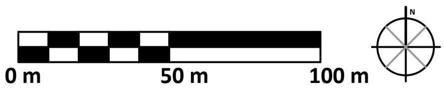
Kitchen/Stairs - 2nd floor | 1 awning window

Ext. Window (room)	Fanlight window	Sashes (total)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.44	opened during day	no	not applicable	no	not applicable
glazed area (m2)	no	0.28	closed at night	no		no	
frame area (m2)	no	0.16		no		no	
percentage of glazed (%)	no	63.64		no		no	
percentage of frame (%)	no	36.36		no		no	
max. Opening area (m2)	no	0.37		no		no	
percentage of max. Opening area (%)	no	84.09		no		no	
Frame material	no	iron (0.5cm)		no		no	
Type of glass	no	single (2mm)		no		no	

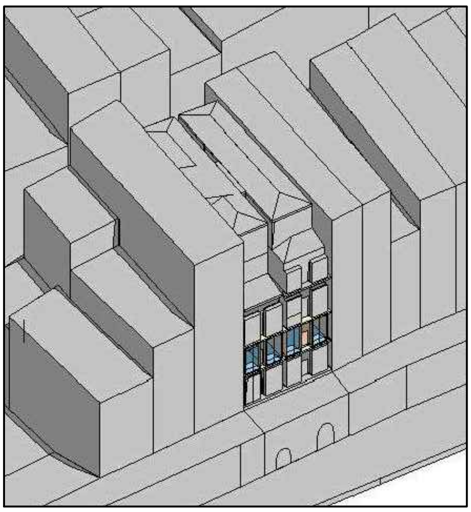
Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways closed
glazed area (m2)	no	no	excepted kitchen
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

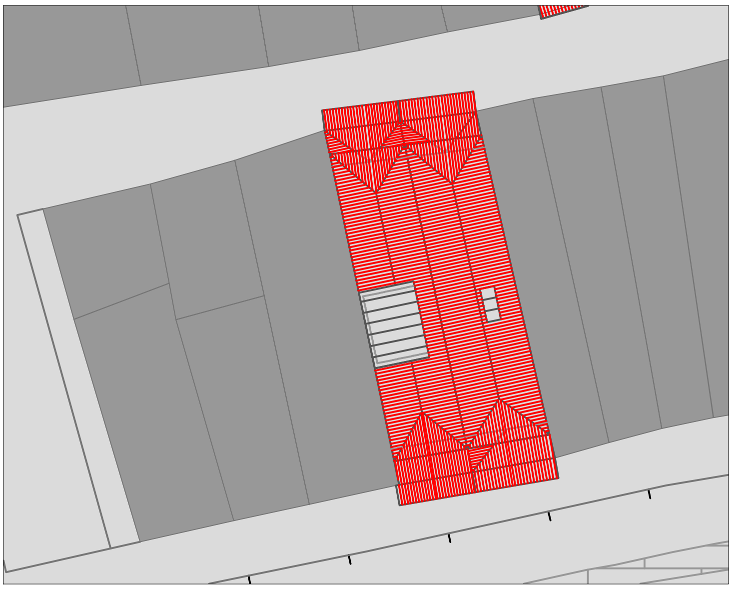
IES VE code	Room	Category	Appliance	model	brand	Power (kW)	Operation profile assumed (average usage hours)	Hours per year (52 weeks, 365 days)	kWh/year	Source
HALL0000	Hall	Lighting	3 lamps			0.12	1.5 hours/day	547.5	65.70	ERSE (40w)
LVNG0000	Living Room	Lighting	7 lamps			0.28	4 hours/day	1460	408.80	ERSE (40w)
LVNG0000	Living Room	Appliance	1 cordless telephone		Siemens	0.003	On continuously	8760	26.28	LG (3w)
LVNG0000	Living Room	Entertainement	1 TV		LG	0.09	4 hours/day	1460	131.40	ERSE (90w)
LVNG0000	Living Room	Entertainement	1 TV in standby		LG	0.00523	20 hours/day	7300	38.18	SELINA (TV CRT 5.23w)
LVNG0000	Living Room	Entertainement	1 Cable TV box decoder		Meo Box	0.0162	4 hours/day	1460	23.65	Quercus (16.2w)
LVNG0000	Living Room	Entertainement	1 Cable TV box decoder in standby		Meo Box	0.0094	20 hours/day	7300	68.62	Quercus (9.4w)
LVNG0000	Living Room	Entertainement	1 Hi-Fi		Sanyo	0.06	0.5 hours / week	26	0.24	ERSE (60w)
LVNG0000	Living Room	Entertainement	1 Hi-Fi in standby		Sanyo	0.00205	167.96 hours/week	8734	17.90	SELINA (2.05w)
LVNG0000	Living Room	Environment	1 Electric oil-filled radiator heater			2	with cold always on in minimum		0.00	ERSE (2000w)
LVNG0000	Living Room	Environment	1 electric fan			0.1	with hot always on		0.00	LG (100w)
FLR20001	Bedroom	Lighting	1 lamp			0.06	1 hour/day	365	21.90	ERSE (60w)
FLR20001	Bedroom	Lighting	1 compact fluorescent lamp			0.011	1 hour/day	365	4.02	ERSE (11w)
FLR20001	Bedroom	Entertainement	1 TV			0.09	0.5 hours / day	182.5	16.43	ERSE (90w)
FLR20001	Bedroom	Entertainement	1 TV in standby			0.00523	23.5 hours/day	8577.5	44.86	SELINA (TV CRT 5.23w)
BDRM0003	Bedroom 1	Lighting	1 lamp			0.06	1 hour/day	365	21.90	ERSE (60w)
BDRM0003	Bedroom 1	Entertainement	1 TV			0.09	0.5 hours / day	182.5	16.43	ERSE (90w)
BDRM0003	Bedroom 1	Entertainement	1 TV in standby			0.00523	23.5 hours/day	8577.5	44.86	SELINA (TV CRT 5.23w)
KTCH0000	Kitchen	Lighting	1 fluorescent lamp			0.058	4 hours/day	1460	84.68	ERSE (58w)
KTCH0000	Kitchen	Appliance	1 Washing machine	6 Kg	Samsung	2	1 wash / day (2 hours)	730	416.10	ERSE (2000w); Topten (1.14 kWh each cycle)
KTCH0000	Kitchen	Appliance	1 Fridge / freezer		Whirlpool	0.3	On continuously	8760	354.00	ERSE (300w); Topten (354 kWh/year)
KTCH0000	Kitchen	Appliance	1 Microwave		Silver	0.9	0.5 hours / day	182.5	164.25	ERSE (900w)
KTCH0000	Kitchen	Appliance	1 Microwave in standby		Silver	0.0043	23.5 hours/day	8577.5	36.88	Deco Proteste Internet simulator
KTCH0000	Kitchen	Appliance	1 Electric Oven	H + 610 ME	Teka	2.693	0.25 hours/day	91.25	245.74	site Teka (2693w) HE610
KTCH0000	Kitchen	Appliance	1 Coffee machine			1.2	0.5 hours / day	182.5	219.00	EDP (1200w)
KTCH0000	Kitchen	Appliance	1 Extractor hood			0.14	allways off	0	0.00	ERSE (140w)
KTCH0000	Kitchen	Appliance	1 Iron			1.6	2 hours /week	104	166.40	ERSE (1600w)
KTCH0000	Kitchen	Appliance	1 Vacuum cleaner			1.6	1 time / week (1.5 hous)	78	124.80	ERSE (1600w)
KTCH0000	Kitchen	Environment	1 electric hot water cylinder		Arierom	2	On continuously	8760	448.95	AKI - 1.23 kWh/Day
KTCH0000	Kitchen	Appliance	1 Gas stove	H + 610 ME	Teka		1.5 bottles / month		0.00	Households
WC__0000	WC	Lighting	1 lamp			0.06	1.5 hours/day	547.5	32.85	ERSE (60w)
WC__0000	WC	Lighting	1 Hair dryer			1.5	0.5 hours / day	182.5	273.75	ERSE (1500w)
STRG0000	Storage	Lighting	1 lamp			0.06	0.25 hours/week	13	0.78	ERSE (60w)
								TOTAL	**3519.35**	
									5692.66	EDP (kWh/Year)

Case Study 6
Study Area Location Plan

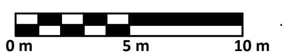


Study area

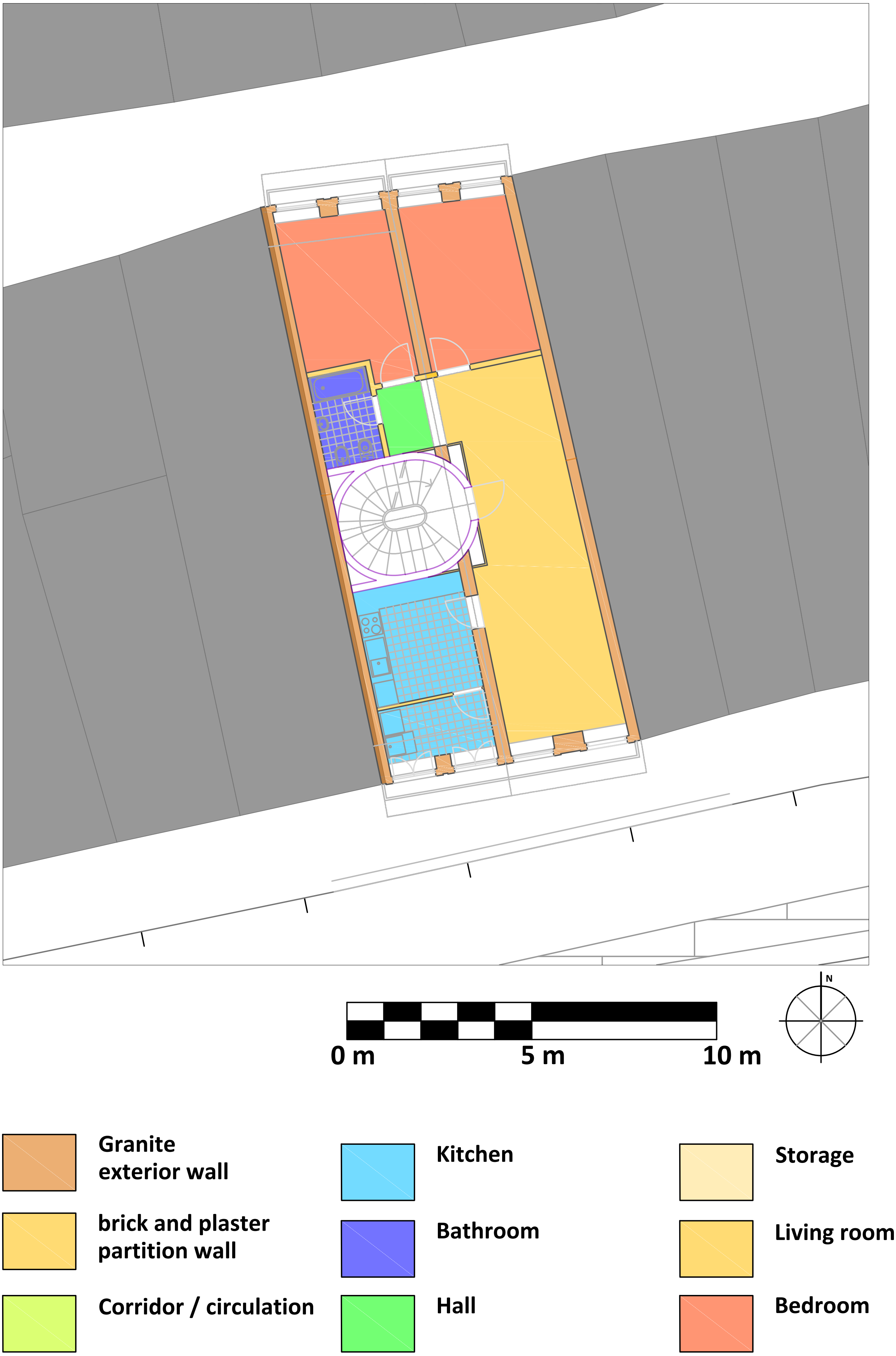




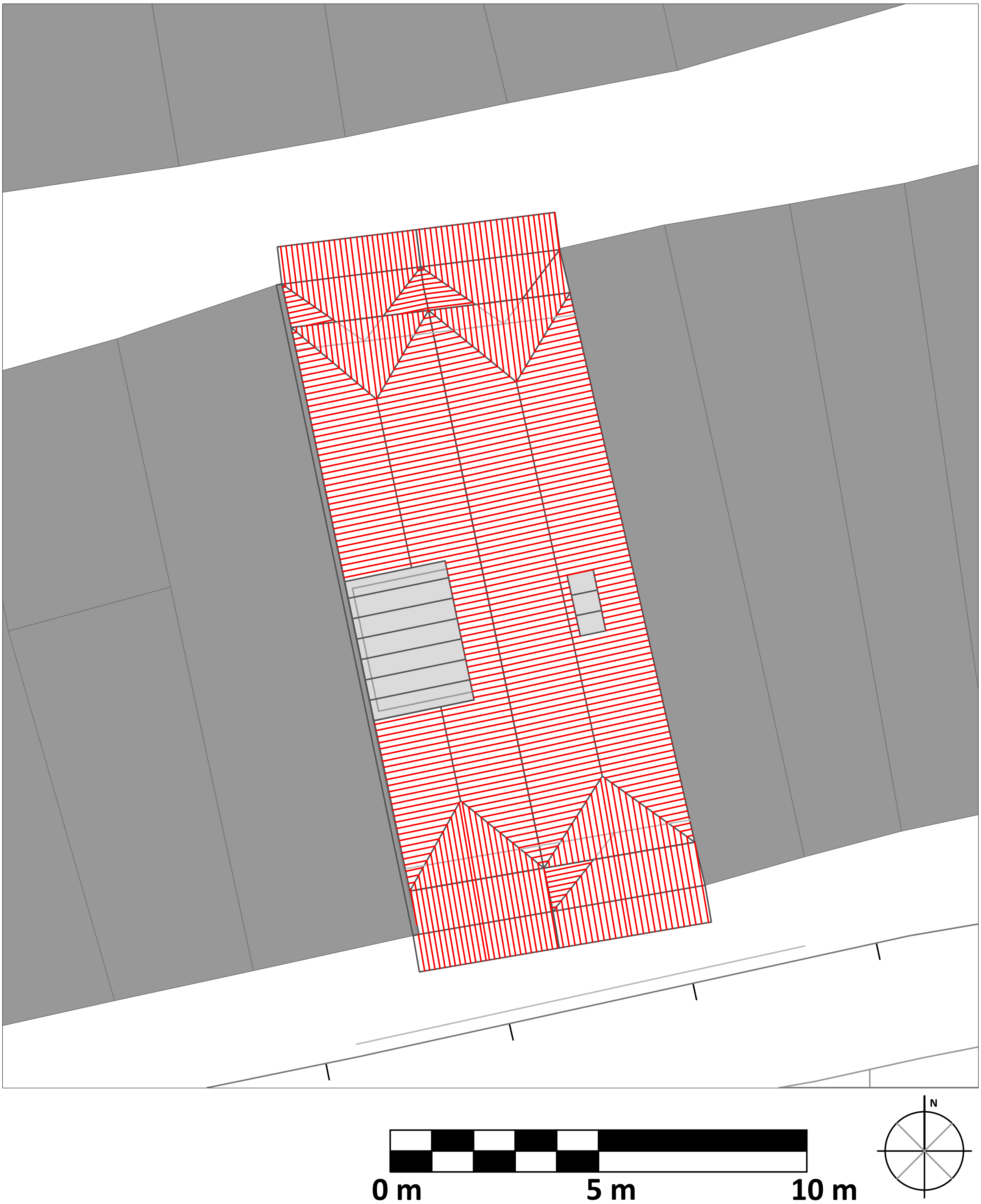
Case 6 site plan

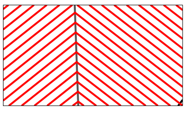


Case Study 6
Variant 3a middle - 2nd floor plan

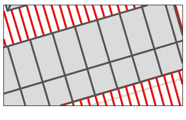


Case Study 6
Variant 3a middle - roof plan



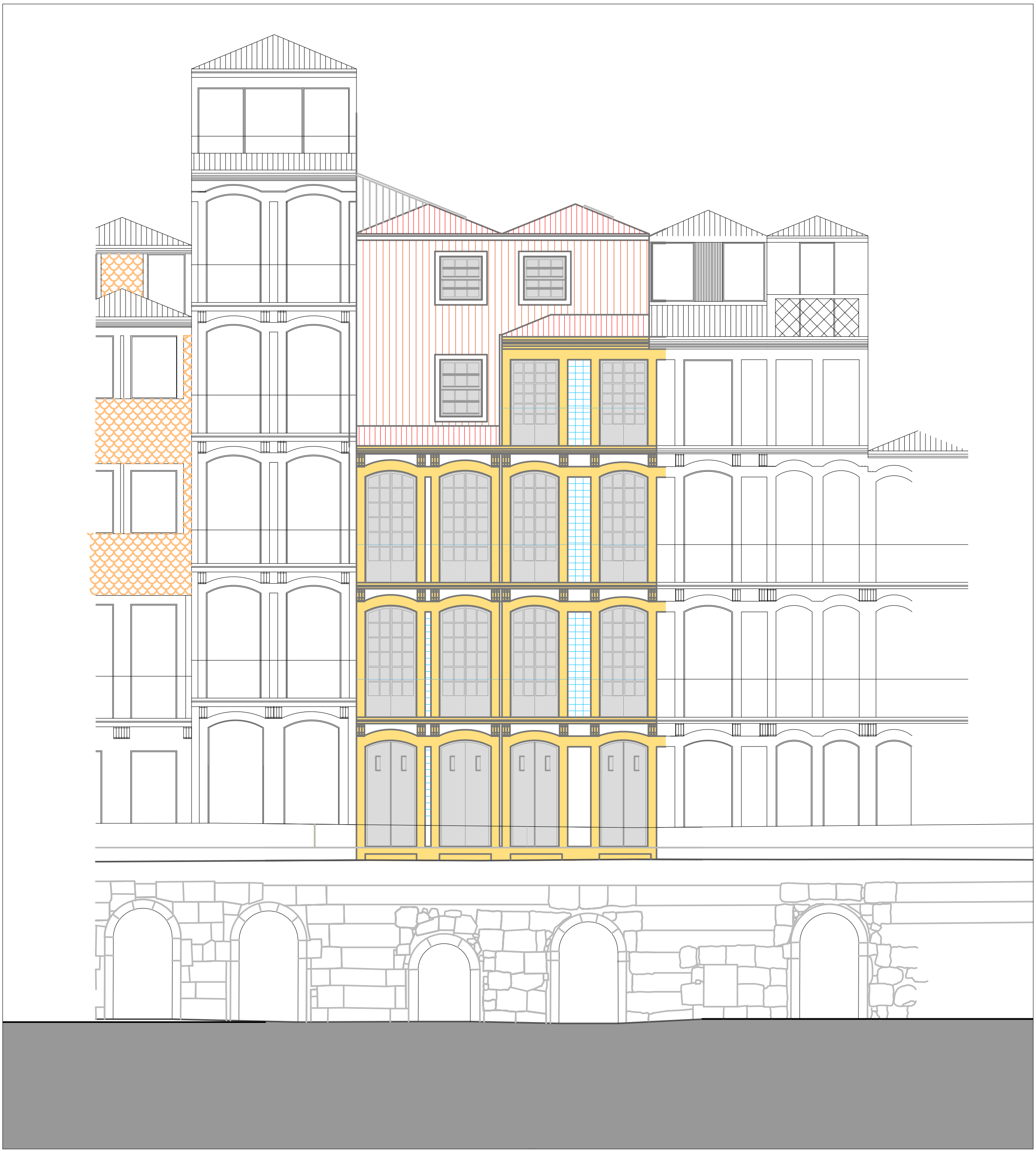


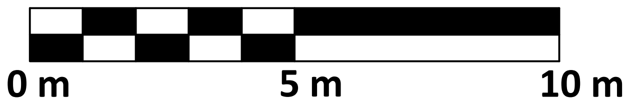
Ceramic roof tiles

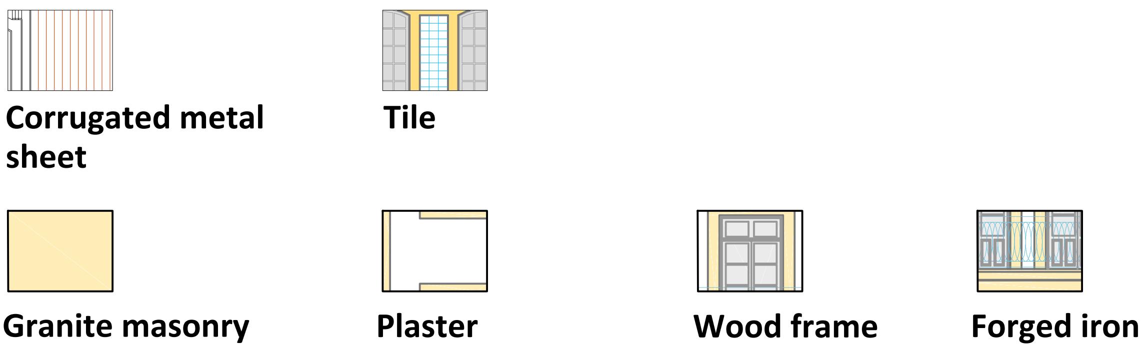


Skylight

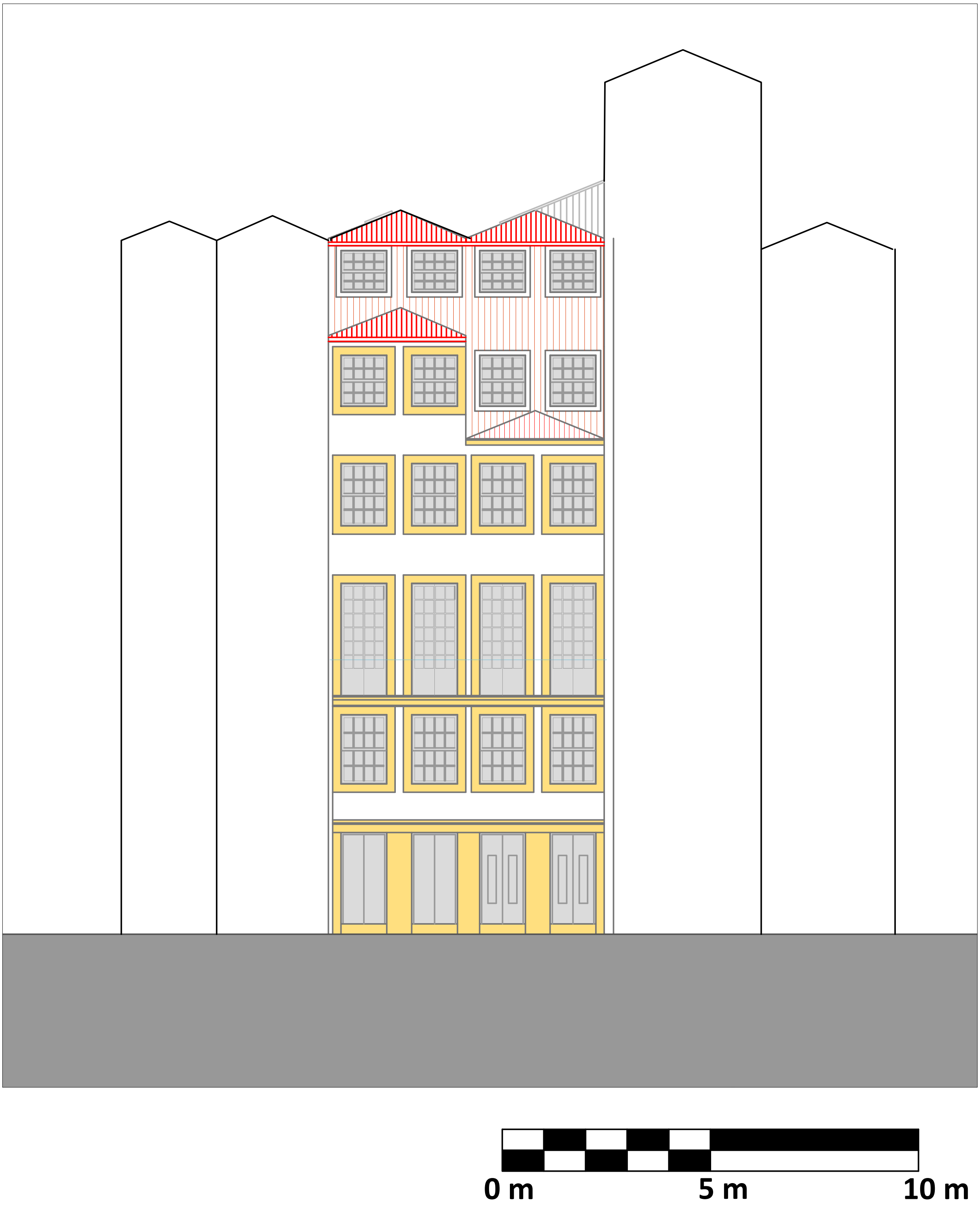
Case Study 6
Variant 3a middle - front facade (river)







Case Study 6
Variant 3a middle - rear facade (street)



Corrugated metal sheet

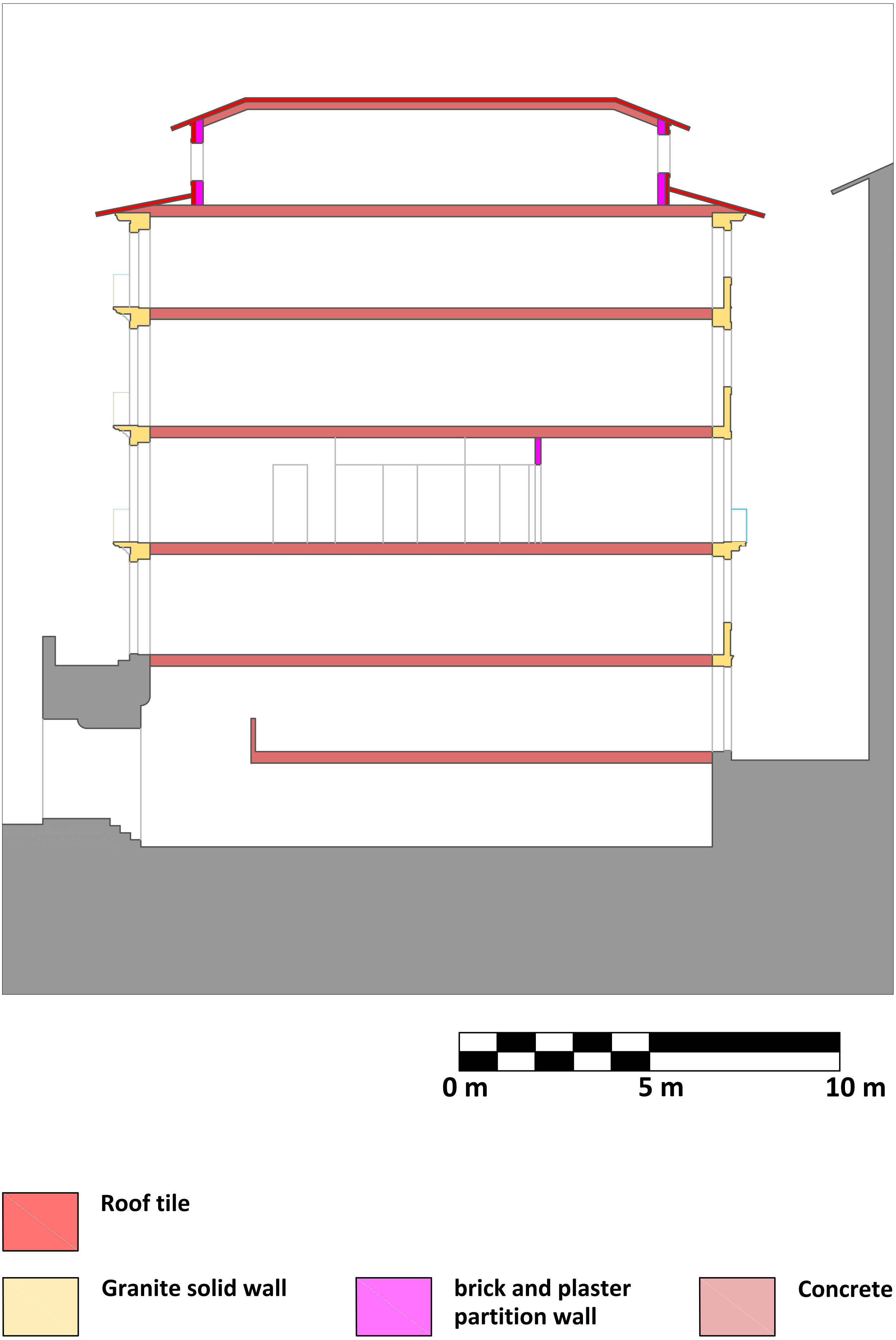
Granite masonry

Plaster

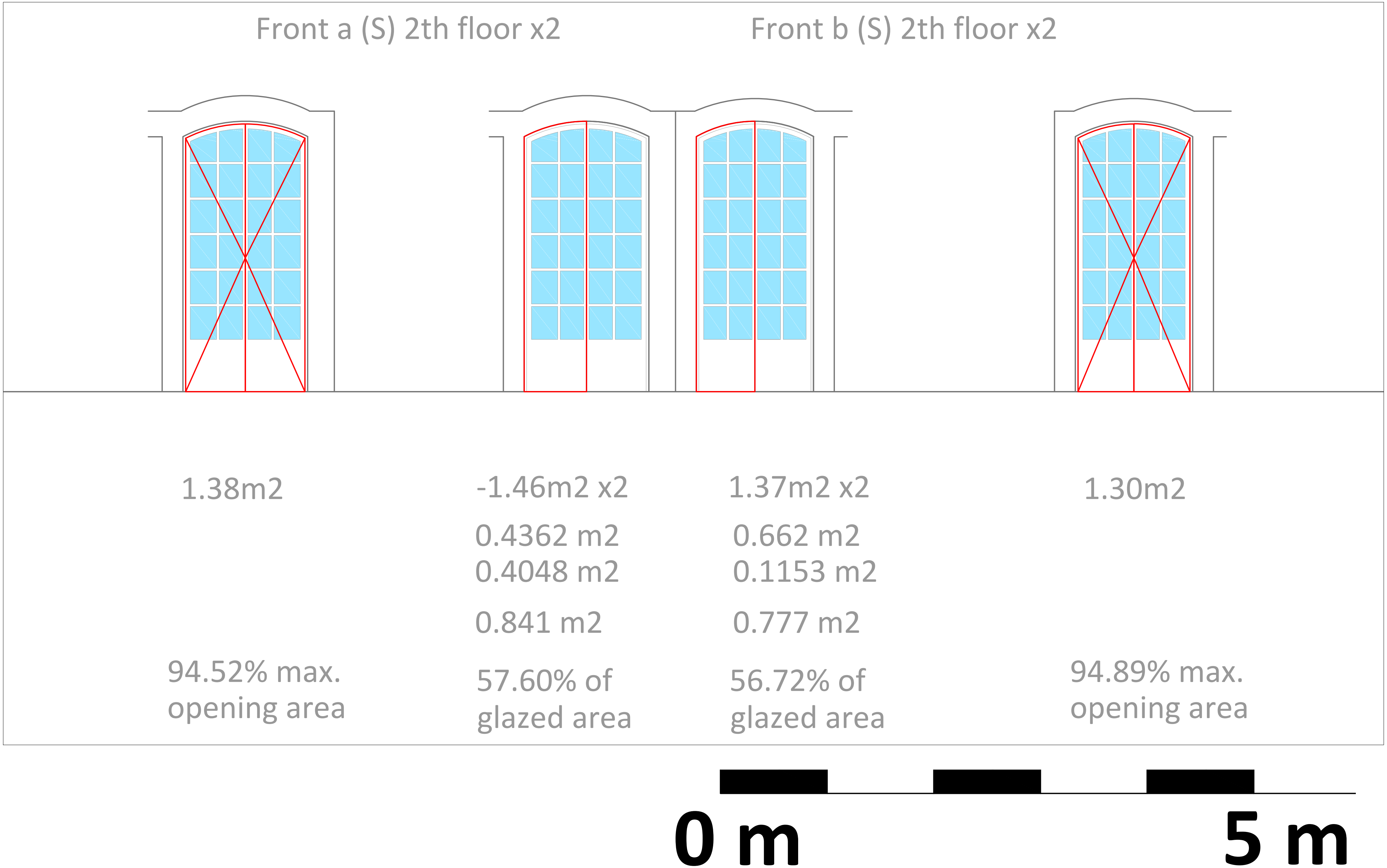
Wood frame

Forged iron

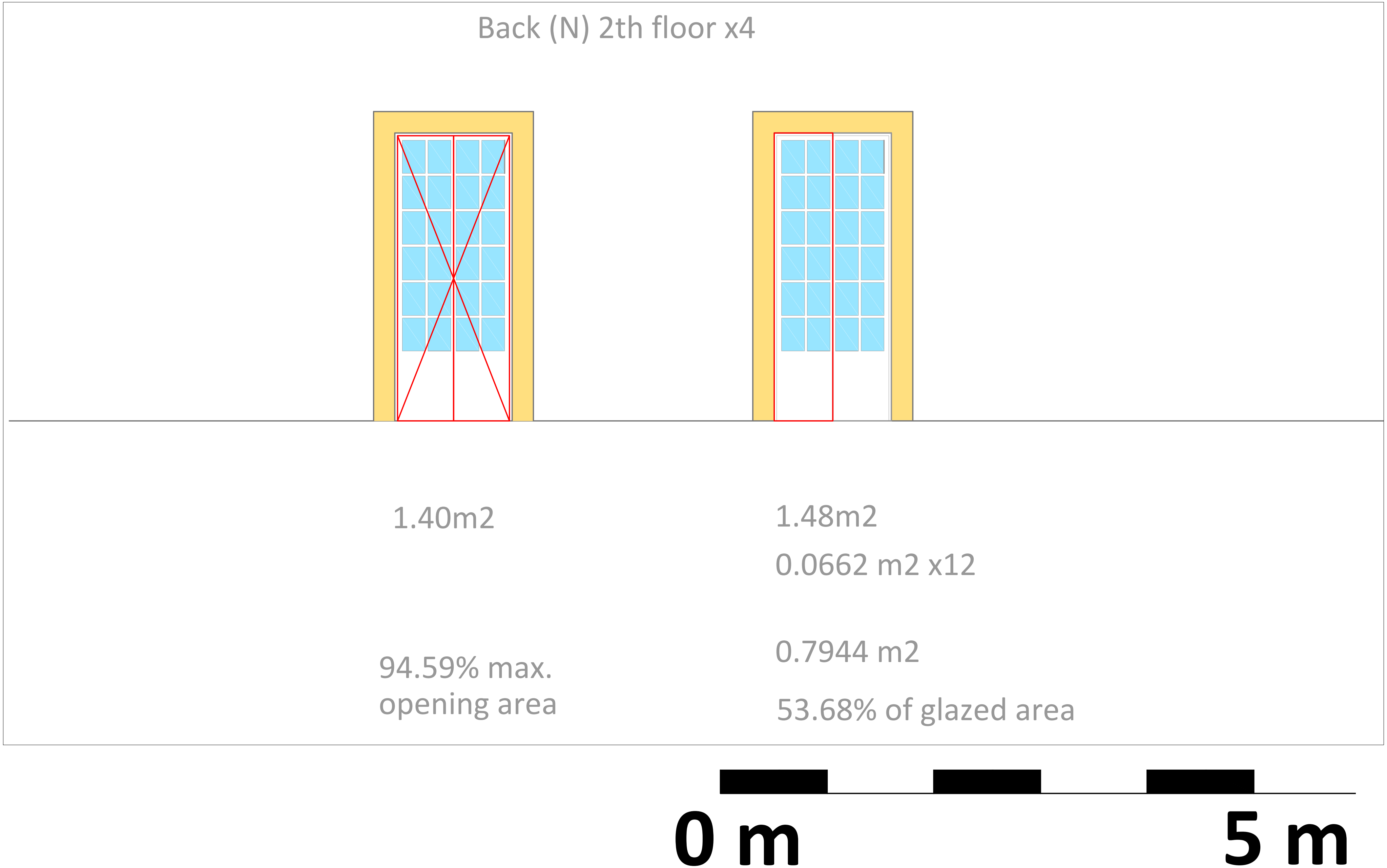
Case Study 6
Variant 3a middle - Section



Case Study 6
Variant 3a - middle floor - Openings



Case Study 6
Variant 3a - middle floor - Openings



	type 1 (livingroom)	type 2 (laundry)	type 3	type 4	type 5
exterior wall	front (S) 2nd floor	front (S) 2nd floor	Back (N) 2nd floor	Side (E,W) 2nd floor	Side (E) Kitchen, WC
Total Thickness	0.510	0.510	0.475	0.290	0.290
ext layer	tile (0.01)	tile (0.01)	plaster (0.015)		
layer 1	mortar (0.02)	mortar (0.02)	granite (0.445)	granite (0.275)	granite (0.275)
layer 2	granite (0.46)	granite (0.465)			
layer 3					
layer 4		mortar (0.01)			mortar (0.01)
int layer	plaster (0.02)	tile (0.005)	plaster (0.015)	plaster (0.015)	tile (0.005)

	type 1	type 2			
partition wall					
Total Thickness	0.14	0.14			
ext layer	plaster (0.015)	plaster (0.015)			
layer 1	brick (0.11)	brick (0.11)			
layer 2					
layer 3					
layer 4		mortar (0.01)			
int layer	plaster (0.015)	tile (0.005)			

	type 1	type 2			
Horizontal separation					
Total Thickness	0.290	0.290			
floor layer	wood (0.025)	tile (0.005)			
layer 1	concrete (0.25)	mortar (0.02)			
layer 2		concrete (0.25)			
layer 3					
layer 4					
ceiling layer	gypsum (0.015)	gypsum (0.015)			

Front a (S) 2th floor — 2 casement doors

Ext. Door (Balcony / Laundry)	Fanlight window	Sashes (x2 each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.46	closed continuously	1.46	open all day	1.46	closed continuously
glazed area (m2)	no	0.841			closed all night		
frame area (m2)	no	0.62					
percentage of glazed (%)	no	57.60					
percentage of frame (%)	no	42.40					
max. Opening area (m2)	no	1.38					
percentage of max. Opening area (%)	no	94.52					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (3mm)					

Front b (S) 2th floor — 2 casement doors

Ext. Door (Balcony / livingroom)	Fanlight window	Sashes (x2 each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.37	open 25% all day, closed night	1.37	open all day	1.37	closed continuously
glazed area (m2)	no	0.777			closed all night		
frame area (m2)	no	0.59					
percentage of glazed (%)	no	56.72					
percentage of frame (%)	no	43.28					
max. Opening area (m2)	no	1.30					
percentage of max. Opening area (%)	no	94.89					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (3mm)					

Back (N) 2th floor — 4 casement doors

Ext. Door (Balcony)	Fanlight window	Sashes (x2 each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.48	closed continuously	1.48	open all day	1.48	closed continuously
glazed area (m2)	no	0.7944			closed all night		
frame area (m2)	no	0.69					
percentage of glazed (%)	no	53.68					
percentage of frame (%)	no	46.32					
max. Opening area (m2)	no	1.40					
percentage of max. Opening area (%)	no	94.59					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (3mm)					

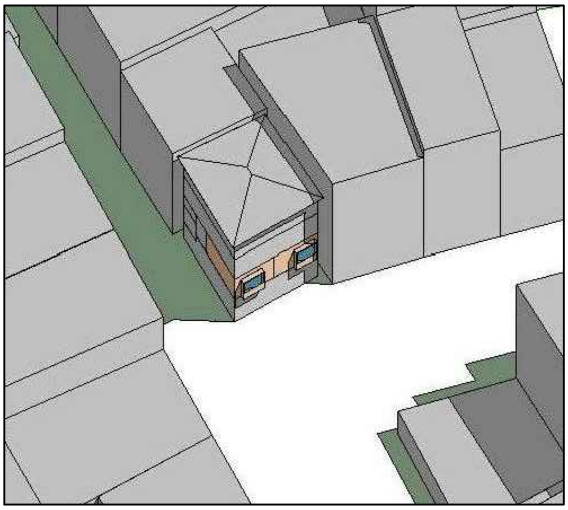
Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	except bedrooms
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

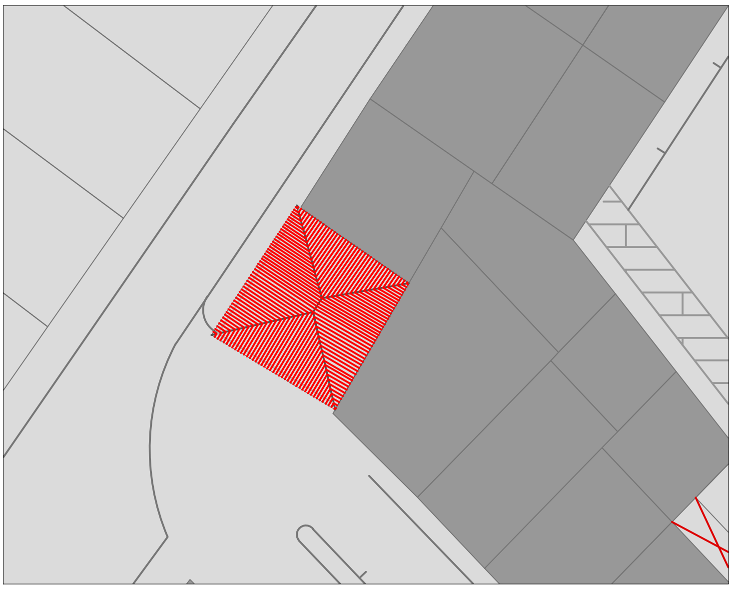
							Operation profile assumed	Hours per year		
IES VE code	Room	category	Appliance	model	brand	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Source
FLR20015	Bedroom Hall	Lighting	1 lamp			0.0400	0.5 hours/day	182.5	7.30	ERSE (40w)
FLR20016	Living Room	Lighting	4 halogen lamps			0.1400	3 hours/day	1095	153.30	ERSE (35w)
FLR20016	Living Room	Lighting	2 lamps			0.1200	0.5 hours/day	182.5	21.90	ERSE (60w)
FLR20016	Living Room	Entertainment	1 Hi-Fi		Sony	0.0600	1 hour/week	52	3.12	ERSE (60w)
FLR20016	Living Room	Entertainment	1 Hi-Fi in standby		Sony	0.0021	167.46 hours/week	8708	17.85	SELINA (2.05w)
FLR20016	Living Room	Entertainment	1 Plasma TV	HD SRS	Samsung	0.3500	4 hours/day	1460	511.00	Samsung internet (350w)
FLR20016	Living Room	Entertainment	1 Plasma TV in standby	HD SRS	Samsung	0.0003	20 hours/day	7300	2.19	Samsung internet (0.3w)
FLR20016	Living Room	Entertainment	1 Cable TV box decoder	HD - DSR 7151	Zon - Pace	0.0090	4 hours/day	1460	13.14	Quercus (9w)
FLR20016	Living Room	Entertainment	1 Cable TV box decoder in standby	HD - DSR 7151	Zon - Pace	0.0083	20 hours/day	7300	60.59	Quercus (8.3w)
FLR20016	Living Room	Entertainment	1 DVD Player		Mitsai	0.2400	1 hour/day	365	87.60	ERSE (240w)
FLR20016	Living Room	Entertainment	1 DVD Player in standby		Mitsai	0.0014	23 hours/day	8395	11.75	Deco Proteste Internet simulator
FLR20014	Bedroom 1	Lighting	3 lamps			0.1200	1 hour/day	365	43.80	ERSE (40w)
FLR20014	Bedroom 1	Lighting	2 lamps (side bed)			0.0800	1 hour/day	365	29.20	ERSE (40w)
FLR20014	Bedroom 1	Entertainment	1 Plasma TV	HD SRS	Samsung	0.3500	3 hours/day	1095	383.25	Samsung internet (350w)
FLR20014	Bedroom 1	Entertainment	1 Plasma TV in standby	HD SRS	Samsung	0.0003	21 hours/day	7665	2.30	Samsung internet (0.3w)
FLR20014	Bedroom 1	Environment	1 electric fan heater			2.0000	1 hour/day when cold		0.00	ERSE (200w)
FLR20014	Bedroom 1	Environment	1 electric fan			0.1000	1 hour/day when hot		0.00	LG (100w)
FLR20013	Bedroom 2	Lighting	3 lamps			0.1200	1 hour/day	365	43.80	ERSE (40w)
FLR20013	Bedroom 2	Lighting	2 lamps (side bed)			0.0800	1 hour/day	365	29.20	ERSE (40w)
FLR20013	Bedroom 2	Entertainment	1 TV	14''	Beko	0.0300	0.5 hours/day	182.5	5.48	Beko Manual (30w)
FLR20013	Bedroom 2	Entertainment	1 TV in standby	14''	Beko	0.0040	23.5 hours/day	8577.5	34.31	Beko Manual (4w)
FLR20013	Bedroom 2	Entertainment	1 DVD Player		Samsung	0.2400	0.5 hours/day	182.5	43.80	ERSE (240w)
FLR20013	Bedroom 2	Entertainment	1 DVD Player in standby		Samsung	0.0014	23.5 hours/day	8577.5	12.01	Deco Proteste Internet simulator
KTCH0003	Kitchen	Lighting	2 Fluorescent lamps			0.0720	4 hours/day	1460	105.12	ERSE (36w)
KTCH0003	Kitchen	Appliance	1 Washing machine	AWO / D8409	Whirlpool	2.0000	3 times/week (1.5 hours)	234	212.16	ERSE (2000w); Manual (1.36 kWh each washing cycle)
KTCH0003	Kitchen	Appliance	1 Microwave	MW2717	Fairline	0.7000	0.25 hours/day	91.25	63.88	Internet (max 700w)
KTCH0003	Kitchen	Appliance	1 Microwave in standby	MW2717	Fairline	0.0043	23.75 hours/day	8668.75	37.28	Deco Proteste Internet simulator
KTCH0003	Kitchen	Appliance	1 Fridge / freezer		no brand identificable	0.0255	On continuously	8760	223.00	Top ten (223 hWh/year)
KTCH0003	Kitchen	Appliance	1 Electric Oven	Princess	Milano	0.7000	0.5 hours/day	182.5	127.75	in situ
KTCH0003	Kitchen	Appliance	1 Extractor hood		Arjero	0.1050	when cooking (2hours/day)	730	76.65	nominal power 105 W
KTCH0003	Kitchen	Appliance	1 Iron			1.6000	2 times/week (1.5 hours)	156	249.60	ERSE (1600w)
KTCH0003	Kitchen	Entertainment	1 Plasma TV	small	Samsung	0.2300	4 hours/day	1460	335.80	Samsung internet (230w)
KTCH0003	Kitchen	Entertainment	1 Plasma TV in standby	small	Samsung	0.0010	20 hours/day	7300	7.30	Samsung internet (1w)
KTCH0003	Kitchen	Appliance	1 Gas stove	Princess	Milano		1 bottle/month		0.00	Households
KTCH0004	Kitchen - Laundry	Lighting	1 Lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
KTCH0004	Kitchen - Laundry	Appliance	1 Freezer	HC150	Tensai	0.0292	On continuously	8760	256.00	Tensai internet (256 kWh/year)
KTCH0004	Kitchen - Laundry	Environment	1 electric hot water cylinder			1.5000	On continuously	8760	321.20	in situ; AKI - 0.88 kWh/Day (50l, 1200w)
WC__0001	WC	Lighting	1 lamp			0.0600	1.5 hours/day	547.5	32.85	ERSE (60w)
								TOTAL	**3587.37**	
									4139.04	EDP (kWh/Year)

Case Study 7
Study Area Location Plan

0 m 50 m 100 m

Study area

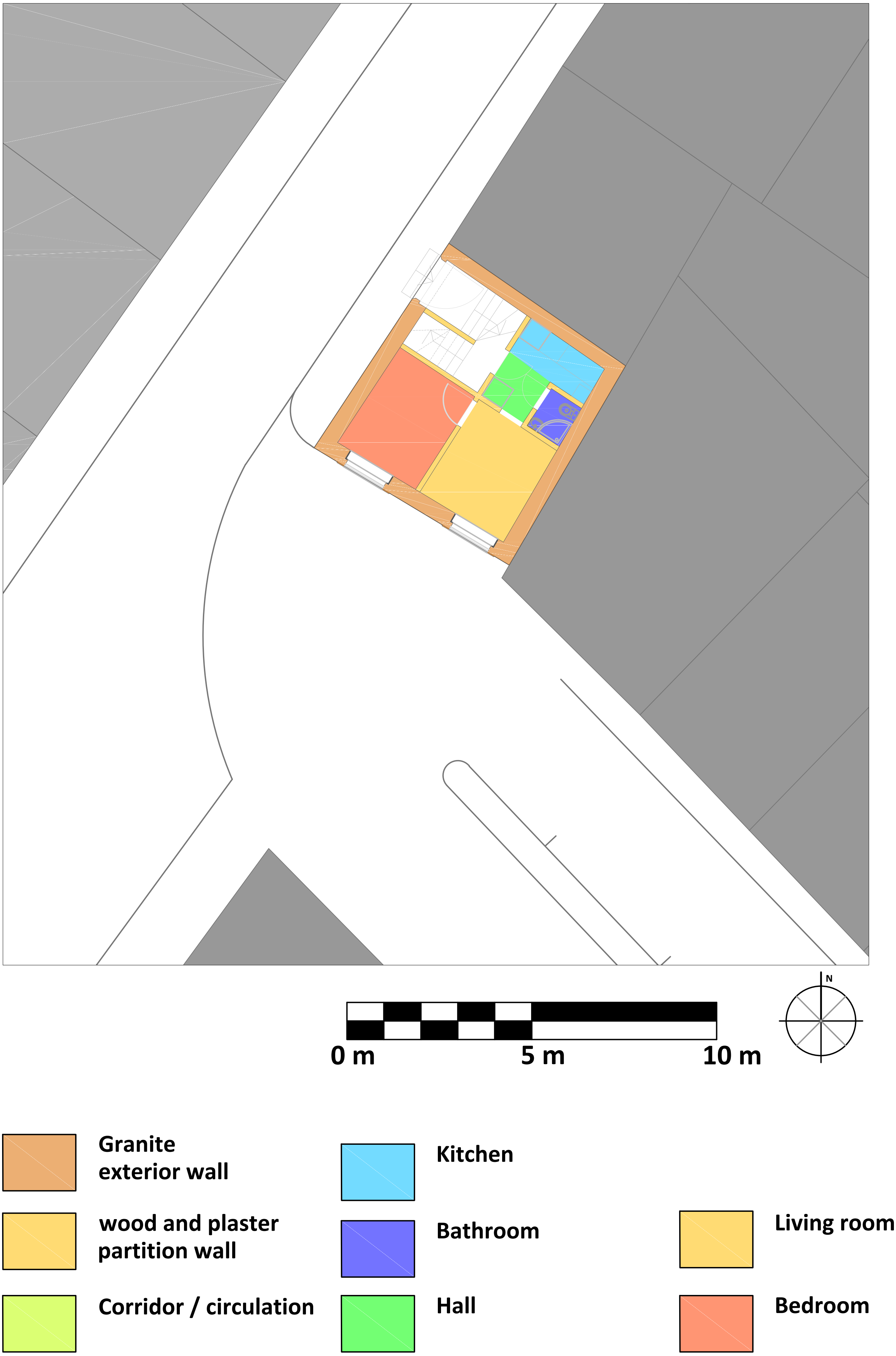




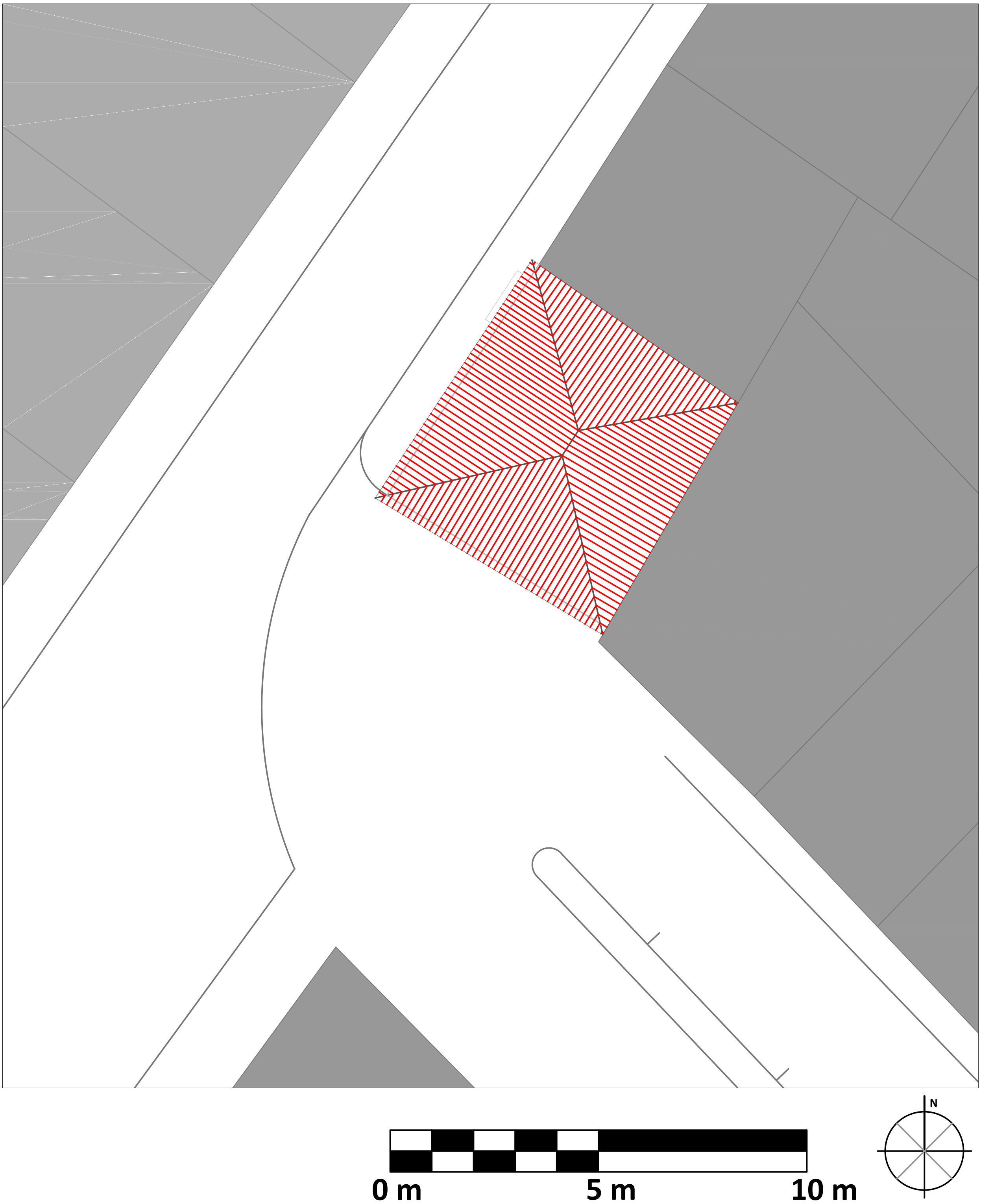
Case 7 site plan

0 m 5 m 10 m

Case Study 7
Variant 2 middle - 1st floor plan

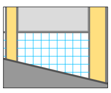


Case Study 7
Variant 2 middle - roof plan

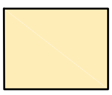


Ceramic roof tiles

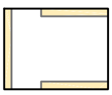
Case Study 7
Variant 2 middle - front facade (street)



Tile



Granite masonry

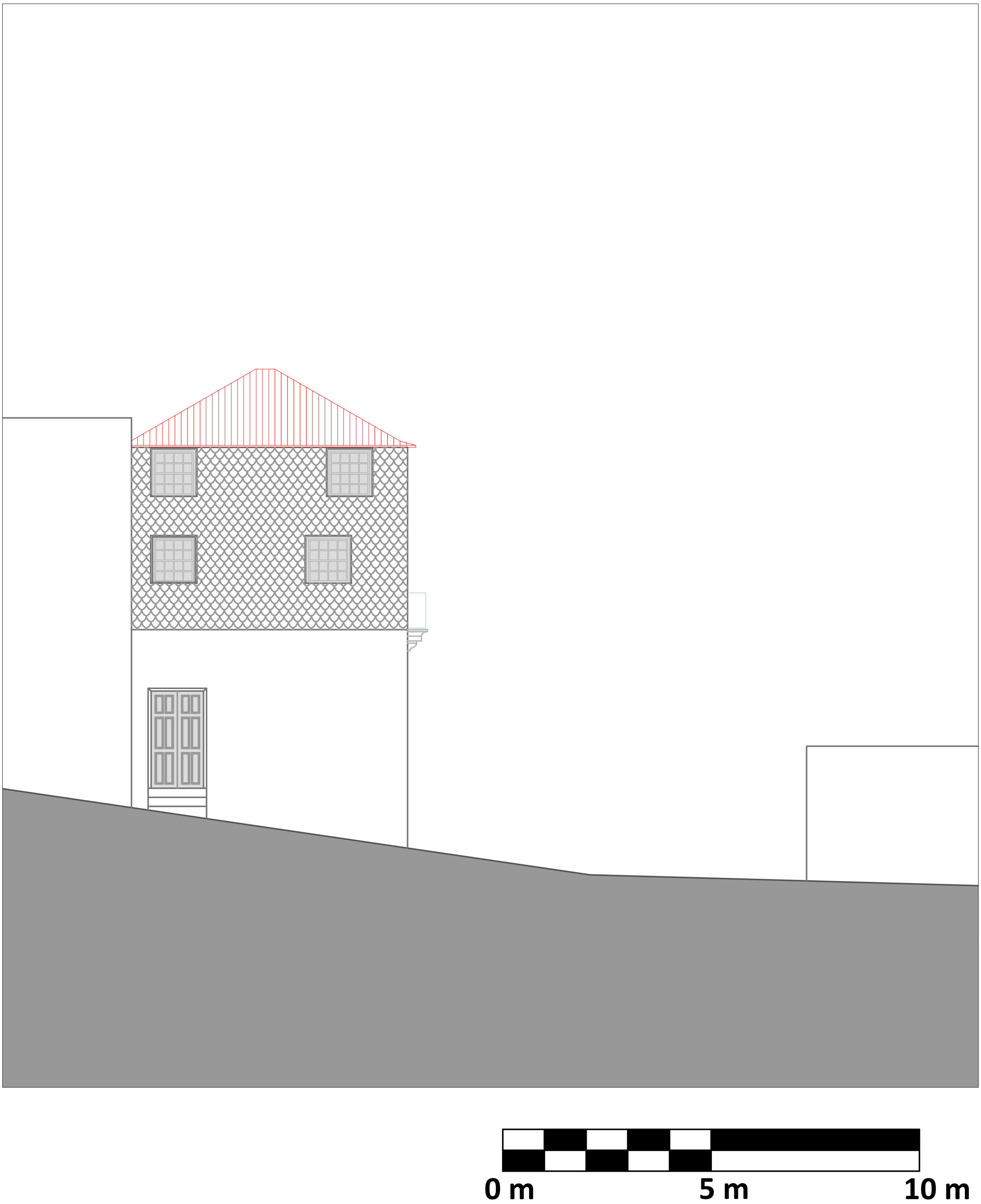


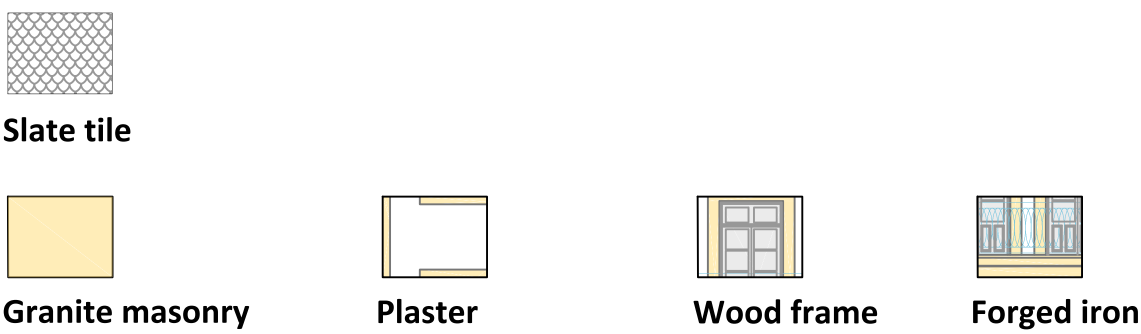
Plaster

Wood frame

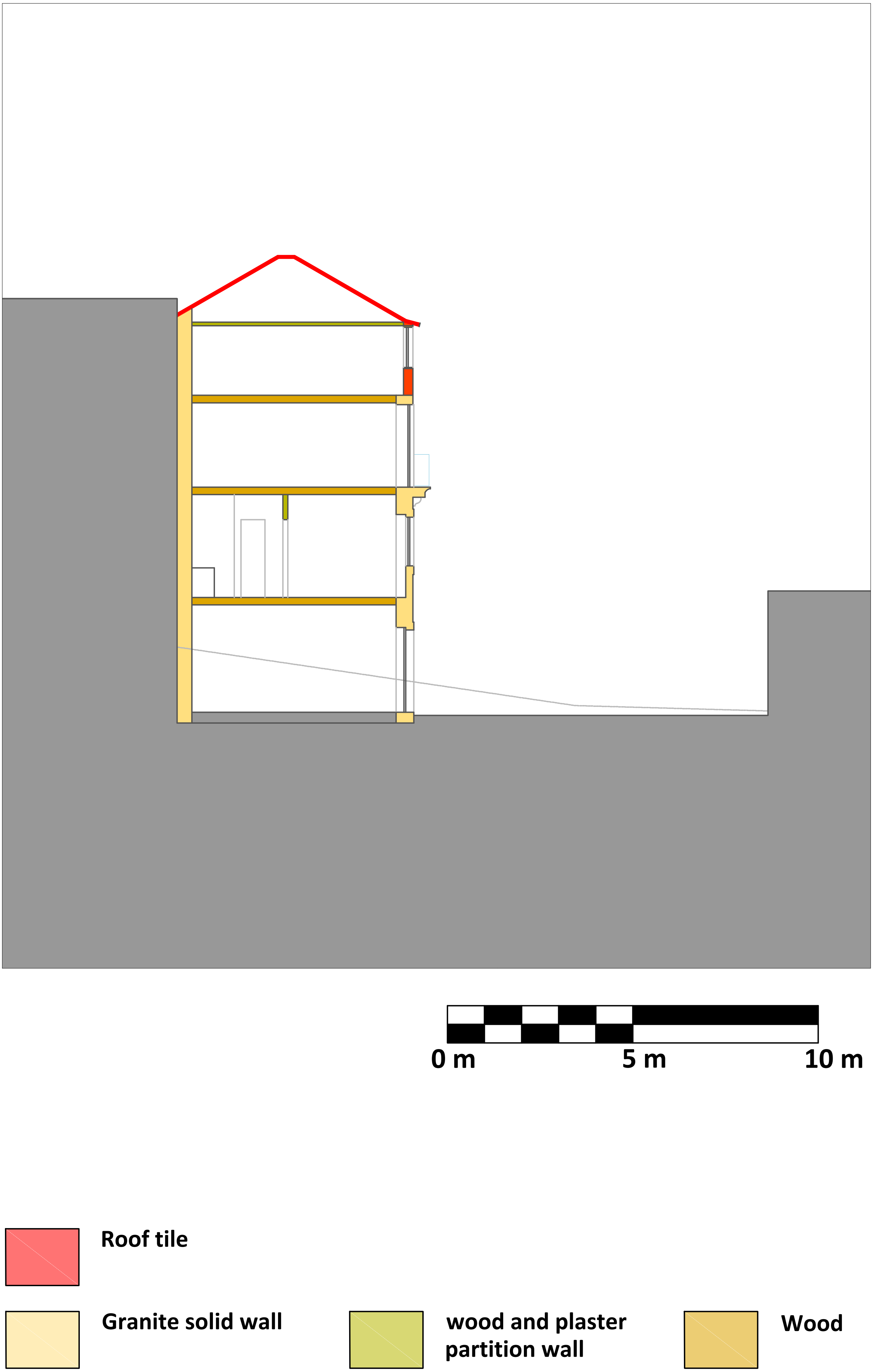
Forged iron

Case Study 7
Variant 2 middle - side facade (street)





Case Study 7
Variant 2 middle - section



Case Study 7
Variant 2 - middle floor - Openings

Front (SW) 1st floor x2

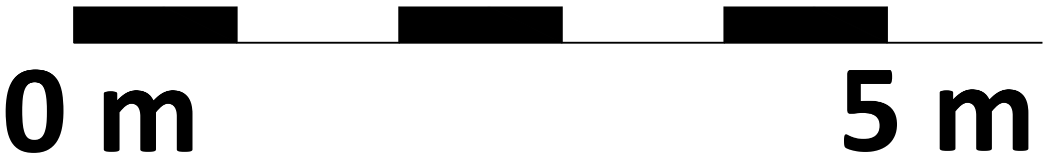
1.41m2

1.58m2

1.02m2

89.24% max.
opening area

64.56% of glazed area



	type 1	type 1	type 2	type 2	type 3	type 4
exterior wall	front 1 (SW) 1st floor	front 2 (NW) 1st floor	side (SE) 1st floor	side (NE) 1st floor	stairs	stairs (Kitchen
Total Thickness	0.450	0.450	0.425	0.425	0.13	0.13
ext layer	plaster (0.025)	plaster (0.025)			plaster (0.025)	plaster (0.025)
layer 1	granite (0.40)	granite (0.40)	granite (0.40)	granite (0.40)	wood+mortar (0.08)	wood+mortar (0.08)
layer 2						
layer 3						
layer 4						mortar (0.02)
int layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	tile (0.005)

	type 1	type 2	type 3			
partition wall		Kitchen-WC/rooms	Kitchen/WC			
Total Thickness	0.13	0.13	0.13			
ext layer	plaster (0.025)	plaster (0.025)	tile (0.005)			
layer 1	wood+mortar (0.08)	wood+mortar (0.08)	mortar (0.02)			
layer 2			'wood+mortar (0.08)			
layer 3						
layer 4		mortar (0.02)	mortar (0.02)			
int layer	plaster (0.025)	tile (0.005)	tile (0.005)			

	type 1	type 2				
Horizontal separation						
Total Thickness	0.26	0.26				
floor layer	hardwood (0.03)	tile (0.005)				
layer 1	wood beams (0.20)	mortar (0.005)				
layer 2		hardwood (0.025)				
layer 3		wood beams (0.20)				
layer 4	timber framing (0.01)	timber framing (0.01)				
ceiling layer	gypsum (0.015)	gypsum (0.015)				

Front (SW) 1st floor 2 casement windows

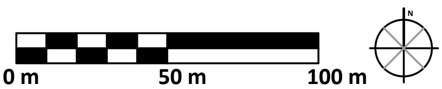
Ext. Window	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile	Exterior blinders	use profile
total area (m2)	no	1.58	allways open 25% during day	no	not applicable	1.58	open all day	1.58	75% open during day
glazed area (m2)	no	1.02	closed when too cold	no			closed in the night		closed during night and away
frame area (m2)	no	0.56		no					
percentage of glazed (%)	no	64.56		no					
percentage of frame (%)	no	35.44		no					
max. Opening area (m2)	no	1.41		no					
percentage of max. Opening area (%)	no	89.24		no					
Frame material	no	wood (3cm)		no		light tissue		plastic (0.01)	
Type of glass	no	single (3mm)							

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	excepted bedroom and WC
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

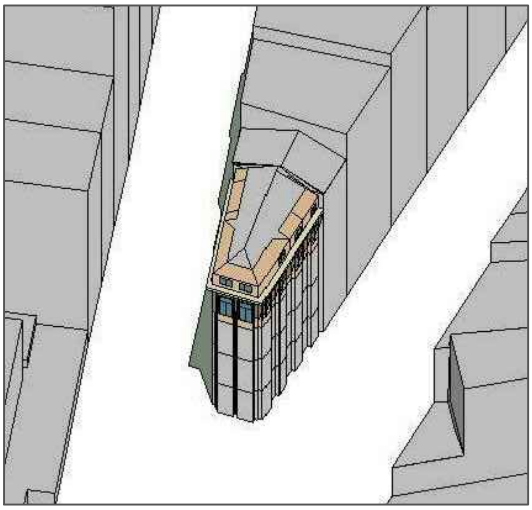
Int. Window	Fanlight window	Window	use profiles
total area (m2)	no	no	not applicable
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

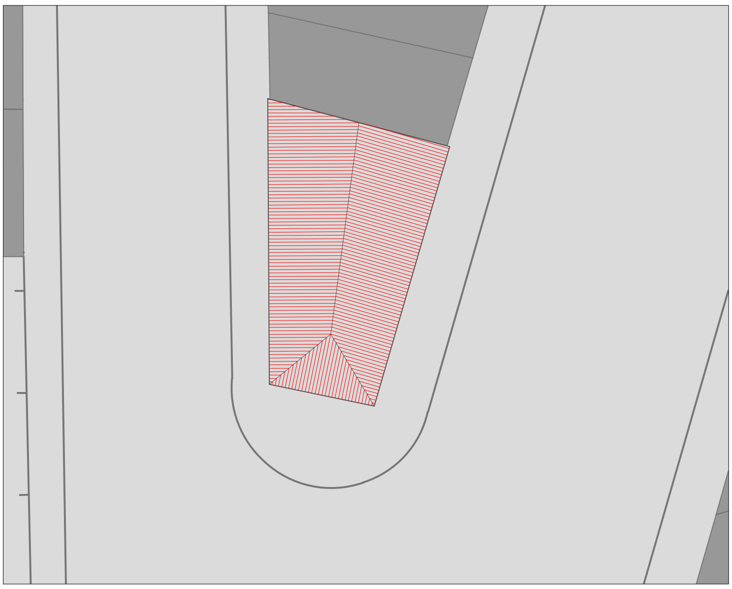
							Operation profile assumed	Hours per year		
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Source
FLR10012	Livingroom	Lighting	3 lamps			0.1200	4 hours/day	1460	175.20	ERSE (40w)
FLR10012	Livingroom	Entertainment	1 TV	old model	Panasonic	0.0900	8 hours/day	2920	262.80	ERSE (90w)
FLR10012	Livingroom	Entertainment	1 TV in standby	old model	Panasonic	0.00523	16 hours/day	5840	30.54	SELINA (TV CRT 5.23w)
FLR10012	Livingroom	Entertainment	1 VCR	Express programming system	JVC	0.0200	no use	0	0.00	ERSE (20w)
FLR10012	Livingroom	Entertainment	1 Hi-Fi	old model	Sanyo	0.0600	no use	0	0.00	ERSE (60w)
FLR10012	Livingroom	Appliance	1 cordless telephone	Gigaset A160	Siemens	0.0030	On continuously	8760	26.28	LG (3w)
FLR10012	Livingroom	Environment	1 Electric oil-filled radiator heater	HR 1500	Fidelis	1.5000	3 hours when cold		0.00	in situ
FLR10013	Bedroom	Lighting	3 compact fluorescent lamps			0.0330	4 hours /day	1460	48.18	ERSE (11w)
FLR10013	Bedroom	Lighting	2 lamps in bed side			0.0800	1 hour/day	365	29.20	ERSE (40w)
FLR10013	Bedroom	Entertainment	1 small TV		Philips	0.0300	2 hours/day	730	21.90	same as BEKO
FLR10013	Bedroom	Entertainment	1 small TV in standby		Philips	0.0040	22 hours/day	8030	32.12	same as BEKO
FLR10006	Kitchen	Lighting	2 Fluorescent lamps			0.0720	8 hours/day	2920	210.24	ERSE (36w)
FLR10006	Kitchen	Appliance	1 Washing machine	TKX 85	Teka	2.0000	2 washes / week (1.5 hours)	156	118.56	Top ten (1.14 kWh each washing cycle)
FLR10006	Kitchen	Appliance	1 Microwave	Grill	LG	0.9000	0.25 hours/day	91.25	82.13	ERSE (900w)
FLR10006	Kitchen	Appliance	1 Microwave in standby	Grill	LG	0.0043	23.75 hours/day	8668.75	37.28	Deco Proteste Internet simulator
FLR10006	Kitchen	Appliance	1 Fridge	Cooler	Bosch	0.0341	On continuously	8760	299.00	Top ten (299 kWh/year)
FLR10006	Kitchen	Appliance	1 Toaster		Silver	0.7500	0.25 hours/day	91.25	68.44	in situ
FLR10006	Kitchen	Appliance	1 Electric Oven	Mini oven grill	Tefal	2.4000	0.25 hours/day	91.25	219.00	ERSE (2400w)
FLR10006	Kitchen	Appliance	1 Electric Oven in standby	Mini oven grill	Tefal	0.0040	23.75 hours/day	8668.75	34.68	EDP (4w)
FLR10006	Kitchen	Environment	1 Electric hot water cylinder	CB 50 -N1	Fagor	1.6000	On continuously	8760	467.20	Fagor internet; AKI - 1.28 kWh/Day (50l, 2000w)
FLR10006	Kitchen	Appliance	1 Gas stove		Ruby		1 bottle / 1.5 months (0.66)		0.00	Households
FLR10007	WC	Lighting	1 lamp			0.0600	2 hours/day	730	43.80	ERSE (60w)
								TOTAL	**2206.54**	
									1796.81	EDP (kWh/Year)

Case Study 8
Study Area Location Plan



Study area

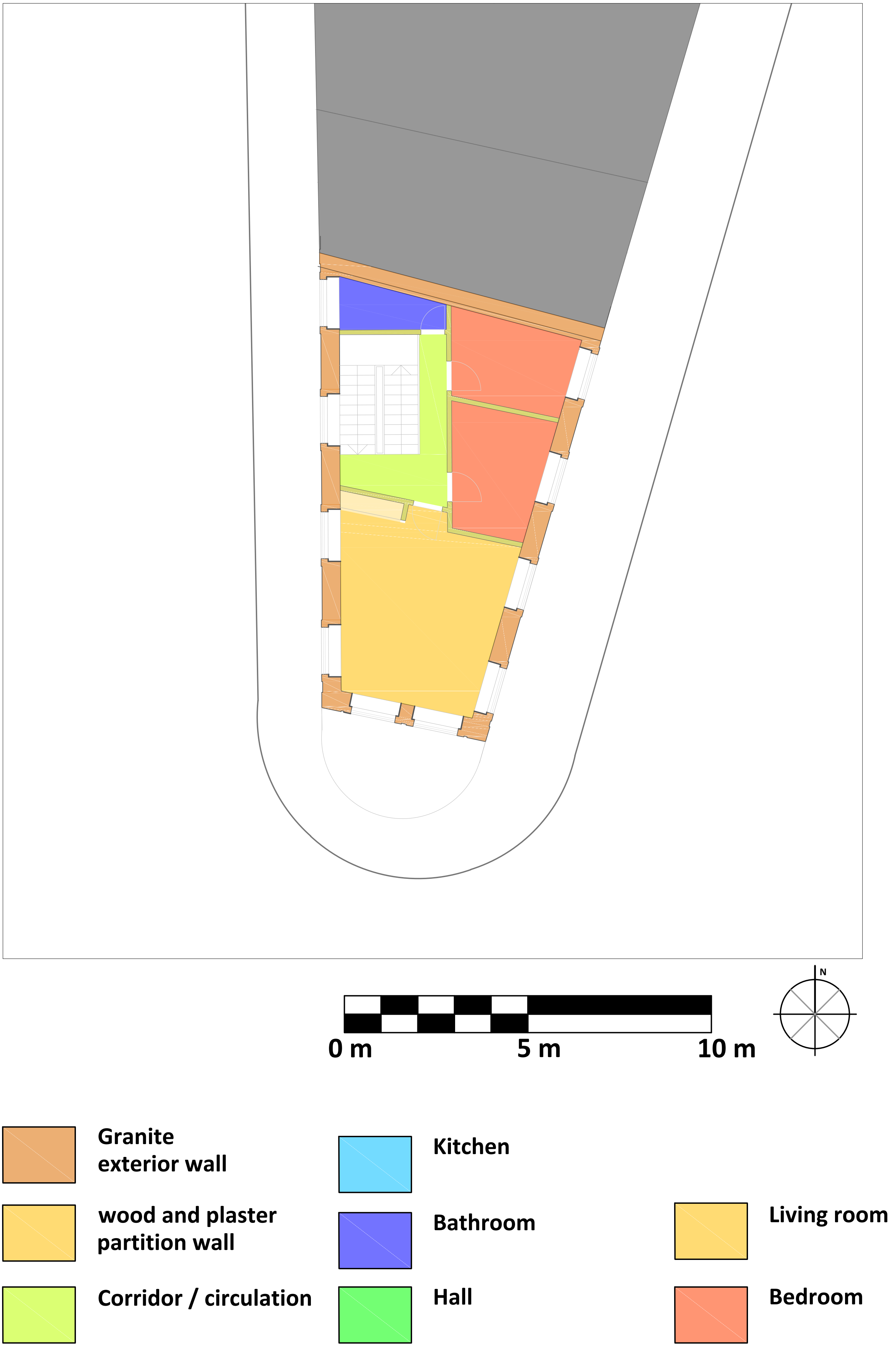




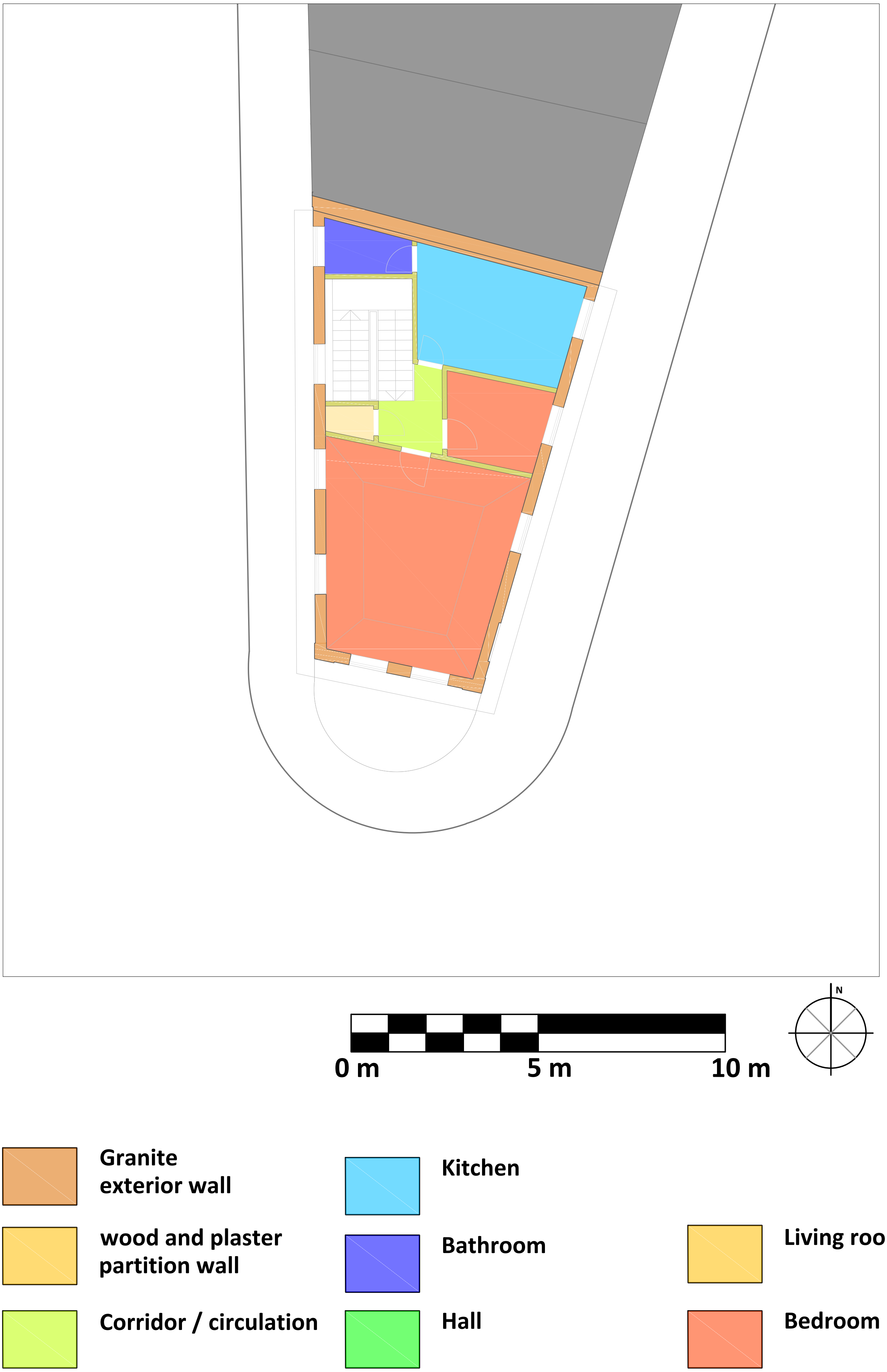
Case 8 site plan

0 m 5 m 10 m

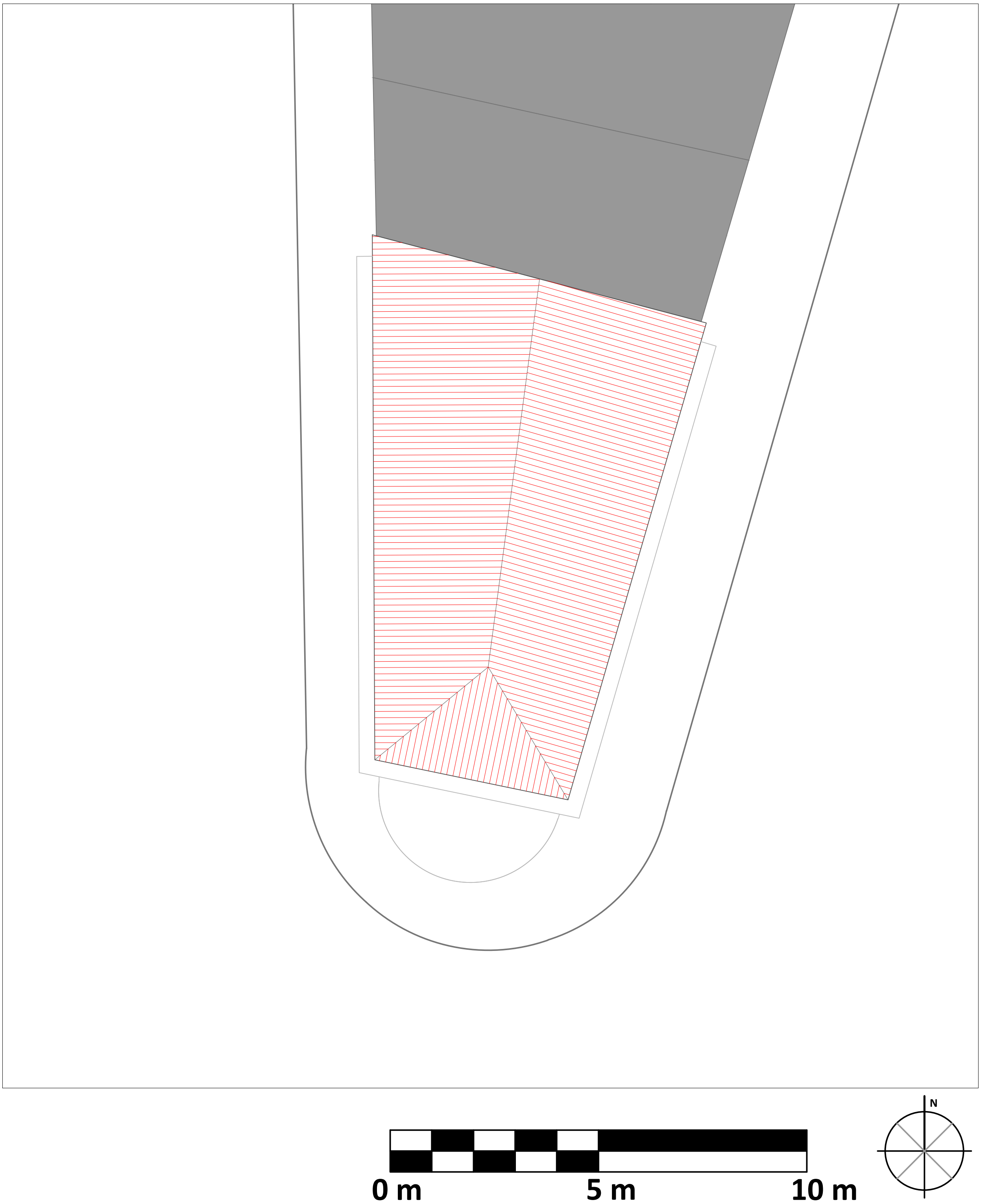
Case Study 8
Variant 1 top - 3rd floor plan

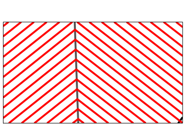


Case Study 8
Variant 1 top - 4th floor plan



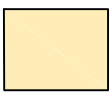
Case Study 8
Variant 1 top - roof plan

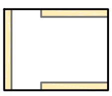




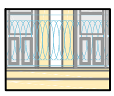
Ceramic roof tiles

Case Study 8
Variant 1 top - front facade (street)

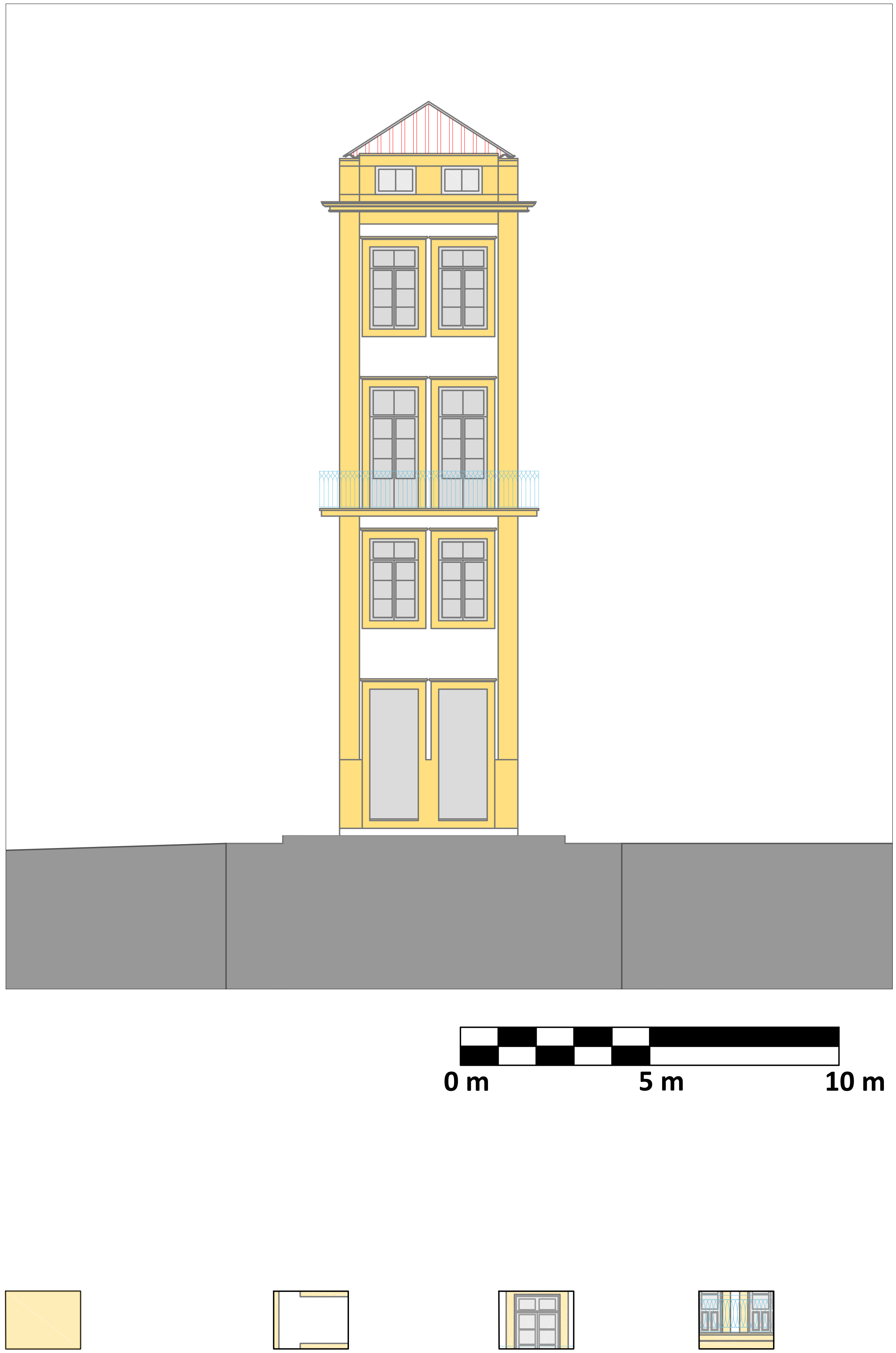

Granite masonry


Plaster

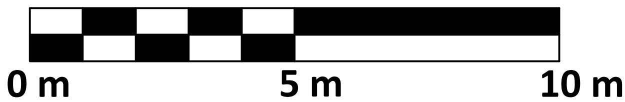

PVC frame


Forged iron

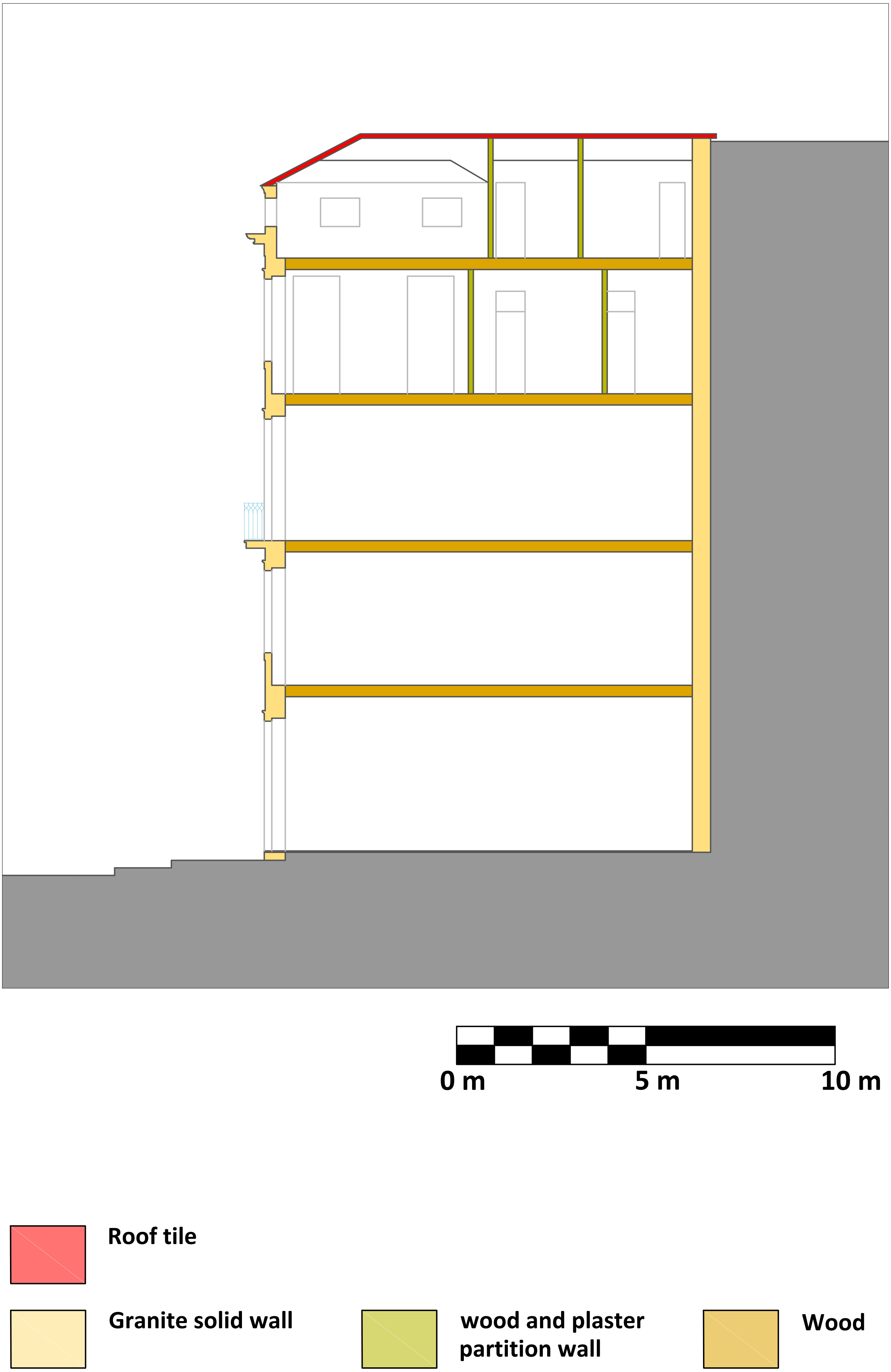
Case Study 8
Variant 1 top - side facade 1 (street)



Case Study 8
Variant 1 top - side facade 2 (street)

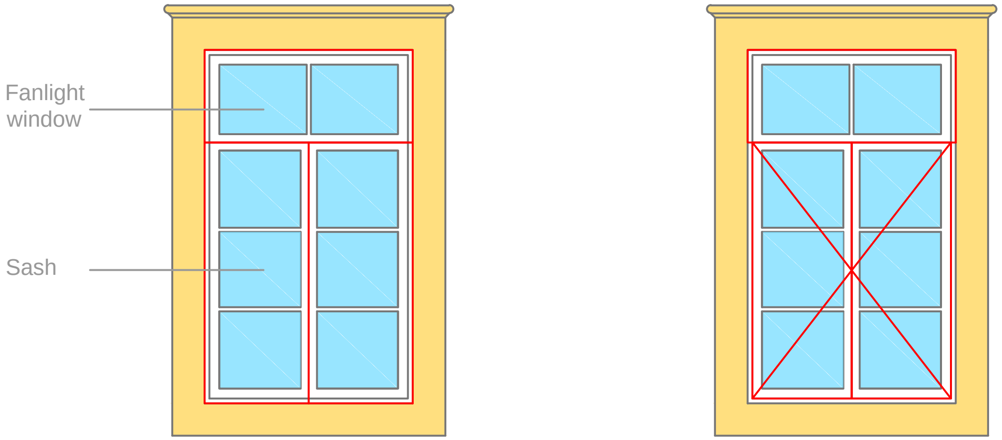


Case Study 8
Variant 1 top - section

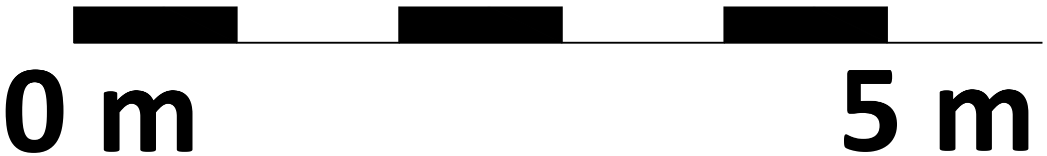


Case Study 8
Variant 1 - top floor - Openings

Front (W); Side (S); Side (E) 3rd floor x10

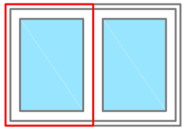


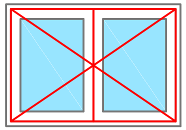
Fanlight window	0.73m2	1.03m2 1 Sash	0.96m2
	0.46m2	0.71m2	
	63.01% of glazed area	68.93% of glazed area	93.20% max. opening area



Case Study 8
Variant 1 - top floor - Openings

Front (W); Side (S); Side (E) 4th floor x9





0.40m2	0.35m2
0.22m2	
55.00% of glazed area	87.50% max. opening area

	type 1	type 1	type 1	type 2 (WC)	type 3 (both floors)	type 4 (WC 3rd floor)	type 5
exterior wall	front (W) 3rd floor	side (E) 3rd floor	side (W) 3rd floor	front (W) 3rd floor	side (N) party wall	side (N) party wall	(W, E, S) - granite
Total Thickness	0.511	0.511	0.511	0.510	0.485	0.485	0.190
ext layer	plaster (0.02)	plaster (0.02)	plaster (0.02)				granite
layer 1							granite (0.19)
layer 2							
layer 3	granite (0.47)	granite (0.47)	granite (0.47)	granite (0.47)	granite (0.465)	granite (0.465)	
layer 4	plaster (0.02)	plaster (0.02)	plaster (0.02)	mortar (0.015)	plaster (0.02)	mortar (0.015)	
int layer	wallpaper (0.001)	wallpaper (0.001)	wallpaper (0.001)	tile (.005)	wallpaper (0.001)	tile (.005)	granite

	type 6	type 6	type 6	type7 (WC)	type 7 (Kitchen)	type 4 (WC 4th floor)	type 4 (Kitchen - 4th floor)
exterior wall	front (W) 4th floor	side (E) 4th floor	side (W) 4th floor	front (W) 4th floor	side (W) 4th floor	side (N) party wall	side (N) party wall
Total Thickness	0.300	0.300	0.300	0.300	0.300	0.485	0.485
ext layer	granite	granite	granite	granite	granite		
layer 1							
layer 2							
layer 3	granite (0.28)	granite (0.28)	granite (0.28)	granite (0.28)	granite (0.28)	granite (0.465)	granite (0.465)
layer 4	plaster (0.02)	plaster (0.02)	plaster (0.02)	mortar (0.015)	mortar (0.015)	mortar (0.015)	mortar (0.015)
int layer	wallpaper (0.001)	wallpaper (0.001)	wallpaper (0.001)	tile (0.005)	tile (0.005)	tile (0.005)	tile (0.005)

	type 1	type 2					
partition wall							
Total Thickness	0.13	0.13					
ext layer	wallpaper (0.001)	wallpaper (0.001)					
layer 1	plaster (0.025)	plaster (0.025)					
layer 2	wood+mortar (0.08)	wood+mortar (0.08)					
layer 3							
layer 4	plaster (0.025)	plaster (0.02)					
int layer	wallpaper (0.001)	tile (0.005)					

	type 1	type 1	type 2				
Horizontal separation	Floor	3rd/4th floor	Roof				
Total Thickness	0.300	0.300	0.21				
floor layer	carpet (0.005)	carpet (0.005)	ceramic tile (0.015)				
layer 1	hardwood (0.03)	hardwood (0.03)	wood (0.18)				
layer 2	wood beams (0.23)	wood beams (0.23)					
layer 3							
layer 4	timber framing (0.01)	timber framing (0.01)					
ceiling layer	gypsum (0.025)	gypsum (0.025)	wood (0.015)				

Front (W); Side (S); Side (E) 3rd floor 10 casement windows

Ext. Window	Fanlight window	Sashes (each window x2)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	0.73	1.03	open in the night with hot temp.	2.79	closed continuously 75%	2.79	closed continuously
glazed area (m2)	0.46	0.71					
frame area (m2)	0.27	0.32					
percentage of glazed (%)	63.01	68.93					
percentage of frame (%)	36.99	31.07					
max. Opening area (m2)	0.00	0.96					
percentage of max. Opening area (%)	0.00	93.20					
Frame material	PVC (3cm)	PVC (3cm)		wood (3cm)		light tissue	
Type of glass	Double (3+2+3mm)	Double (3+2+3mm)					

Front (W); Side (S); Side (E) 4th floor 10 casement windows

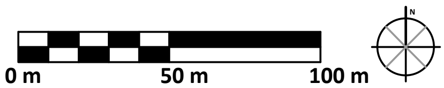
Ext. Window	Fanlight window	Sashes (each window x2)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.4	open in the night with hot temp.	no	not applicable	0.8	closed continuously
glazed area (m2)	no	0.22		no			
frame area (m2)	no	0.18		no			
percentage of glazed (%)	no	55.00		no			
percentage of frame (%)	no	45.00		no			
max. Opening area (m2)	no	0.35		no			
percentage of max. Opening area (%)	no	87.50		no			
Frame material	no	PVC (3cm)		no		light tissue	
Type of glass	no	Double (3+2+3mm)		no			

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

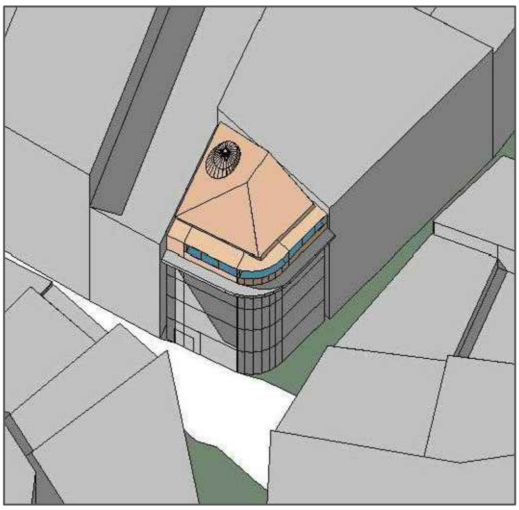
Int. Window	Fanlight window	Door	use profiles
total area (m2)	no	no	not applicable
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

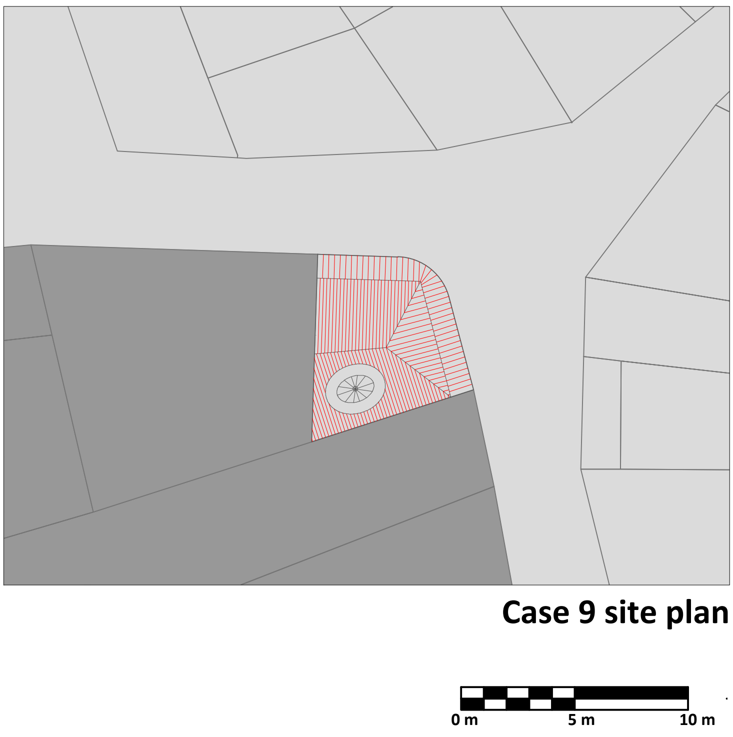
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
FLR30022	Hall/Stairs - Floor 3	Lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
FLR30017	Livingroom - floor 3	Lighting	5 lamps			0.2000	2 hours/day	730	146.00	ERSE (40w)
FLR30017	Livingroom - floor 3	Entertainmnet	1 TV			0.0900	1 hour/day	365	32.85	ERSE (90w)
FLR30017	Livingroom - floor 3	Entertainmnet	1 TV in standby			0.0052	23 hours/day	8395	43.91	SELINA (TV CRT 5.23w)
FLR30017	Livingroom - floor 3	Environment	1 old Electric oil-filled radiator heater		Forster	1.0000	1.5 hours/day when cold		0.00	in situ
FLR30011	Bedroom 2 - Floor 3	Lighting	1 lamp			0.0600	0.25 hours/week	13	0.78	ERSE (60w)
FLR30013	Bedroom 1 - Floor 3	Lighting	3 lamps			0.1200	0.25 hours/week	13	1.56	ERSE (40w)
FLR30013	Bedroom 1 - Floor 3	Lighting	2 side bed lamps			0.0800	no use	0	0.00	ERSE (40w)
FLR30013	Bedroom 1 - Floor 3	Entertainmnet	1 TV			0.0900	no use	0	0.00	ERSE (90w)
FLR30013	Bedroom 1 - Floor 3	Entertainmnet	1 TV in standby			0.0052	no use	0	0.00	SELINA (TV CRT 5.23w)
FLR30019	WC - Floor 3	Lighting	1 lamp			0.0600	0.25 hours/day	91.25	5.48	ERSE (60w)
FLR30019	WC - Floor 3	Environment	1 Electric hot water cylinder		Arierom	2.0000	On continuously	8760	448.95	AKI - 1.23 kWh/Day (like case 5)
FLR40031	Hall/Stairs - Floor 4	Lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
FLR40015	Bedroom 1 - Floor 4	Lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
FLR40015	Bedroom 1 - Floor 4	Lighting	2 bed side lamps			0.0800	1 hour/day	365	29.20	ERSE (40w)
FLR40015	Bedroom 1 - Floor 4	Entertainmnet	1 TV			0.0900	3.5 hours/day	1277.5	114.98	ERSE (90w)
FLR40015	Bedroom 1 - Floor 4	Entertainmnet	1 TV in standby			0.0052	20.5 hours/day	7482.5	39.13	SELINA (TV CRT 5.23w)
FLR40015	Bedroom 1 - Floor 4	Environment	1 old Electric oil-filled radiator heater		Century	1.0000	allways on when cold		0.00	in situ
FLR40021	Bedroom 2 - Floor 4	Lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
FLR40016	Kitchen - Floor 4	Lighting	2 Fluorescent lamps			0.0720	4 hours/day	1460	105.12	ERSE (36w)
FLR40016	Kitchen - Floor 4	Appliance	1 Washing machine	C40T Jolly	Candy		1 wash/week (1.5 hours)	78	59.28	Top ten (1.14 kWh each washing cycle)
FLR40016	Kitchen - Floor 4	Appliance	1 Fridge / freezer		Indesit	0.0404	On continuously	8760	354.00	Top ten (354 kWh/year)
FLR40016	Kitchen - Floor 4	Appliance	1 Electric Oven		Tecnogas	2.4000	0.25 hours/day	91.25	219.00	ERSE (2400w)
FLR40016	Kitchen - Floor 4	Appliance	1 Electric Oven in standby		Tecnogas	0.0040	23.75 hours/day	8668.75	34.68	EDP (4w)
FLR40016	Kitchen - Floor 4	Appliance	1 Gas stove		Tecnogas		0.5 bottles/month		0.00	Households
FLR40035	WC - Floor 4	Lighting	1 lamp			0.0600	2 hours/day	730	43.80	ERSE (60w)
FLR40019	Storage - Floor 4	Lighting	1 lamp			0.0400	0.125 hours/day	45.625	1.83	ERSE (40w)
								TOTAL	**1768.13**	
									3421.76	EDP (kWh/Year)

Case Study 9
Study Area Location Plan



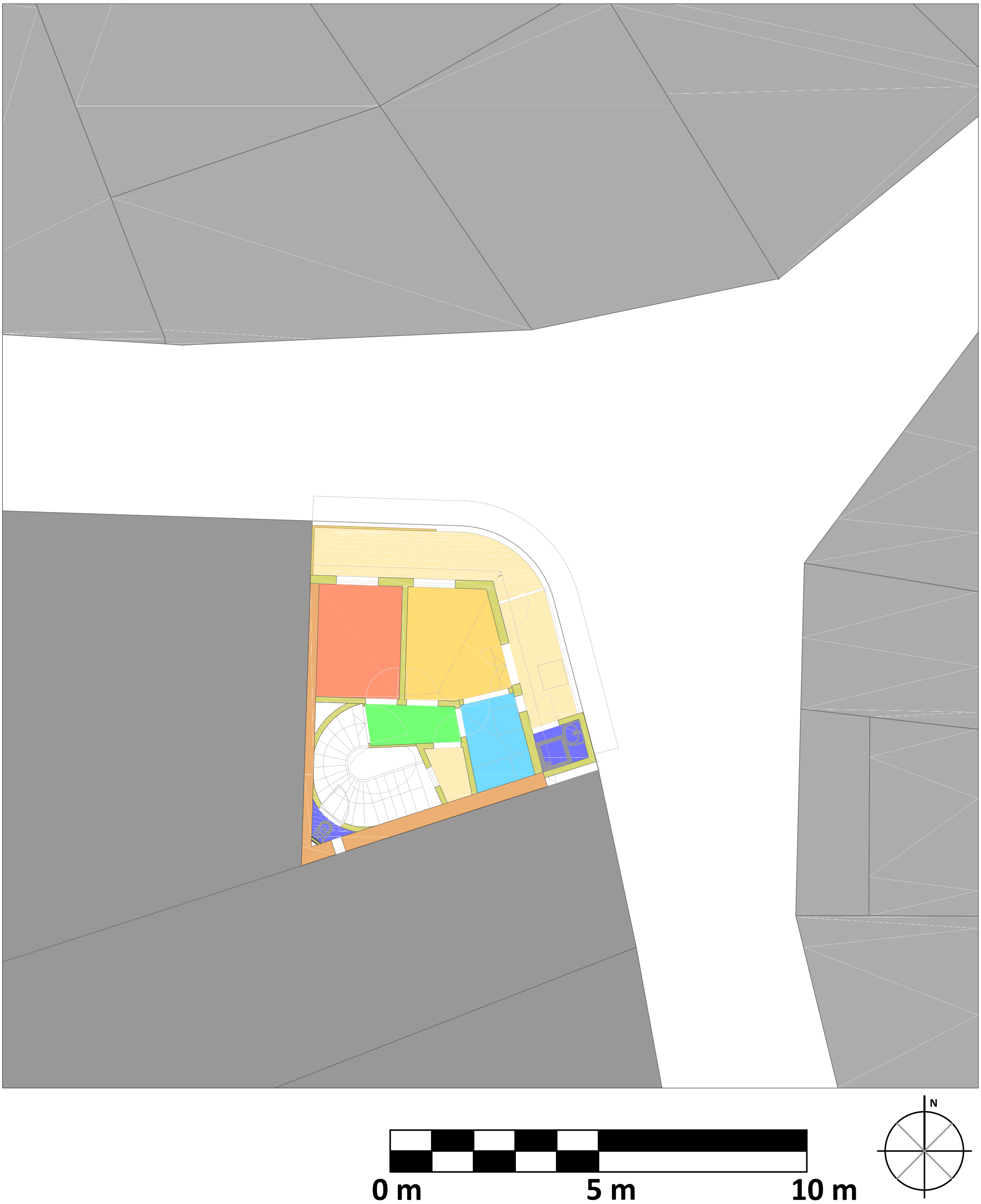
Study area





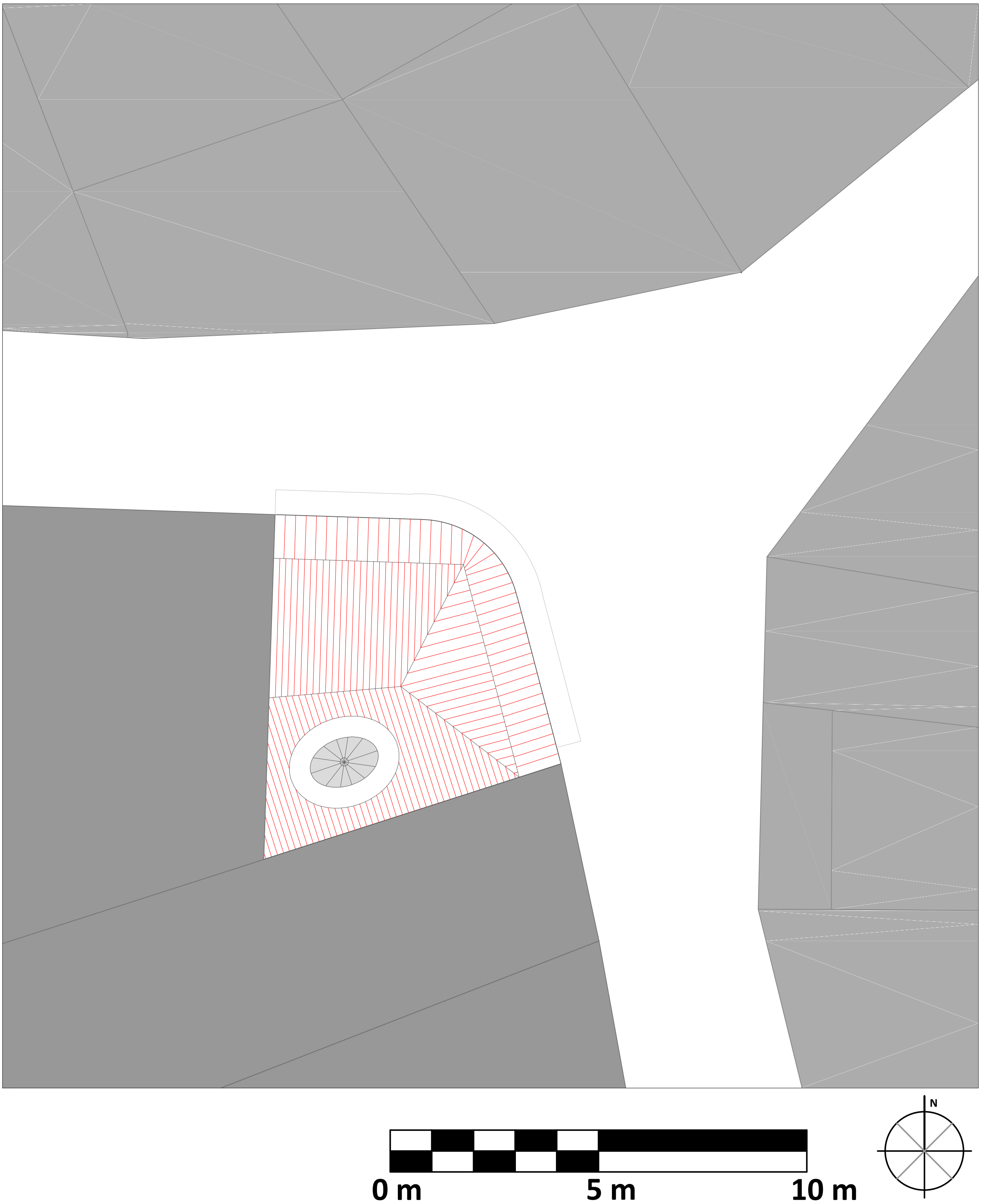
Case 9 site plan

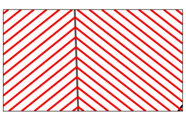
Case Study 9
Variant 2 top - 4th floor plan

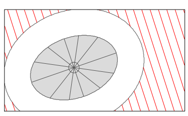


Granite exterior wall		Kitchen			
wood and plaster partition wall		Bathroom		Living room	
Corridor / circulation		Hall		Bedroom	

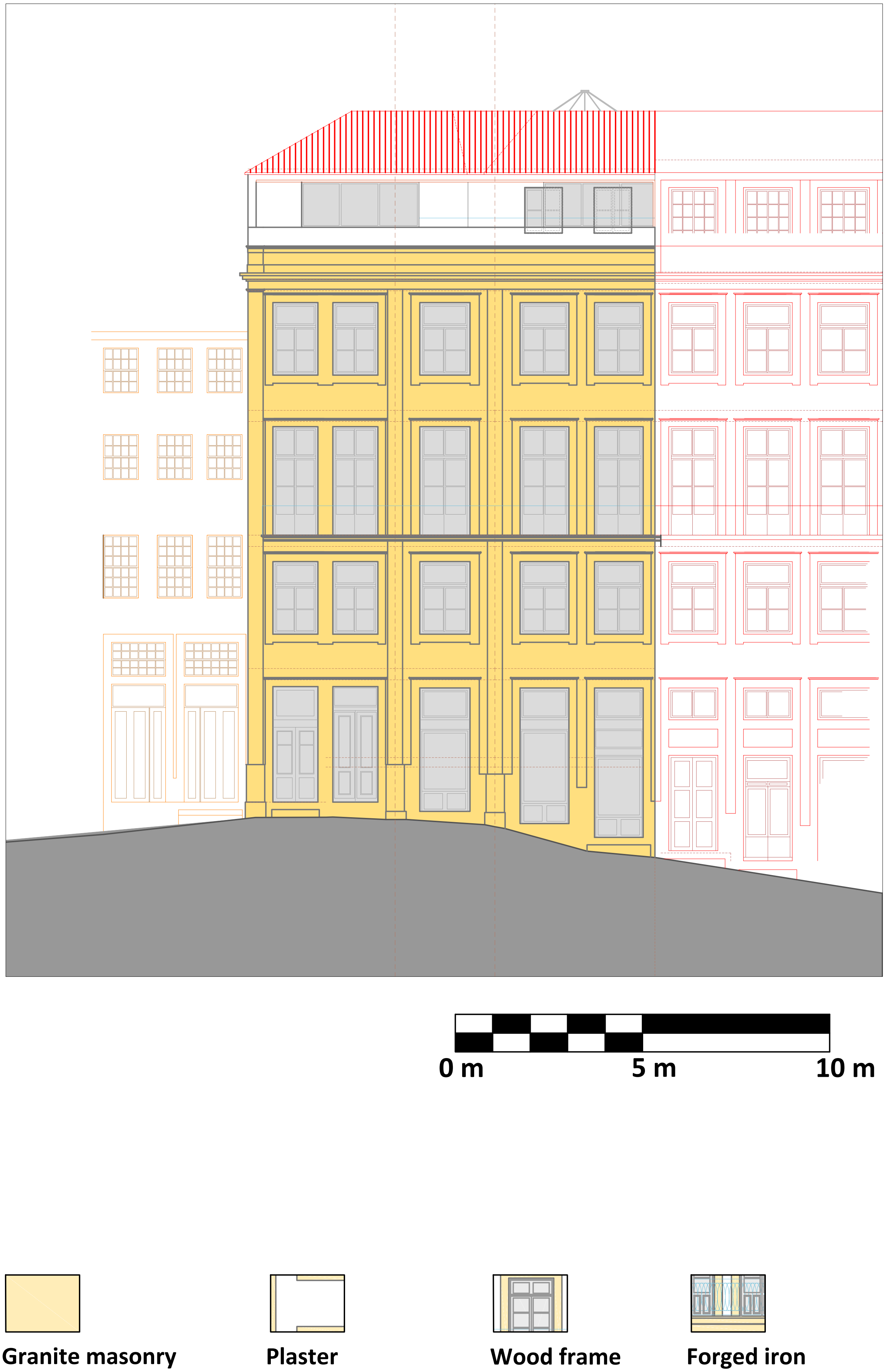
Case Study 9
Variant 2 top - roof plan



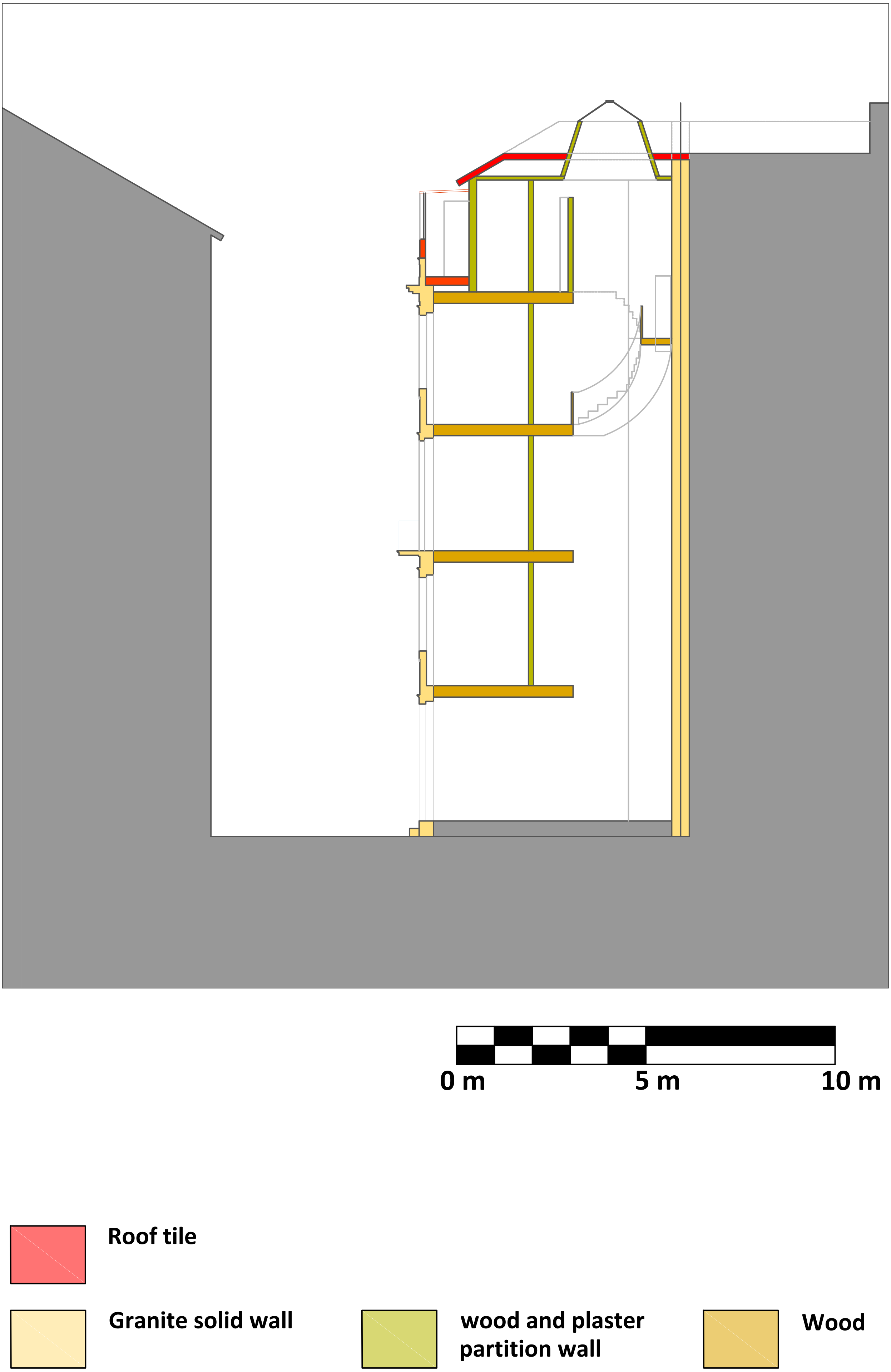




Case Study 9
Variant 2 top - facades (street)

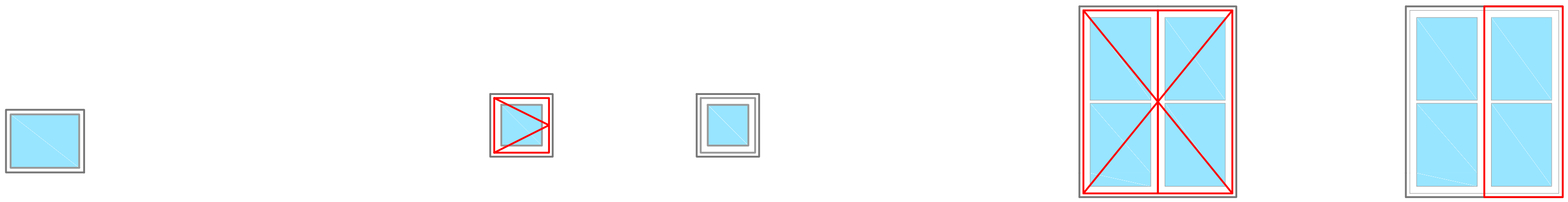


Case Study 9
Variant 2 top - section

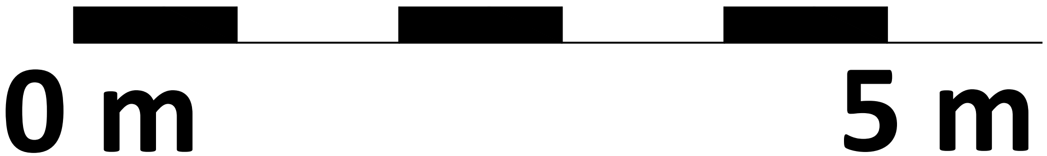


Case Study 9
Variant 2 - top floor - Openings

interior window (fixed)	Front (E) 4th floor x1		Side (N) 4th floor x2	



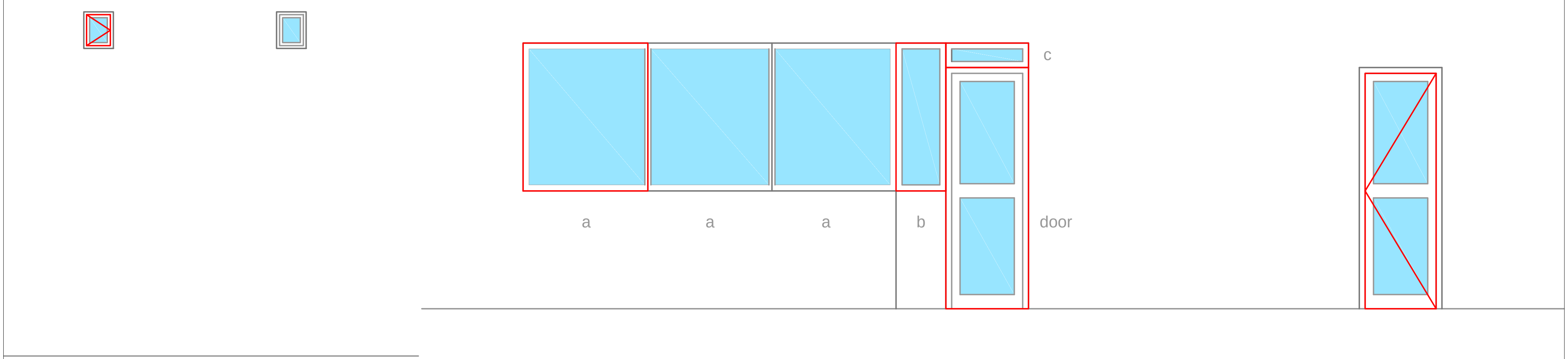
0.20m2	0.12m2	0.16m2	0.56m2	0.61m2 1 Sash
0.15m2		0.07m2		0.41m2
75.00% of glazed area	75.00% max. opening area	43.75% of glazed area	91.80% max. opening area	67.21% of glazed area



Case Study 9
Variant 2 - top floor - Openings

Side (SE) 4th floor x1

Front (E) 4th floor

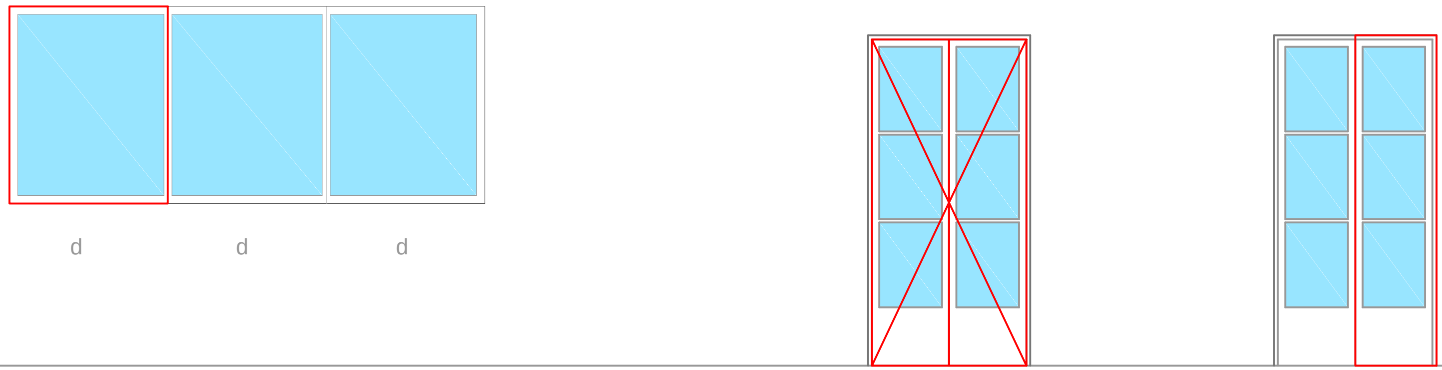


		a	b	c	door	
0.05m2	0.08m2	1.32m2	0.53m2	0.14m2	1.43m2	1.19m2
	0.03m2	1.13m2	0.37m2	0.06m2	0.40m2 0.38m2	
62.50% max. opening area	37.50% of glazed area	85.61% of glazed area	69.81% of glazed area	42.86% of glazed area	54.55% of glazed area	83.22% max. opening area

Case Study 9
Variant 2 - top floor - Openings

Side (N) 4th floor

Front (E) 4th floor x1



d 1.18m2

1.00m2

84.75% of glazed area

0.95m2

94.06% max. opening area

1.01m2 1 door

0.60m2

59.41% of glazed area

0 m 5 m

	type 1	type 1	type 2	type 3	type 4 (Kitchen)	type 5 (WC)	type 6 (Kitchen)
exterior wall	front (E) 4th floor	side (N) 4th floor	side (W) party wall	side (SE) party wall	front (E)	front, side (E, SE)	side (SE) party wall
Total Thickness	0.200	0.200	0.210	0.360	0.200	0.155	0.360
ext layer	slate+wood (0.05)	slate+wood (0.05)			slate+wood (0.05)	plaster (0.02)	
layer 1	wood+mortar (0.125)	wood+mortar (0.125)	granite (0.185)	granite (0.335)	wood+mortar (0.125)	brick (0.11)	granite (0.335)
layer 2							
layer 3							
layer 4					plaster (0.02)	plaster (0.02)	plaster (0.02)
int layer	plaster (0.025)	plaster (0.025)	plaster (0.025)	plaster (0.025)	tile (0.005)	tile (0.005)	tile (0.005)

	type 1	type 2	type 3				
partition wall		rooms / Kitchen	Kitchen / WC				
Total Thickness	0.13	0.13	0.175				
ext layer	plaster (0.025)	plaster (0.025)	tile (0.005)				
layer 1	wood+mortar (0.08)	wood+mortar (0.08)	plaster (0.02)				
layer 2			wood+mortar (0.125)				
layer 3							
layer 4		plaster (0.02)	plaster (0.02)				
int layer	plaster (0.025)	tile (0.005)	tile (0.005)				

	type 1 (Floor)	type 2	type 3	type 4	type 5		
Horizontal separation	Floor	Floor (Kitchen)	Floor (Balcony)	ceiling	roof - balcony		
Total Thickness	0.300	0.300	0.700	0.220	0.03		
floor layer	hardwood (0.03)	tile (0.005)	tile (0.005)		corrugated metal sheet (0.005)		
layer 1	wood beams (0.23)	mortar (0.005)	wood + mortar (0.225)		iron (0.025)		
layer 2		hardwood (0.02)	cavity (0.2)				
layer 3		wood beams (0.23)	wood beams (0.23)	wood beams (0.18)			
layer 4	timber framing (0.015)	timber framing (0.015)	timber framing (0.015)	timber framing (0.015)			
ceiling layer	gypsum (0.025)	gypsum (0.025)	gypsum (0.025)	gypsum (0.025)			

Side (N) 4th floor — 2 casement windows

Ext. Window	Fanlight window	Sashes (each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.61	open with hot temperature	no	not applicable	1.22	closed continuously
glazed area (m2)	no	0.41		no			
frame area (m2)	no	0.20		no			
percentage of glazed (%)	no	67.21		no			
percentage of frame (%)	no	32.79		no			
max. Opening area (m2)	no	0.56		no			
percentage of max. Opening area (%)	no	91.80		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (3mm)		no			

Front (E) 4th floor — 1 casement window

Ext. Window (Kitchen)	Fanlight window	Sash	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.16	open continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.07		no		no	
frame area (m2)	no	0.09		no		no	
percentage of glazed (%)	no	43.75		no		no	
percentage of frame (%)	no	56.25		no		no	
max. Opening area (m2)	no	0.12		no		no	
percentage of max. Opening area (%)	no	75.00		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Front (E) 4th floor — 1 door (2 sashes)

Ext. Door (to balcony)	Fanlight window	Door (each)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.01	open continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.6		no		no	
frame area (m2)	no	0.41		no		no	
percentage of glazed (%)	no	59.41		no		no	
percentage of frame (%)	no	40.59		no		no	
max. Opening area (m2)	no	0.95		no		no	
percentage of max. Opening area (%)	no	94.06		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Side (SE) 4th floor — 1 casement

Ext. Window (WC)	Fanlight window	Sash	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.08	open continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.03		no		no	
frame area (m2)	no	0.05		no		no	
percentage of glazed (%)	no	37.50		no		no	
percentage of frame (%)	no	62.50		no		no	
max. Opening area (m2)	no	0.05		no		no	
percentage of max. Opening area (%)	no	62.50		no		no	
Frame material	no	wood (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Front (E) 4th floor 3 fixed windows

Ext. Window (balcony)	Fanlight window	window a x3	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.32	not applicable	no	not applicable	1.32	closed continuously
glazed area (m2)	no	1.13		no			
frame area (m2)	no	0.19		no			
percentage of glazed (%)	no	85.61		no			
percentage of frame (%)	no	14.39		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	Aluminium (3cm)		no		light tissue	
Type of glass	no	PVC (3mm)		no			

Front (E) 4th floor 1 fixed window

Ext. Window (balcony)	Fanlight window	window b	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.53	not applicable	no	not applicable	0.53	closed continuously
glazed area (m2)	no	0.37		no			
frame area (m2)	no	0.16		no			
percentage of glazed (%)	no	69.81		no			
percentage of frame (%)	no	30.19		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	Aluminium (3cm)		no		light tissue	
Type of glass	no	PVC (3mm)		no			

Front (E) 4th floor 1 fixed window

Ext. Window (balcony)	Fanlight window	window c	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.14	not applicable	no	not applicable	0.14	closed continuously
glazed area (m2)	no	0.06		no			
frame area (m2)	no	0.08		no			
percentage of glazed (%)	no	42.86		no			
percentage of frame (%)	no	57.14		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	Aluminium (3cm)		no		light tissue	
Type of glass	no	PVC (3mm)		no			

Front (E) 4th floor 1 door

Ext. Door (Balcony)	Fanlight window	Door	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.43	closed continuously	no	not applicable	no	not applicable
glazed area (m2)	no	0.78		no		no	
frame area (m2)	no	0.65		no		no	
percentage of glazed (%)	no	54.55		no		no	
percentage of frame (%)	no	45.45		no		no	
max. Opening area (m2)	no	1.19		no		no	
percentage of max. Opening area (%)	no	83.22		no		no	
Frame material	no	Aluminium (3cm)		no		no	
Type of glass	no	single (3mm)		no		no	

Side (N) 4th floor 3 fixed windows

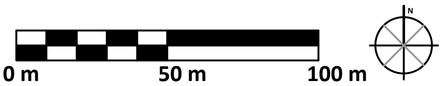
Ext. Window (balcony)	Fanlight window	window d x3	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.18	not applicable	no	not applicable	1.18	closed continuously
glazed area (m2)	no	1		no			
frame area (m2)	no	0.18		no			
percentage of glazed (%)	no	84.75		no			
percentage of frame (%)	no	15.25		no			
max. Opening area (m2)	no	0.00		no			
percentage of max. Opening area (%)	no	0.00		no			
Frame material	no	Aluminium (3cm)		no		light tissue	
Type of glass	no	PVC (3mm)		no			

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	excepted bedrooms
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

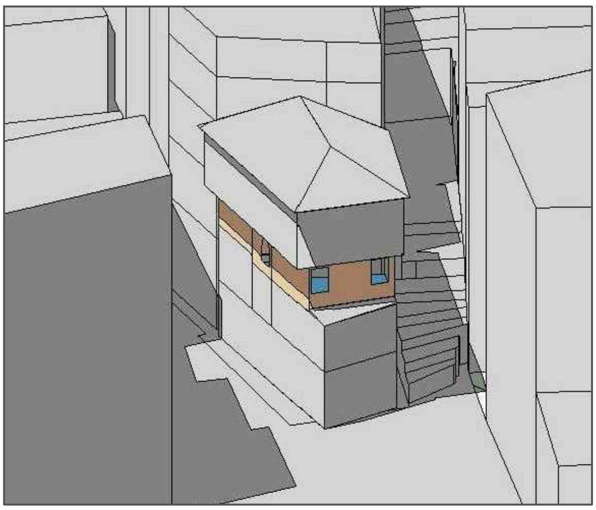
Int. Window	Fanlight window	window	use profiles
total area (m2)	no	0.2	not applicable
glazed area (m2)	no	0.15	
frame area (m2)	no	0.05	
percentage of glazed (%)	no	75.00	
percentage of frame (%)	no	25.00	
max. Opening area (m2)	no	0.00	
percentage of max. Opening area (%)	no	0.00	
Frame material	no	wood (3cm)	
Type of glass	no	single (3mm)	

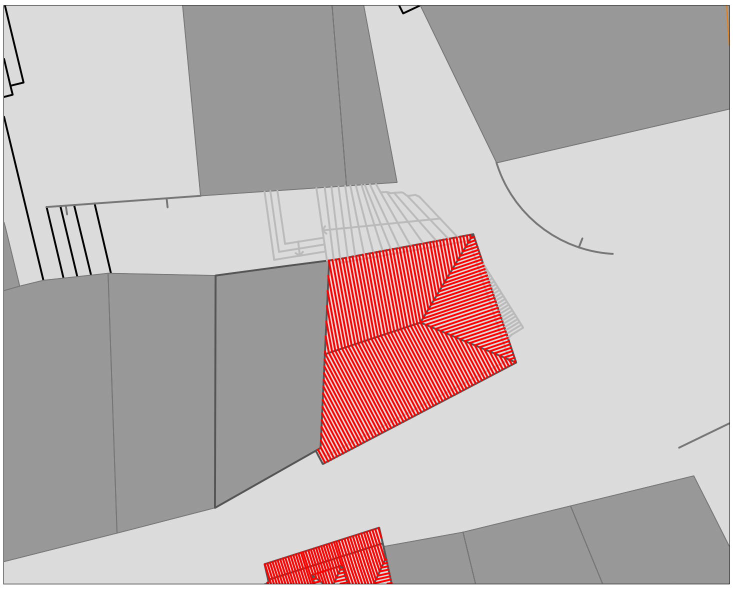
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
HALL0000	Hall	Lighting	1 lamp			0.0600	0.125 hours/day	45.625	2.74	ERSE (60w)
LVNG0000	Living Room	Lighting	3 lamps			0.1200	3 hours/day	1095	131.40	ERSE (40w)
LVNG0000	Living Room	Entertainment	1 Plasma TV		Samsung	0.1180	2 hours/day	730	86.14	Samsung internet (118w)
LVNG0000	Living Room	Entertainment	1 Plasma TV in standby		Samsung	0.0003	22 hours/day	8030	2.41	Samsung internet (0.3w)
LVNG0000	Living Room	Entertainment	1 Hi-FI			0.0600	1 hour/day	365	21.90	ERSE (60w)
LVNG0000	Living Room	Entertainment	1 Hi-FI in standby			0.0021	23 hours/day	8395	17.21	SELINA (2.05w)
LVNG0000	Living Room	Entertainment	1 Radio			0.0070	1 hour/day	365	2.56	LG (7w)
LVNG0000	Living Room	Entertainment	1 Radio in standby			0.0015	23 hours/day	8395	12.59	SELINA (1.5w)
LVNG0000	Living Room	Entertainment	1 Modem Router			0.0052	On continuously	8760	45.38	SELINA (5.18w)
LVNG0000	Living Room	Entertainment	1 Laptop computer			0.0500	2 hours/day	730	36.50	LG (50w)
LVNG0000	Living Room	Environment	1 Electric fan			0.1000	On with hot temperature		0.00	LG (100w)
BDRM0000	Bedroom 1	Lighting	1 lamp			0.0600	1 hour/day	365	21.90	ERSE (60w)
BDRM0000	Bedroom 1	Lighting	1 side bed lamp			0.0400	1 hour/day	365	14.60	ERSE (40w)
BDRM0000	Bedroom 1	Entertainment	1 Plasma TV		Samsung	0.1180	2 hours/day	730	86.14	Samsung internet (118w)
BDRM0000	Bedroom 1	Entertainment	1 Plasma TV in standby		Samsung	0.0003	22 hours/day	8030	2.41	Samsung internet (0.3w)
KTCH0000	Kitchen	Lighting	1 Fluorescent lamp			0.0580	3 hours/day	1095	63.51	ERSE (58w)
KTCH0000	Kitchen	Appliance	1 Fridge	Cooler	Bosch	0.0346	On continuously	8760	303.00	Bosch manual (KIL 38A40 IE Cooler - 303 kWh/year)
KTCH0000	Kitchen	Appliance	1 Microwave			0.9000	0.25 hours/day	91.25	82.13	ERSE (900w)
KTCH0000	Kitchen	Appliance	1 Microwave in standby			0.0043	23.75 hours/day	8668.75	37.28	Deco Proteste Internet simulator
KTCH0000	Kitchen	Appliance	1 Extractor hood		Tecnogas	0.1400	2 hours/day	730	102.20	ERSE (140w)
KTCH0000	Kitchen	Environment	1 Electric hot water cylinder		Termobrasa	1.5000	On continuously	8760	321.20	50 l in situ; AKI - 0.88 kWh/Day (1200w, 50L)
KTCH0000	Kitchen	Appliance	1 Gas stove				1.5 bottles/month		0.00	Households
WC1_0000	WC 1	Lighting	1 lamp			0.0400	0.75 hours/day	273.75	10.95	ERSE (40w)
WC2_0000	WC 2 - Balcony	Lighting	1 Compact fluorescent lamp			0.0110	2 hours/day	730	8.03	ERSE (11w)
FLR40000	Storage 1	Lighting	1 lamp			0.0400	0.125 hours/day	45.625	1.83	ERSE (40w)
STRG0001	Storage 2 - Balcony	Lighting	1 lamp			0.0400	1 hour/day	365	14.60	ERSE (40w)
STRG0001	Storage 2 - Balcony	Appliance	1 Washing machine		Balay	2.0000	2 washes/week (1.5 hours)	156	118.56	ERSE (2000w); Top ten (1.14 kWh each washing cycle)
STRG0002	Storage 3 - Balcony	Lighting	1 lamp			0.0400	1 hour/day	365	14.60	ERSE (40w)
STRG0003	Storage 4 - Balcony curve	Lighting	1 lamp			0.0400	1 hour/day	365	14.60	ERSE (40w)
								TOTAL	**1576.35**	
									804.13	EDP (kWh/Year)

Case Study 10
Study Area Location Plan

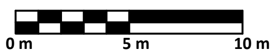


Study area

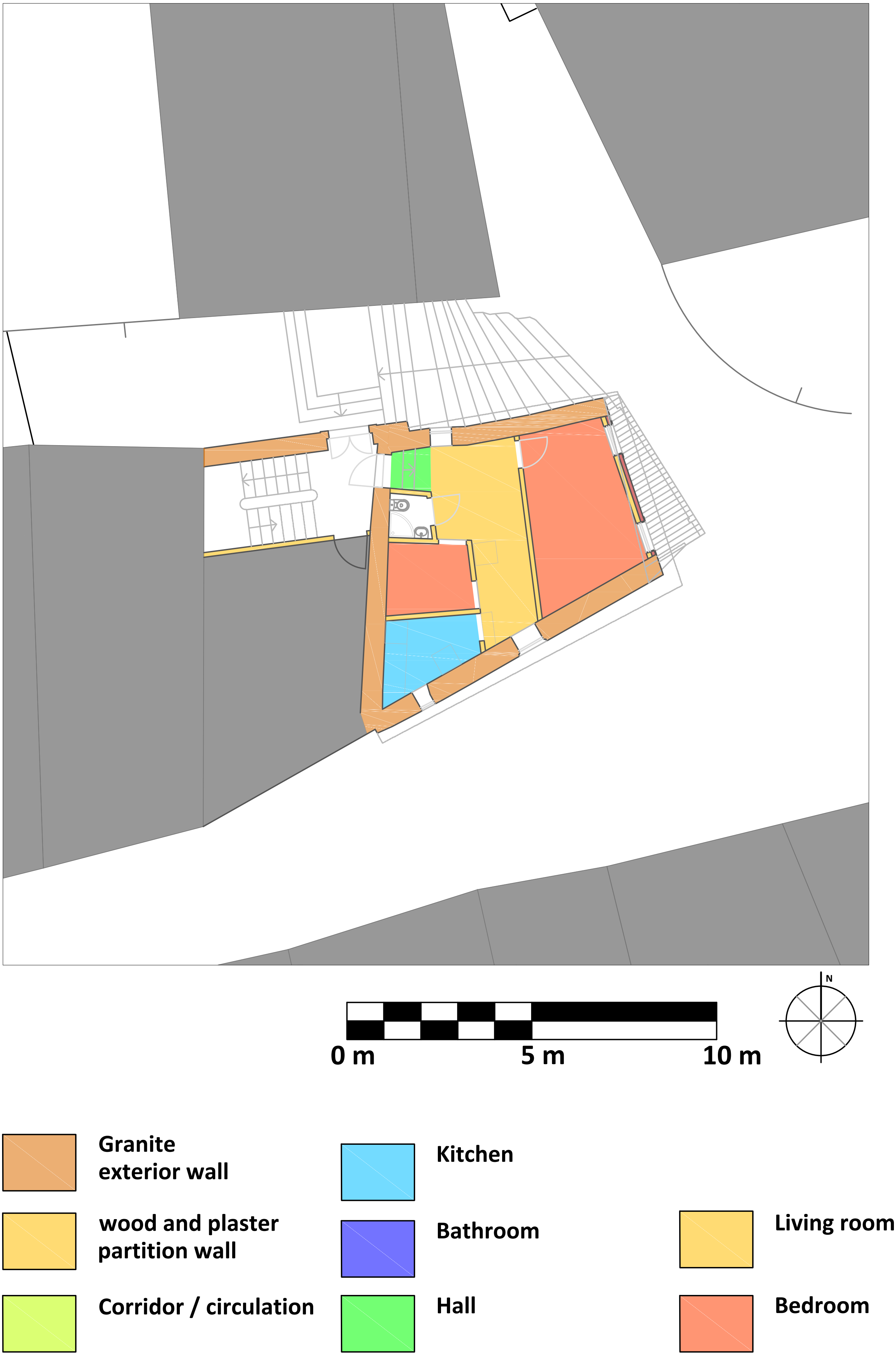




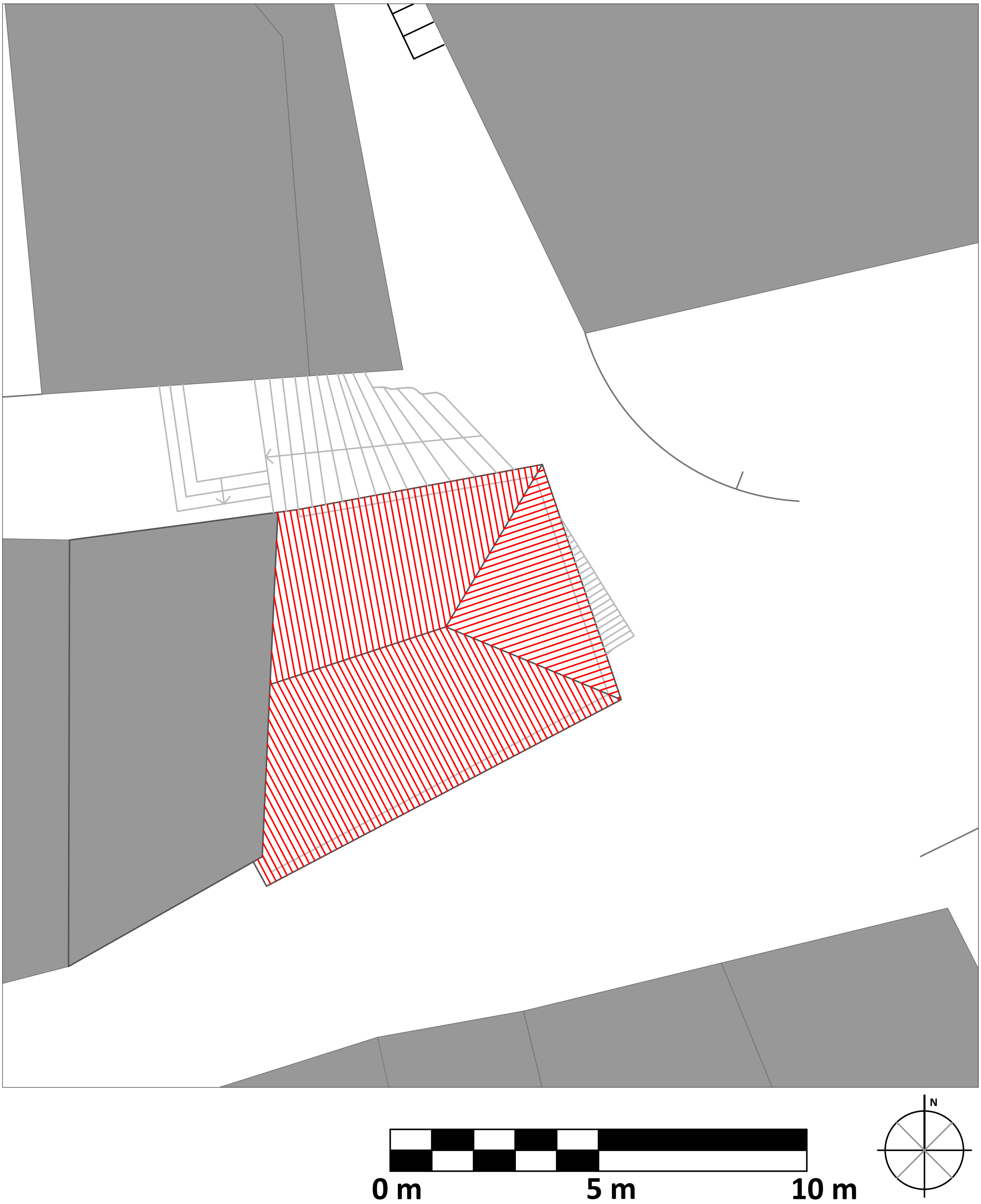
Case 10 site plan

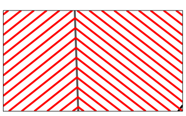


Case Study 10
Variant 1 middle - 2nd floor plan



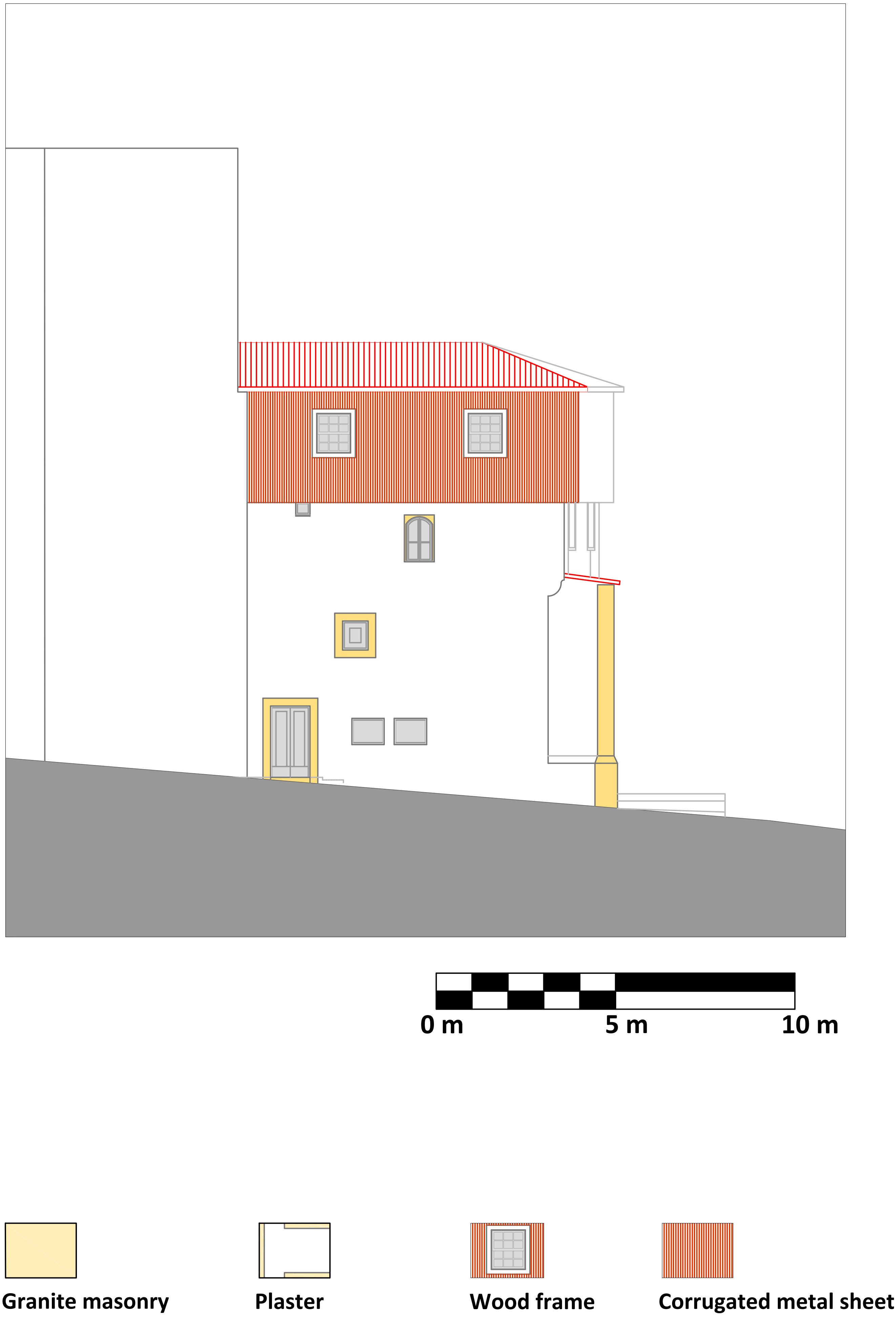
Case Study 10
Variant 1 middle - roof plan



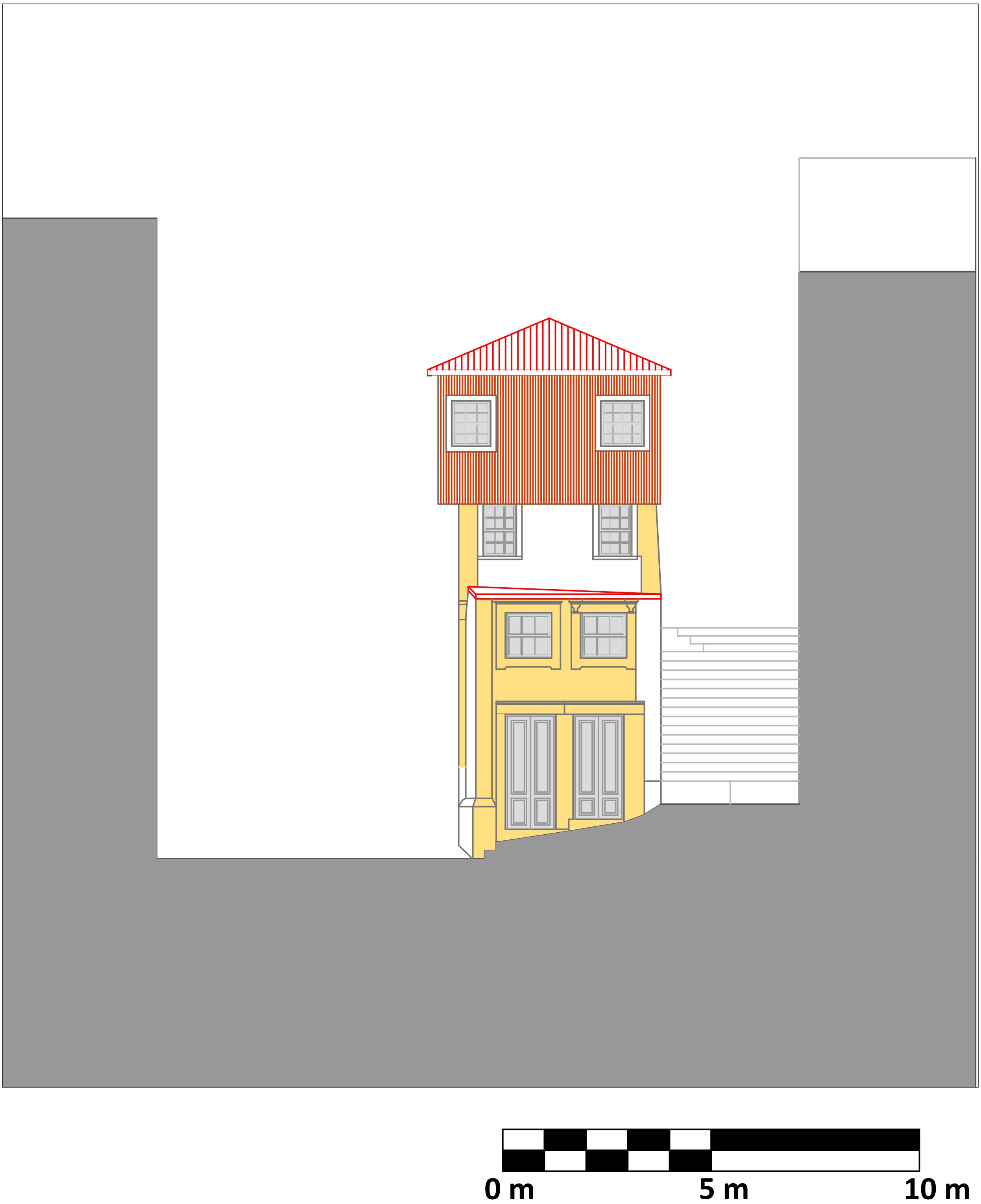


Ceramic roof tiles

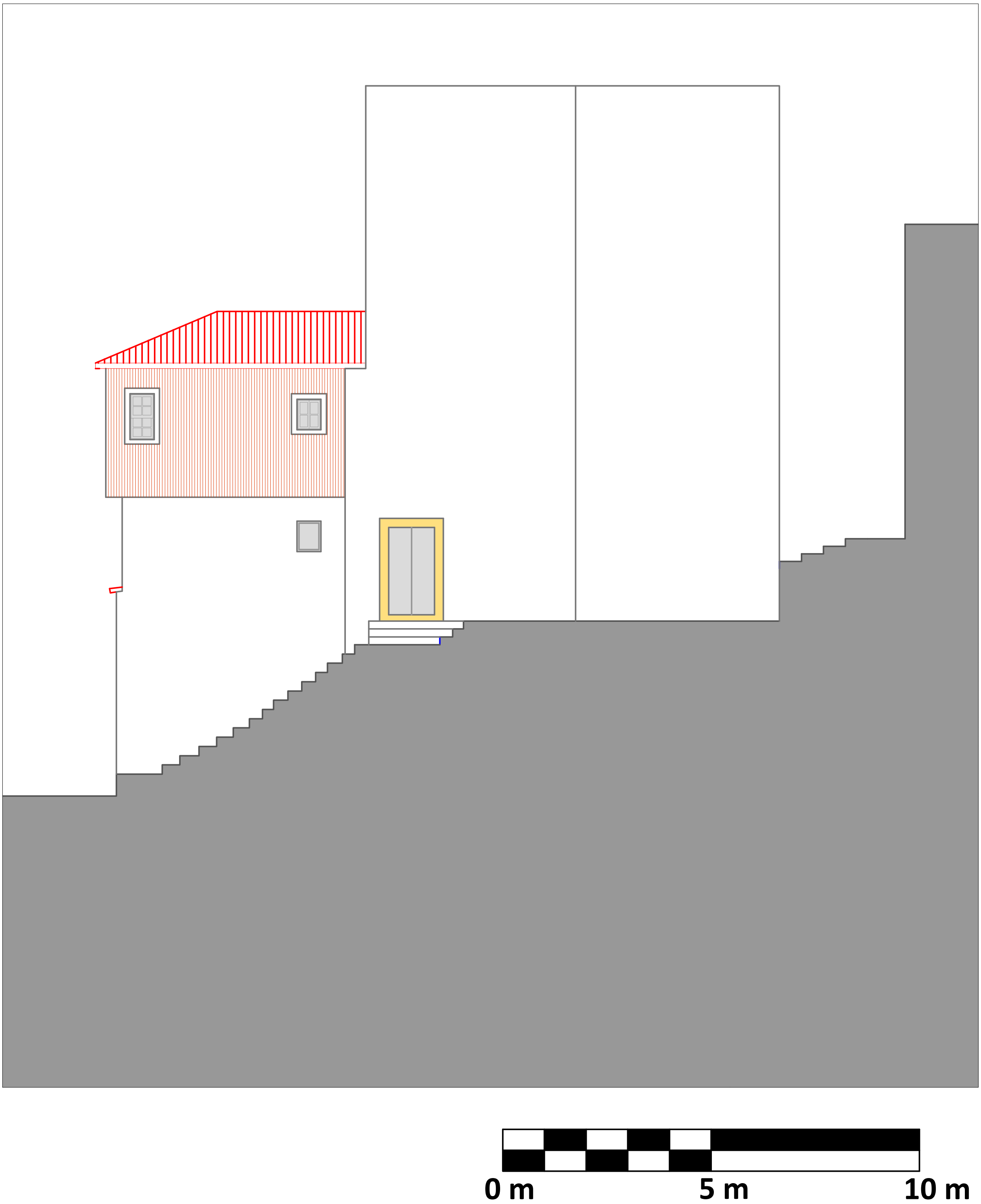
Case Study 10
Variant 1 middle - front facade (street)



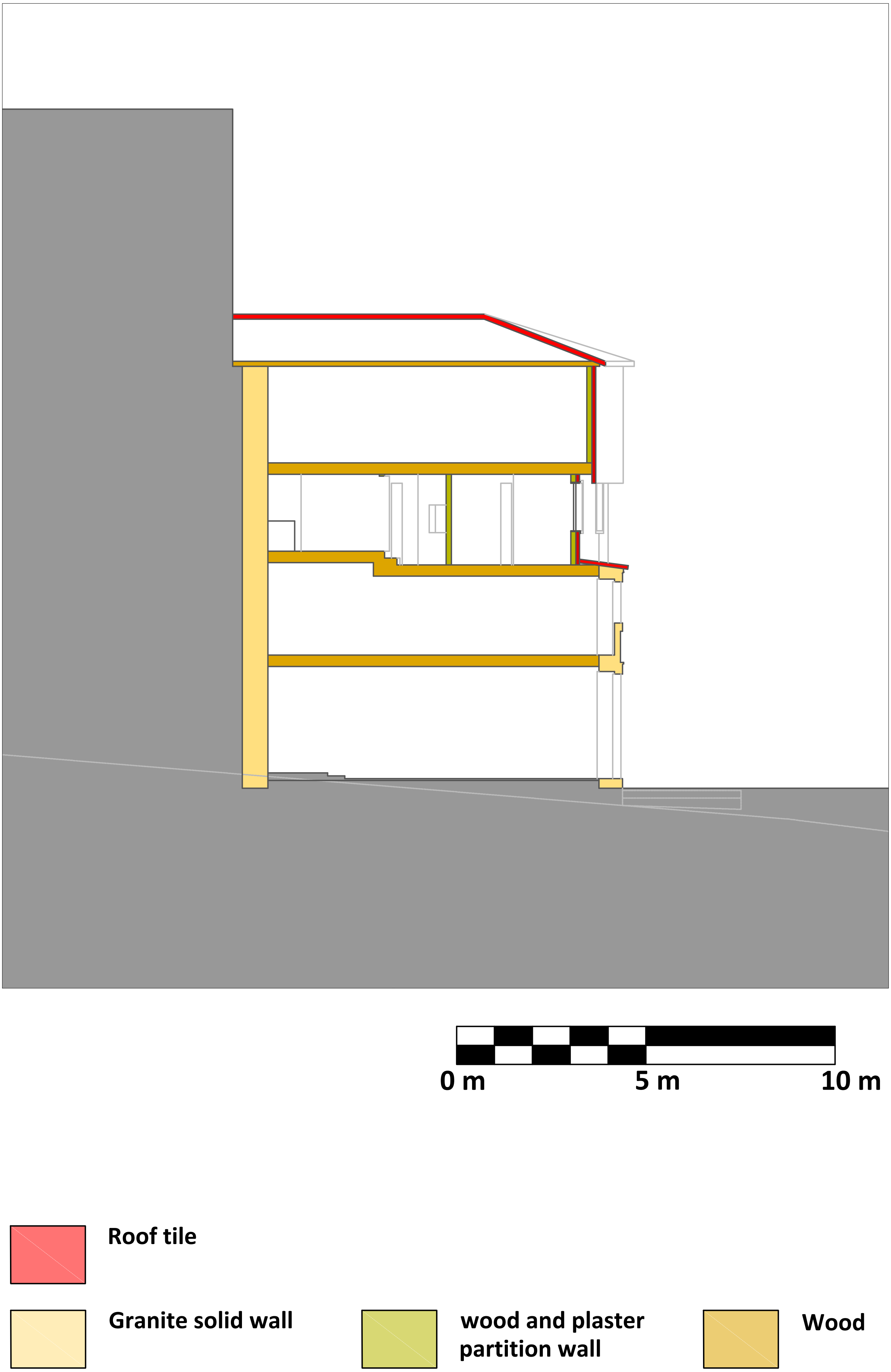
Case Study 10
Variant 1 middle - side facade1 (street)



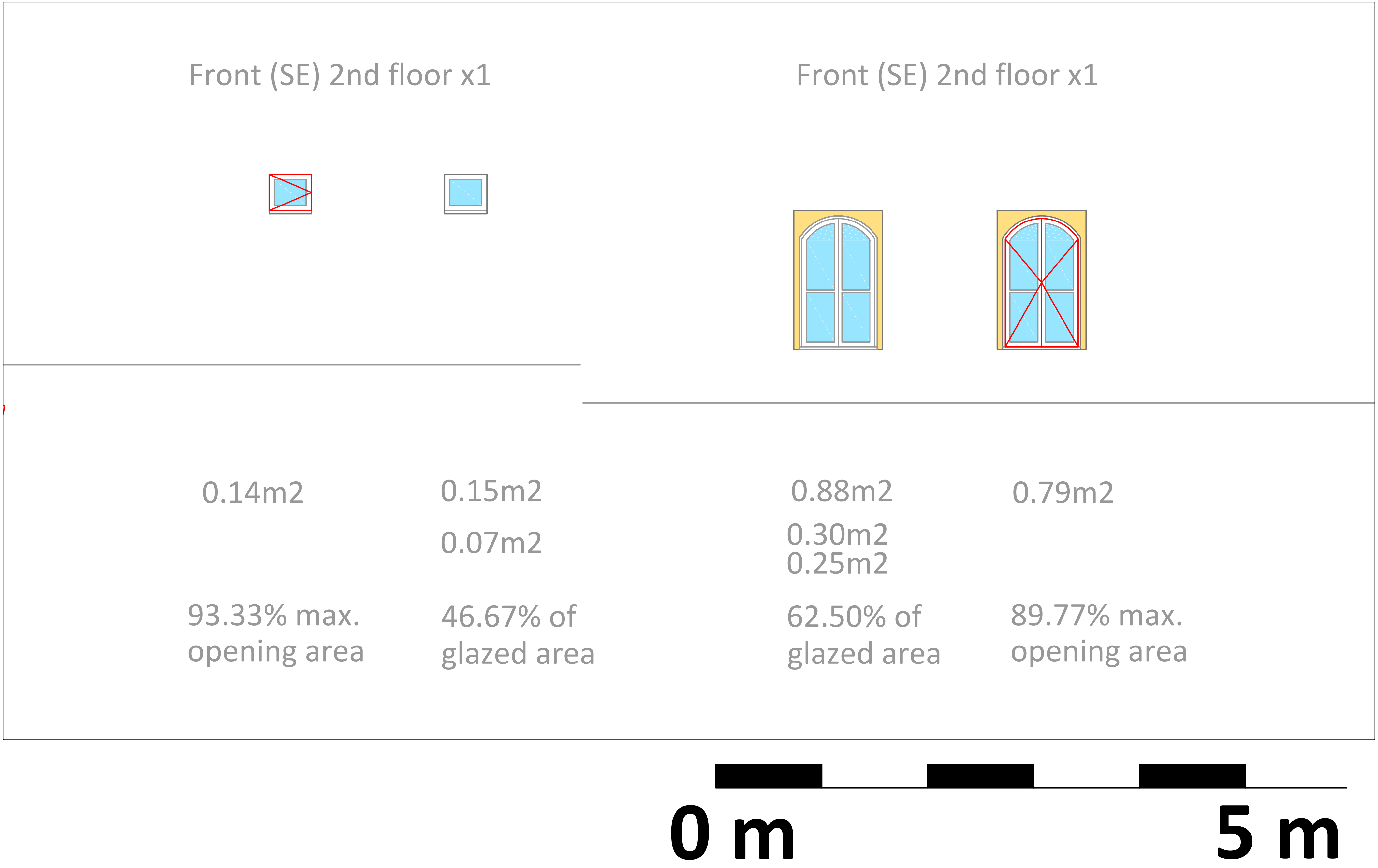
Case Study 10
Variant 1 middle - side facade2 (street)



Case Study 10
Variant 1 middle - section



Case Study 10
Variant 1 - middle floor - Openings



Case Study 10
Variant 1 - middle floor - Openings

Side 1 (E) 2nd floor x2

Side 2 (N) 2nd floor x2

Side 1 (E) 2nd floor x2		Side 2 (N) 2nd floor x2	
1.01m2 0.61m2	0.43m2	0.42m2 0.00 m2	0.30m2
60.40% of glazed area	42.57% max. opening area	0.0% of glazed area	71.43% max. opening area

0 m 5 m

	type 1	type 2	type 3	type 4	type 5	type 6
exterior wall	front (SE) 2nd floor	front (SE) 2nd floor	side 1 (E) 2nd floor	Side 2 (N) 2nd floor	Side 3 (W) party wall	Side 3 (W) party wall
Total Thickness	0.580	0.580	0.230	0.500	0.525	0.525
ext layer	plaster (0.025)	plaster (0.025)	corrugated metal sheet (5 mm)	plaster (0.025)		
layer 1	granite (0.53)	granite (0.53)	wood / cavity (0.02)	granite (0.45)	granite (0.50)	granite (0.50)
layer 2			wood+mortar (0.18)			
layer 3						
layer 4		mortar (0.02)				mortar (0.02)
int layer	plaster (0.025)	tile (0.005)	plaster (0.025)	plaster (0.025)	plaster (0.025)	tile (0.005)

	type 1					
partition wall		Kitchen/WC				
Total Thickness	0.13	0.13	0.13			
ext layer	plaster (0.025)	tile (0.005)	tile (0.005)			
layer 1	wood+mortar (0.08)	mortar (0.02)	mortar (0.02)			
layer 2		wood+mortar (0.08)	wood+mortar (0.08)			
layer 3						
layer 4		mortar (0.02)				
int layer	plaster (0.025)	tile (0.005)	plaster (0.025)			

	type 1	type 2 (floor WC / Kitchen)				
Horizontal separation						
Total Thickness	0.30	0.30				
floor layer	hardwood (0.04)	tile (0.005)				
layer 1	wood beams (0.235)	mortar (0.005)				
layer 2		hardwood (0.03)				
layer 3		wood beams (0.235)				
layer 4	timber framing (0.01)	timber framing (0.01)				
ceiling layer	gypsum (0.015)	gypsum (0.015)				

Front (SE) 2nd floor — 1 casement window

Ext. Window (Rooms)	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.88	open when occupied and hot	0.88	open in day, closed at night	0.88	closed continuously
glazed area (m2)	no	0.55					
frame area (m2)	no	0.33					
percentage of glazed (%)	no	62.50					
percentage of frame (%)	no	37.50					
max. Opening area (m2)	no	0.79					
percentage of max. Opening area (%)	no	89.77					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (3mm)					

Front (SE) 2nd floor (Kitchen) — 1 casement window

Ext. Window (room)	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.15	open during day except when cold	no	not applicable	0.15	closed continuously
glazed area (m2)	no	0.07		no			
frame area (m2)	no	0.08		no			
percentage of glazed (%)	no	46.67		no			
percentage of frame (%)	no	53.33		no			
max. Opening area (m2)	no	0.14		no			
percentage of max. Opening area (%)	no	93.33		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	single (0.3cm)		no			

Side 1 (E) 2nd floor — 2 sash windows

Ext. Window	Fanlight window	Sashes (total window)	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	1.01	open when occupied and hot	1.01	open in day, closed at night	1.01	closed continuously
glazed area (m2)	no	0.61					
frame area (m2)	no	0.40					
percentage of glazed (%)	no	60.40					
percentage of frame (%)	no	39.60					
max. Opening area (m2)	no	0.43					
percentage of max. Opening area (%)	no	42.57					
Frame material	no	wood (3cm)		wood (3cm)		light tissue	
Type of glass	no	single (0.3cm)					

Side 2 (N) 2nd floor 1 casement

Ext. Window	Fanlight window	Sashes	use profile	Shutters	use profile	Curtains	use profile
total area (m2)	no	0.42	open during day except when cold	no	not applicable	0.42	closed continuously
glazed area (m2)	no	0		no			
frame area (m2)	no	0.42		no			
percentage of glazed (%)	no	0.00		no			
percentage of frame (%)	no	100.00		no			
max. Opening area (m2)	no	0.30		no			
percentage of max. Opening area (%)	no	71.43		no			
Frame material	no	wood (3cm)		no		light tissue	
Type of glass	no	no glass		no			

Int. Door	Fanlight window	Door	use profiles
total area (m2)	no	not applicable	allways open
glazed area (m2)	no	no	excepted bedroom and WC
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no	wood (3cm)	
Type of glass	no	no	

Int. Window	Fanlight window	Sash	use profiles
total area (m2)	no	no	not applicable
glazed area (m2)	no		
frame area (m2)	no		
percentage of glazed (%)	no		
percentage of frame (%)	no		
max. Opening area (m2)	no		
percentage of max. Opening area (%)	no		
Frame material	no		
Type of glass	no		

IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Operation profile assumed (average usage hours	Hours per year (52 weeks, 365 days)	Kwh/year	Source
FLR20010	Living Room	Lighting	1 fluorescent lamp			0.0580	3 hours/day	1095	63.51	ERSE (58w)
FLR20010	Living Room	Lighting	5 lamps			0.2000	no use	0	0.00	ERSE (40w)
FLR20010	Living Room	Entertainment	1 TV		Sony	0.0900	2 hours/day	730	65.70	ERSE (90w)
FLR20010	Living Room	Entertainment	1 TV in standby		Sony	0.0052	22 hours/day	8030	42.00	SELINA (TV CRT 5.23w)
FLR20010	Living Room	Appliance	1 Fridge			0.0255	On continuously	8760	223.00	Top ten (223 kWh/year)
FLR20010	Living Room	Appliance	1 Cordless telephone			0.0030	On continuously	8760	26.28	LG (3w)
FLR20002	Bedroom 1	Lighting	1 lamp			0.0400	1 hour/day	365	14.60	ERSE (40w)
FLR20012	Bedroom 2	Lighting	1 lamp			0.0400	no use	0	0.00	ERSE (40w)
FLR20013	Kitchen	Lighting	1 fluorescent lamp			0.0580	allways on with house occupied (13 hours)	4745	275.21	ERSE (58w)
FLR20013	Kitchen	Appliance	1 washing machine				1 wash/week (1.5 hours)	104	59.28	Top ten (1.14 kWh each washing cycle)
FLR20013	Kitchen	Appliance	Electric stove		Leco	2.4000	2 hours/day	730	1752.00	ERSE (2400w)
FLR20011	WC	Lighting	1 lamp			0.0400	2 hours/day	730	29.20	ERSE (40w)
FLR20011	WC	Environment	1 Electric hot water cylinder			1.5000	On continuously	8760	321.20	50 l in situ; AKI - 0.88 kWh/Day (1200w, 50L)
								TOTAL	**2871.98**	
									2605.74	EDP (kWh/Year)

Occupancy profiles

persons in the house

case 1 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	5	0	0	0	0	0	5	5	5	5
Tue	5	5	0	0	0	0	5	5	5	5
Wed	5	0	0	0	0	0	5	5	5	5
Thu	5	0	0	0	0	0	5	5	5	5
Fri	5	0	0	0	1	0	5	5	5	5
Sat	5	2	2	2	2	5	5	5	0	0
Sun	5	5	5	5	5	5	5	5	5	5

ages	occupants
<18	3
18-64	2
>65	0
total	**5**
each	**20%**

case 2 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	6	4	2	2	2	2	2	6	6	6
Tue	6	4	2	2	2	2	2	6	6	6
Wed	6	4	2	2	2	2	2	6	6	6
Thu	6	4	2	2	2	2	2	6	6	6
Fri	6	4	2	2	2	2	2	6	6	6
Sat	6	6	6	6	6	6	6	6	6	6
Sun	6	6	6	6	6	6	6	6	6	6

ages	occupants
<18	3
18-64	3
>65	0
total	**6**
each	**16.66%**

case 3 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	4	4	2	2	2	2	2	4	4	4
Tue	4	4	2	2	2	2	2	4	4	4
Wed	4	4	2	2	2	2	2	4	4	4
Thu	4	4	2	2	2	2	2	4	4	4
Fri	4	4	2	2	2	2	2	4	4	4
Sat	4	4	4	4	4	4	4	4	4	4
Sun	4	4	4	4	4	4	4	4	4	4

ages	occupants
<18	1
18-64	3
>65	0
total	**4**
each	**25%**

case 4 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	3	1	1	1	1	1	1	3	3	3
Tue	3	1	1	1	1	1	1	3	3	3
Wed	3	1	1	1	1	1	1	3	3	3
Thu	3	1	1	1	1	1	1	3	3	3
Fri	3	1	1	1	1	1	1	3	3	3
Sat	4	4	4	4	4	4	4	4	4	4
Sun	4	4	4	4	4	4	4	4	4	4

ages	occupants
<18	0
18-64	3
>65	1
total	**4**
each	**25%**

case 5 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	4	2	2	1	1	1	1	3	3	4
Tue	4	2	2	1	1	1	1	3	3	4
Wed	4	2	2	1	1	1	1	3	3	4
Thu	4	2	2	1	1	1	1	3	3	4
Fri	4	2	2	1	1	1	1	3	3	4
Sat	2	2	2	2	2	2	2	2	2	2
Sun	2	2	2	2	2	2	2	2	2	2

ages	occupants
<18	2
18-64	2
>65	0
total	**4**
each	**25%**

case 6 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	3	3	1	1	2	1	1	1	3	3
Tue	3	3	1	1	2	1	1	1	3	3
Wed	3	3	1	1	2	1	1	1	3	3
Thu	3	3	1	1	2	1	1	1	3	3
Fri	3	3	1	1	2	1	1	1	3	3
Sat	3	3	3	3	3	3	3	3	3	3
Sun	3	3	3	3	3	3	3	3	3	3

ages	occupants
<18	1
18-64	2
>65	0
total	**3**
each	**33%**

Occupancy profiles persons in the house

case 7 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	2	5	5	5	5	5	5	2	2	2
Tue	2	5	5	5	5	5	5	2	2	2
Wed	2	5	5	5	5	5	5	2	2	2
Thu	2	5	5	5	5	5	5	2	2	2
Fri	2	5	5	5	5	5	5	2	2	2
Sat	0	0	0	0	0	0	0	0	0	0
Sun	0	0	0	0	0	0	0	0	0	0

ages	occupants
<18	3
18-64	2
>65	0
total	**5**
each	**20%**

case 8 10 days out in summer

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	1	1	1	1	1	1	0	1	1	1
Tue	1	1	1	1	1	1	0	1	1	1
Wed	1	1	1	1	1	1	0	1	1	1
Thu	1	1	1	1	1	1	0	1	1	1
Fri	1	1	1	1	1	1	0	1	1	1
Sat	1	1	1	1	1	1	0	1	1	1
Sun	1	1	1	1	1	1	0	1	1	1

ages	occupants
<18	0
18-64	0
>65	1
total	**1**
each	**100%**

case 9 out of house in the summer for 1 month

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	5	5	1	0	2	0	0	0	5	5
Tue	5	5	1	0	2	0	0	0	5	5
Wed	5	5	1	0	2	0	0	0	5	5
Thu	5	5	1	0	2	0	0	0	5	5
Fri	5	5	1	0	2	0	0	0	5	5
Sat	5	5	5	0	0	0	0	0	5	5
Sun	5	5	5	0	0	0	0	0	5	5

ages	occupants
<18	2
18-64	3
>65	0
total	**5**
each	**20%**

case 10 same all year

days\hours	0-7	7-8.30	8.30-10	10-12.30	12.30-14	14-16	16-18	18-20	20-22	22-24
Mon	2	2	2	2	2	0	1	2	2	2
Tue	2	2	2	2	2	0	1	2	2	2
Wed	2	2	2	2	2	0	1	2	2	2
Thu	2	2	2	2	2	0	1	2	2	2
Fri	2	2	2	2	2	0	1	2	2	2
Sat	2	2	2	2	2	0	1	2	2	2
Sun	2	2	2	2	2	0	1	2	2	2

ages	occupants
<18	0
18-64	1
>65	1
total	**2**
each	**50%**

Appendix C

Modelling

Simulation Variables

U-values

Building envelope requirements

Thermal protection requirements (U values in W/(m² K))

	Roof	Walls	Floor	Windows
Austria	0.2	0.35	0.4	1.4
Belgium	0.3	0.4	0.6	2.5
Bulgaria	0.3	0.35	0.5	1.8
Cyprus	0.85	0.85	2	3.8
Czech Republic	0.24	0.3	0.45	1.7
Denmark	0.2	0.3	0.2	1.8
Estonia	0.15 to 0.2	0.2 to 0.25	0.15 to 0.2	0.7 to 1.4
Finland	0.09	0.17	0.16	1
France	0.2 to 0.25	0.36 to 0.4	0.37 to 0.4	1.7 to 1.9
Germany	0.24	0.24	0.3	
Greece	0.35 to 0.5	0.4 to 0.6	0.45 to 0.5	2.6 to 3.2
Hungary	0.25	0.45	0.45	1.6
Ireland	0.25	0.37	0.37	2.2
Italy	0.32 to 0.65	0.33 to 0.62	0.29 to 0.38	1.3 to 1.7
Latvia	0.2k to 0.35k	0.25k to 0.5k	0.2k to 0.35k	1.8k to 2.4k
Lithuania	0.16	0.2	0.25	1.6
Malta	0.59	1.57	1.57	5.8
Netherlands	0.4	0.4	0.4	4.2
Norway	0.18	0.22	0.18	1.6
Poland	0.25	0.3	0.45	1.7
Portugal	0.9 to 1.25	1.45 to 1.8	1.2 to 1.65	3.3 to 4.3
Romania	0.2	0.56	0.35	1.3
Slovakia	0.19	0.32	1.7	
Slovenia	0.2	0.28	0.9	1.1 to 1.6
Spain	0.45 to 0.65	0.57 to 0.94	0.62 to 0.69	3.1 to 5.7
Sweden	0.4 to 0.6			
Switzerland	0.17 to 0.2	'0.17 to 0.2	'0.17 to 0.2	1.3
United Kingdom	0.2	0.3	0.25	2

http://www.buildingsdata.eu/results
Data HUB for the Energy Performance of Buildings

The values in yellow were completed using Portuguese regulation

Materials

EN-ISO 6946

Material ID:	Description:	Specific heat capacity J/(kg·K)	source	Conductivity W/(m·K)	source	Density (kg/m³)	source	Vapour resistance GN·s (kg·m)	Source	Notes	Calculation Method
[GST11]	Granite - ITE50	650	Mendonça	2.8	ITE50	2600	ITE50 (average)	300	Mendonça		EN-ISO 6946
[USPM0004]	Traditional Plaster - ITE50	1046	Mendonça	0.8	ITE50	1600	ITE50	15	Mendonça	Traditional plaster and mortar with sand and lime	EN-ISO 6946
[GPL1]	Traditional stucco - ITE50	1046	Mendonça	0.8	ITE50	1600	ITE50	-	-	Traditional ceiling stucco - sand and gypsum	EN-ISO 6946
[USPM0005]	Traditional Mortar - ITE50	1046	Mendonça	0.8	ITE50	1600	ITE50	15	Mendonça	Traditional plaster and mortar with sand and lime	EN-ISO 6946
[CYT1]	Traditional glazed ceramic tile - ITE50	960	Mendonça (average)	1.3	ITE50	2300	ITE50	200	Mendonça (average)	cerâmica vidrada/grés cerâmico	EN-ISO 6946
[USBC0001]	Hollow Brick 11 - ITE50	837	IES VE	0.34	ITE50	740	Cerâmica Torreense (tijolo 11)	0			EN-ISO 6946
[ST]	Slate Tiles - ITE50	753	IES VE	2.2	ITE50	2400	ITE50 (average)	Infinite	Mendonça		EN-ISO 6946
[CLT1]	Roof Clay tiles - ITE50	837	IES VE	0.34	ITE50	1000	ITE50 (lowest)	200	Mendonça (average)		EN-ISO 6946
[TMF1]	Pine Wood - ITE50	2720	IES VE	0.18	ITE50	565	ITE50 (average)	70	Mendonça		EN-ISO 6946
[TMF11]	Oak and Chestnut Wood - ITE50	2390	IES VE	0.23	ITE50	810	ITE50 (average)	60	Mendonça		EN-ISO 6946
	Paper (wallpaper)			0.042							
[CF411]	Ordinary Simple Glass - ITE50	850	FEUP (V. Freitas)	1.0	ITE50	2500	ITE50	Infinite	Mendonça		
	Well ventilated air layer	1008	EN 12524	0.0	EN-ISO 6946	1.23	EN 12524			BuildDesk U 3.4	EN-ISO 6946
	Unventilated, heat flow upwards - 50mm	1008	EN 12524	0.313	EN-ISO 6946	1.23	EN 12524			BuildDesk U 3.4	EN-ISO 6946
	Unventilated, heat flow upwards - 100mm	1008	EN 12524	0.625	EN-ISO 6946	1.23	EN 12524			BuildDesk U 3.4	EN-ISO 6946
	Unventilated, heat flow upwards - 300mm	1008	EN 12524	1.875	EN-ISO 6946	1.23	EN 12524			BuildDesk U 3.4	EN-ISO 6946
[O1112]	Combined Layer_Studs_Mortar_BuildeskU3.4	1551	BuilDesk U 3.4 combined (30%+70%)	0.61	BuilDesk U 3.4	1289.5	BuilDesk U 3.4 combined (30%+70%)			Layer - studs + mortar	EN-ISO 6946 combined method
[O1111]	Combined Layer_Oak_Unvent_BuildeskU3.4	1424	BuilDesk U 3.4 combined (30%+70%)	1.37	BuilDesk U 3.4	243.84	BuilDesk U 3.4 combined (30%+70%)			Layer - Oak beams + unventilated	EN-ISO 6946 combined method
[O111]	Combined Layer_wood_Unvent_BuildeskU3.4	1300.7	BuilDesk U 3.4 combined (17%+83%)	0.291	BuilDesk U 3.4	97.05	BuilDesk U 3.4 combined (17%+83%)			Layer - studs + unventilated	EN-ISO 6946 combined method
[ST11111]	Combined Layer_wood_Vent_Roof_BuildeskU3.4	1232.3	BuilDesk U 3.4 combined (13%+87%)	0.023	BuilDesk U 3.4	74.5	BuilDesk U 3.4 combined (13%+87%)			Layer - studs + well ventilated under roof tiles	EN-ISO 6946 combined method
[ST1111]	Combined Layer_wood_Vent_BuildeskU3.4	1352	BuilDesk U 3.4 combined (20%+80%)	0.035	BuilDesk U 3.4	113.96	BuilDesk U 3.4 acombined (20%+80%)			Layer - studs + well ventilated	EN-ISO 6946 combined method
[O11]	Traditional floor-ceiling - ITE54	2390		0.7		700		0		Inhomogeneous layers combined method in ITE54	EN-ISO 6946 combined method
[CAIN11]	Wood studs and plaster	837		0.382		32		0		Inhomogeneous layers combined method - IES VE	EN-ISO 6946 combined method

Source	page	material (granite)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.4	Granite	2500-2700	2.800	granito	650 (Mendonça) 790 (Toolbox)	300 (Mendonça)
IES-VE (apache tables)	18	GST - Granite (red)	2650	2.900	granito (vermelho)	900.00	0
AdePorto	PE1	Stone wall		2.900	parede de granito		

Source	page	material (slate)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.4	Slate	2000-2800	2.200	ardósia	753 (IES-VE)	∞ (Mendonça)
IES-VE (Apache tables)	19	Slate tiles	2700	2.000		753	
IES-VE (Apache tables)	20	Slate - SL01	1602	1.442		1464	

Source	page	material (wall ceramic tiles)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.10	glazed ceramic tiles	2300	1.300	azulejo	920 - 1000 (Mendonça)	100 - 300 (Mendonça)
IES-VE (Apache tables)	19	Clay tile	1900	0.840		800.00	0
IES-VE (Apache tables)	19	Clay tile - HF-C1	1121	0.571		837.00	0

Source	page	material (ceramic roof tiles)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.4	Brick, tiles and roof tiles (fausto simões)	1900 (IES-VE)	0.770	Telha cerâmica	837 (IES-VE)	
Quercus - Ecocasa		Ceramic roof tile	1800-2000	1.150	Telha cerâmica		
IES-VE (Apache tables)	19	Ceiling tiles	380	0.056		1000	
IES-VE (Apache tables)	19	CYT - Clay tiles	1900	0.84		800	
IES-VE (Apache tables)	19	USCT0000 - Clay tile - HF-C1	1121	0.571		837	

Source	page	material (wall plaster)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.7	Traditional **mortar** and plaster (walls)	1800-2000	1.300	argamassa tradicional	1046 (Mendonça)	15 (Mendonça)
ITE50 - table I.2	I.7	Traditional mortar and plaster (walls)	>2000	1.800		1046 (Mendonça)	
ITE50 - table I.2	I.7	Traditional **lime and sand mortar or plaster** (walls)	1600	0.800	reboco tradicional de cal e areia	1046 (Mendonça)	15 (Mendonça)
Quercus - Ecocasa		Traditional plaster	1500-2100	1.150	rebobo tradicional		
IES-VE (Apache tables)	18	USPM0001 - Perlite Plaster - sand aggregate (ASHRAE)	1860	0.720		800.00	0
IES-VE (Apache tables)	18	USPM0000 - Cement Plaster - sand aggregate (ASHRAE)	1680	0.810		800.00	0
IES-VE (Apache tables)	17	PLD - Plaster (dense)	1300	0.500		1000.00	
IES-VE (Apache tables)	17	PLL - Plaster (lighweight)	600	0.160		1000.00	
IES-VE (Apache tables)	17	GPL - Gypsum Plastering	1200	0.420	estuque	837.00	
IES-VE (Apache tables)	18	Stucco - HF-A1	2659	0.721	estuque	837.00	

Source	page	material (ceiling plaster)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.6	Traditional stucco or plaster (ceiling)	≤1000	0.400	gesso (Mendonça) (0.35)	837 (IES-VE)	
IES-VE (Apache tables)	17	GPL - Gypsum Plastering	1200	0.420		837.00	

Source	page	material (glass)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.10	Sodium-Limestone glass (incl. Float glass)	2500	1.000	vidro simples Sódico-calcário	850 (V Freitas - lowest)	∞ (Mendonça)
IES-VE	CF4	Clear float 4 mm		1.060			
Mendonça	4.67	clear glass 5 mm					
UFP (Martins)	16	Ordinary single glass	2500	1.160		795	

Source	page	material (wood)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.7	Wood (semi-dense) -folhosas	565-765	0.180	carvalho, castanho		
ITE50 - table I.2	I.7	Wood (dense) - folhosas	750-870	0.230	**carvalho** (Mendonça)	2390 IESVE	40 - 60 (Mendonça)
ITE50 - table I.2	I.7	Wood (resinosas densas)	520-610	0.180	casquinha	2720 IES VE	
ITE50 - table I.2	I.7	Wood (resinosas muito densas)	> 610	0.230	pinho	(Mendonça - 530-600 kg/m3)	70
Mendonça	?	Hardwood				1500 - 2510 (Mendonça) 1700 (Toolbox)	
Quercus - Ecocasa		Hardwood	450-1000	0.12-0.29	madeira maciça		
IES-VE (Apache tables)	20	Timber flooring	650	0.140	soalho	1200.00	
IES-VE (Apache tables)	20	**Pine (20% moist)**	419	0.140	pinho	2720.00	
IES-VE (Apache tables)	20	**Oak (radial)**	700	0.190	carvalho	2390.00	
IES-VE (Apache tables)	20	Soft Wood - WD01	513	0.115	carvalho	1381.00	
IES-VE (Apache tables)	20	Hard Wood - WD11	721	0.158	carvalho	1255.00	
IES-VE (Apache tables)	20	Wood - WF-B7	593	0.121	carvalho	837.00	

Source	page	material (metal)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.9	Steel	7800	50.000	aço	450 - 512 (Mendonça)	∞ (Mendonça)
ITE50 - table I.2	I.9	Inox	7900	17.000	aço inox		∞ (Mendonça)
ITE50 - table I.2	I.9	Aluminium	2700	230.000	alumínio	830 - 950 (Mendonça)	∞ (Mendonça)
ITE50 - table I.2	I.9	Iron	7870	72.000	ferro		∞ (Mendonça)
ITE50 - table I.2	I.9	Cast iron	7500	50.000	ferro fundido		∞ (Mendonça)
IES-VE (Apache tables)	17	Steel	7800	50.000	aço	480.00	
IES-VE (Apache tables)	17	Aluminium	2800	160.000	alumínio	896.00	
IES-VE (Apache tables)	17	Lightweight metallic cladding	1250	0.290	chapa metálica	1000.00	
IES-VE (Apache tables)	17	Steel siding - HF-A3	7690	44.970	chapa aço ondulada	418.00	

Source	page	material (brick)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.4	Brick, tiles and roof tiles (fausto simões)	1800-2000	0.770	tijolo cerâmico	837 (IES-VE)	
IES-VE (Apache tables)	13	Common brick - BK01	1922	0.721	tijolo cerâmico	837.00	
IES-VE (Apache tables)	13	Common brick - HF-C4	1922	0.727	tijolo cerâmico	837.00	

Source	page	material (carpeting)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.10	Textile (carpet)	200	0.060	carpete		
ITE50 - table I.2	I.10	Linoleum	1200	0.170	linóleo		1800 (Mendonça)
IES-VE (Apache tables)	13	Wilton carpet	186	0.060	alcatifa	1360.00	
IES-VE (Apache tables)	13	Synthetic carpet	160	0.060	carpete	2500.00	

Source	page	material (Plastic)	Density (Kg/m3)	thermal conductivity [W/(m.°C)]	Portuguese	Specific heat capacity J/(Kg.K)	Vapour resistance GN.s/(Kg.m)
ITE50 - table I.2	I.8	PVC	1390	0.170		1040 (Mendonça)	20000 (Mendonça)

source	page	material (external wall)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	walls superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
ITE50	II.2	external simple wall (granite, plaster or tile)	0.40-0.60	2.9		
ITE54	I.25	external simple wall (granite, mortar, plaster or other)	0.30	2.4	680	
ITE54	I.25	external simple wall (granite, mortar, plaster or other)	0.60	1.8	1350	
ITE54	I.25	external simple wall (granite, mortar, plaster or other)	0.90	1.4	2030	
ITE54	I.25	external simple wall (granite, mortar, plaster or other)	1.20	1.2	2700	
Mendonça	A1 . 28	granite and plaster	0.40 + 0.02	3.05		
Mendonça	A1 . 28	granite, lã rocha, plasterboard (int)	0.40+0.05+0.013	0.69		
ITE54	I.7 - I.8	external simple wall (granite)	0.20	3.7	520	
ITE54	I.7 - I.8	external simple wall (granite)	0.40	2.9	1040	
ITE54	I.7 - I.8	external simple wall (granite)	0.60	2.4	1560	
ITE54	I.7 - I.8	external simple wall (granite)	0.80	2.1	2080	
ITE54	I.7 - I.8	external simple wall (granite)	1.00	1.8	2600	
AdePorto	12	Stone wall (generic) - PE1		2.9		112
Adeporto	12	Brick wall (generic) - PE3		1.3		50
AdePorto	12	Timber stud wall - PE2		3		116

source	page	material (exterior floor with usual finishes)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
ITE54	I.57 - I.58	floor with ceiling finished with intermediate space with weak ventilation	0.21 - 0.25	1.4	60	
ITE54	I.57 - I.58	floor without ceiling finished or with intermediate space heavily ventilated	0.18 - 0.22	2.2	40	

source	page	material (interior floor with usual finishes)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
ITE54	I.57 - I.58	floor with ceiling finished with intermediate space with weak ventilation	0.21 - 0.25	1.2	60	
ITE54	I.57 - I.58	floor without ceiling finished or with intermediate space heavily ventilated	0.18 - 0.22	1.7	40	

source	page	material (partition wall)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
AdePorto	12	Timber stud partition wall		3		116

source	page	material (partition wall)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
AdePorto	12	Timber stud partition wall		3		116

source	page	material (glazed elements)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
AdePorto	12	Wood frame (protected)		4.3		166
AdePorto	12	Wood frame (unprotected)		3.7		143
AdePorto	12	Metal frame (protected)		5		193
AdePorto	12	Metal frame (unprotected)		4.3		166

source	page	Roofing (slope)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
AdePorto	12	Light		3.8		147
AdePorto	12	Light concrete		2.8		108
AdePorto	12	Heavy concrete		3.4		131

source	page	Roofing (horizontal)	thickness (m)	heat transfer coefficient U [W/(m2.°C)]	floor superficial mass [(kg/m2)] (ITE54)	Q (kWh/m2.year) (AdePorto)
AdePorto	12	Light concrete		2.3		89
AdePorto	12	Heavy concrete		2.6		100

U – heat transfer coefficient [W/(m2.ºC)].
Q – annual energy per m2 demanded to compensate the annual heat losses (Q = 0,024 x U x GD) [kWh/m2.year].

Building Template Manager (BTM)

Room attributes templates

Templates	Lettable floor area (%)	Circulation floor area (%)		
Rooms	80	20		
Circulation	1	99		

Constructions

Specific

Macroflo Opening Types

Specific

Thermal conditions

Building regulations

template	Room type	NCM Building type	NCM Activity	External ventilation rate
Rooms	Heated or occupied room	Residential spaces	NCM Dwell: Bedroom/Kitchen/Dining Room/Lounge/bathroom	Not applicable
Circulation	Other buffer space	Residential spaces	NCM Dwell: Circulation area	0

Room conditions	Profile	constant simulation setpoint	DHW consumption l/(h.pers)
Heating	specific	20	
DHW	specific		RCCTE: 40l/(day.pers)
Cooling	specific	25	
Plant (auxiliary energy)	specific		

Model settings

Solar reflected fraction	Furniture mass factor
0.05	1

Humidity control

Min. Percentage saturation	Max. Percentage saturation
0	100

System

System

HVAC system — specific Apache System

Heating

Heating plant radiant fraction	0.2	IES Manual: 0 for forced warm air heaters and 0.9 for high temperature radiant heaters	electric radiators 0.9 and thermo-ventilators 0
Simulation heating unit capacity	unlimited		

Cooling

Cooling plant radiant fraction	0	IES manual: 0 for an air system
Simulation cooling unit capacity	unlimited	

System outside air supply

Min. Flow	0.8 (l/s.m2)	
Additional free cooling flow capacity	5 (ach.)	IES manual: free cooling typical open window 5 ach
Variation profile	off continuously	

Internal gains (casual gains)

Specific

Air exchanges	variation profile	Adjacent conditions	Max. Flow
Infiltration	on continuously	External air	0.25 ach

Electric Lighting

Not used

Radiance Surface Properties

Not used

Apache Systems

Heating

Generator			
	Fuel	electricity oy Butane gas	
	Is it a heat pump?	never	
	Seasonal efficiency		
	Delivery efficiency	not available	
	SCoP kW/kW		
	Generator size kW	not available	
Heat recovery	Note used		
	Vent. Heat recovery effectiveness		
	Vent heat recovery return air temp. (°C)		
CH(C)P	Not used		
	Is this heat source used in conjunction with CHP?	never	
	What ranking does this heat source have after the CH(C)P Plant?		

Cooling

Generator	(Never air conditioning)		
	Cooling/ventilation mechanism	Natural ventilation	Mechanical ventilation ?

Hot Water

Generator					
	Is DHW served by ApacheHVAC boiler?	never		Electric Water Heaters	Electric water heating cylinders
	DHW deliver efficiency	0.8	0.7	RCCTE (p.2506)	RCCTE Simplified (p.17415) equipment with 0-9 years
Set points					
	Mean cold water inlet temp. (°C)	15 °C		RCCTE (p.2506)	
	Hot water supply temp. (°C)	60 °C	ΔT 45 °C	RCCTE (p.2506)	
Storage					
	Is this a storage system?	always yes			
	Storage volume (l)	variable	50 to 75l		
		Insulation	not available		
		Storage losses (kWh(l.day))	0.0075 ?		
Secondary circulation	never				

Solar Water Heating

Solar panel			
	Is there a solar heating system?	No. To be simulated	
	Area (m2)		
	Azimuth (° clockwise from north)		
	Tilt (° from horizontal)	23	roof slope
	Shading factor		
	Degradation factor		
	Conversion efficiency at ambient temperatura		
	First order heat loss coefficient (a1) (W/m2.K)		
	Second order heat loss coefficient (a2) (W/m2.K2)		
	Flow rate (l/(h.m2))		
	Pump power (kW)		
	Heat exchanger effectiveness		
Storage tank			
	Volume (l)		
	Storage loss at max. Temp. (kWh/(l.day))		

Aux. Energy

Method	(never)?		
	Auxiliary energy method	specific	

Auxiliary energy			
	Auxiliary energy value W/m2		
	Off-schedule heating/cooling AEV W/m2		

Air Supply

Outside air supply			
	supply condition	external air	

Cooling air supply sizing			
	Air supply temperature difference (0 for no sizing) K		

Control

Master zone control			
	Master zone	specific	

Appendix D

Case Studies Simulation

Design Scenarios

IES VE Dynamic Simulation Results

Appliances Simulation Results

Simulations results

		Baseline	Scenario 1	gain	Scenario 2	gain	Scenario 3a	gain	Scenario 3b	gain	Scenario 4	gain	Scenario 5	gain	Scenario 6	gain	Scenario 7	gain	Scenario 8	gain	Scenario 8b	gain	Scenario 9	gain	Scenario 10	gain
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	5177.3	0.3	5177.3	0.3	5177.3	0.3	5056.5	121.1	5020	157.6	5177.3	0.3	5177.3	0.3	5177.3	0.3			5177.3	0.3	5177.3	0.3
	CO2 (kgCO2)	**1131**	1131	0	1131	0	1131	0	1131	0	1103	28	1095	36	1131	0	1131	0	1131	0			1131	0	1131	0
	PPD (Mean %)	16.63	16.71	-0.09	16.62	0.01	16.62	0.01	15.70	0.93	16.63	0.00	16.62	0.01	16.38	0.25	16.46	0.17	11.61	5.02			16.62	0.01	16.24	0.39
Case 2	**Energy (kWh/year)**	**6412.6**	6391.5	21.1	6409.6	3	6349.4	63.2	6340.1	72.5	6169.8	242.8	5983.8	428.8	6320.1	92.5	6331.2	81.4	6336.9	75.7	6360.3	52.3	6273.9	139	6091	322
	CO2 (kgCO2)	**1440**	1435	5	1439	1	1425	15	1423	17	1384	56	1342	98	1418	22	1421	19	1422	18	1428	12	1408	32	1366	74
	PPD (Mean %)	27.49	28.10	-0.60	27.55	-0.05	30.49	-2.99	25.28	2.22	27.49	0.00	27.49	0.00	28.63	-1.14	29.02	-1.53	27.85	-0.36	27.76	-0.27	29.43	-1.94	32.51	-5.01
Case 3	**Energy (kWh/year)**	**6632.9**	6611.5	21.4	6633.2	-0.3	6601.5	31.4	6614.9	18	6431.7	201.2	6286.9	346	6629.6	3.3	6606.1	26.8	6616.6	16.3	6616.6	16.3	6596.5	36.4	6596.6	36.3
	CO2 (kgCO2)	**1437**	1433	4	1438	-1	1430	7	1433	4	1391	46	1358	79	1437	0	1431	6	1434	3	1434	3	1429	8	1429	8
	PPD (Mean %)	26.49	25.93	0.56	26.50	-0.01	25.61	0.88	24.87	1.62	26.48	0.00	26.48	0.00	26.31	0.17	25.70	0.78	25.65	0.84	25.66	0.82	22.48	4.00	22.50	3.99
Case 4	**Energy (kWh/year)**	**4522.5**	4460.9	61.6	4519.9	2.6	4464	58.5	4489	33.5	4407.4	115.1	4362.2	160.3	4454.7	67.8	4400.6	122	4440.3	82.2	4441.7	80.8	4099.8	423	4099.8	423
	CO2 (kgCO2)	**1013**	999	14	1012	1	999	14	1005	8	987	26	976	37	997	16	985	28	994	19	994	19	916	97	916	97
	PPD (Mean %)	26.75	26.93	-0.18	26.76	-0.01	27.58	-0.83	24.81	1.95	26.75	0.00	26.75	0.00	26.75	0.01	27.08	-0.33	26.57	0.19	26.59	0.16	30.48	-3.72	0.00	26.75
Case 5	**Energy (kWh/year)**	**8495.3**	8429.1	66.2	8495.3	0	8495.1	0.2	8495.3	0	8253.1	242.2	8101.5	393.8	8495.6	-0.3	8429.1	66.2	8490.1	5.2					8490.5	4.8
	CO2 (kgCO2)	**1863**	1848	15	1863	0	1863	0	1863	0	1808	55	1773	90	1863	0	1848	15	1862	1					1862	1
	PPD (Mean %)	33.42	30.89	2.54	33.36	0.07	34.95	-1.52	0.00	33.42	33.36	0.07	33.36	0.07	33.28	0.14	30.71	2.72	33.48	-0.06					0.00	33.42
Case 6	**Energy (kWh/year)**	**6178.3**	6137.3	41	6177.8	0.5	6178.3	0	6193.7	-15.4	6098.3	80	6074.9	103.4	6169.8	8.5	6120.9	57.4	6175.1	3.2					6170.9	7.4
	CO2 (kgCO2)	**1360**	1350	10	1360	0	1360	0	1363	-3	1341	19	1336	24	1358	2	1347	13	1359	1					1358	2
	PPD (Mean %)	22.29	21.72	0.57	21.25	1.04	0.00	22.29	20.20	2.09	21.28	1.01	21.28	1.01	0.00	22.29	20.77	1.52	21.35	0.94					20.92	1.37
Case 7	**Energy (kWh/year)**	**2948.1**	2944	4.1	2948	0.1	2934.2	13.9	2937.2	10.9	2906.3	41.8	2921.2	26.9	2943.5	4.6	2938.3	9.8	2948.4	-0.3					2927.5	20.6
	CO2 (kgCO2)	**650**	649	1	650	0	647	3	647	3	640	10	644	6	649	1	648	2	650	0					645	5
	PPD (Mean %)	26.29	26.34	-0.05	25.86	0.43	27.21	-0.91	25.27	1.02	25.85	0.44	25.85	0.44	26.04	0.25	26.68	-0.38	25.91	0.38					24.90	1.40
Case 8	**Energy (kWh/year)**	**4433.7**	4415.7	18	4433.2	0.5	4374.5	59.2	4475.4	-41.7	4424.2	9.5	4505.1	-71.4	4470.4	-36.7	4433.7	0	4413.1	20.6	4074.3	359			4295.3	138
	CO2 (kgCO2)	**988**	984	4	988	0	975	13	998	-10	986	2	1005	-17	997	-9	988	0	984	4	906	82			957	31
	PPD (Mean %)	30.17	27.90	2.27	27.93	2.24	27.39	2.78	26.56	3.62	27.93	2.24	27.93	2.24	28.08	2.10	0.00	30.17	28.07	2.11	26.15	4.03			28.54	1.63
Case 9	**Energy (kWh/year)**	**3229**	3229	0	3229	0	3229	0	3229	0	3210.3	18.7	3373.3	-144.3	3229	0	3229	0	3229	0	3229	0	3229	0	3229	0
	CO2 (kgCO2)	**684**	684	0	684	0	684	0	684	0	680	4	718	-34	684	0	684	0	684	0	684	0	684	0	684	0
	PPD (Mean %)	26.63	25.31	1.33	26.63	0.00	25.75	0.88	25.88	0.75	26.63	0.00	26.63	0.00	26.41	0.22	24.92	1.71	25.73	0.90	25.50	1.13	0.00	26.63	26.06	0.57
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	2427.1	0	2427.1	0	2427.1	0	2359.1	68	2354.7	72.4	2427.1	0	2427.1	0	2427.1	0					2427.1	0
	CO2 (kgCO2)	**555**	555	0	555	0	555	0	555	0	539	16	538	17	555	0	555	0	555	0					555	0
	PPD (Mean %)	17.43	17.42	0.01	17.42	0.01	0.00	17.43	16.68	0.75	17.43	0.00	17.43	0.00	17.20	0.23	17.17	0.26	17.45	-0.02					17.08	0.35

Variant	Case	Indicators	Baseline	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 8b	Scenario 9	Scenario 10	Scenarios 1, 4 and 5	Scenarios 1, 4, 5, and 3	Scenario Solar DHW	Scenario Solar DHW and scenario 4
V3b		Energy (kWh/year)	5177.60	0.30	0.30	0.30	0.30	121.10	157.60	0.30	0.30	0.30		0.30	0.30	251.70	251.70	373.00	449.10
mid	Case 1	CO2 (kgCO2)	1131.00	0.00	0.00	0.00	0.00	28.00	36.00	0.00	0.00	0.00		0.00	0.00	58.00	58.00	85.00	103.00
		PPD (Mean %)	16.63	-0.09	0.01	0.01	0.93	0.00	0.01	0.25	0.17	5.02		0.01	0.39	-0.09	-0.08	0.00	0.00
V3b		Energy (kWh/year)	6412.60	21.10	3.00	63.20	72.50	242.80	428.80	92.50	81.40	75.70	52.30	138.70	321.60	638.50	709.90	733.00	898.90
top	Case 2	CO2 (kgCO2)	1440.00	5.00	1.00	15.00	17.00	56.00	98.00	22.00	19.00	18.00	12.00	32.00	74.00	146.00	163.00	169.00	206.00
		PPD (Mean %)	27.49	-0.60	-0.05	-2.99	2.22	0.00	0.00	-1.14	-1.53	-0.36	-0.27	-1.94	-5.01	-0.60	1.66	0.00	0.00
V3a		Energy (kWh/year)	6632.90	21.40	-0.30	31.40	18.00	201.20	346.00	3.30	26.80	16.30	16.30	36.40	36.30	524.00	555.90	618.90	762.40
top	Case 3	CO2 (kgCO2)	1437.00	4.00	-1.00	7.00	4.00	46.00	79.00	0.00	6.00	3.00	3.00	8.00	8.00	119.00	127.00	141.00	174.00
		PPD (Mean %)	26.49	0.56	-0.01	0.88	1.62	0.00	0.00	0.17	0.78	0.84	0.82	4.00	3.99	0.56	1.62	0.00	0.00
V4		Energy (kWh/year)	4522.50	61.60	2.60	58.50	33.50	115.10	160.30	67.80	121.90	82.20	80.80	422.70	422.70	311.40	365.20	459.10	515.30
top	Case 4	CO2 (kgCO2)	1013.00	14.00	1.00	14.00	8.00	26.00	37.00	16.00	28.00	19.00	19.00	97.00	97.00	71.00	84.00	105.00	118.00
		PPD (Mean %)	26.75	-0.18	-0.01	-0.83	1.95	0.00	0.00	0.01	-0.33	0.19	0.16	-3.72	0.00	-0.18	-1.03	0.00	0.00
V4		Energy (kWh/year)	8495.30	66.20	0.00	0.20	0.00	242.20	393.80	-0.30	66.20	5.20			4.80	648.30	645.20	735.40	900.90
mid	Case 5	CO2 (kgCO2)	1863.00	15.00	0.00	0.00	0.00	55.00	90.00	0.00	15.00	1.00			1.00	148.00	147.00	168.00	206.00
		PPD (Mean %)	33.42	2.54	0.07	-1.52	0.00	0.07	0.07	0.14	2.72	-0.06			0.00	2.54	0.98	0.00	0.00
V3a		Energy (kWh/year)	6178.30	41.00	0.50	0.00	-15.40	80.00	103.40	8.50	57.40	3.20			7.40	206.50	210.10	238.40	284.10
mid	Case 6	CO2 (kgCO2)	1360.00	10.00	0.00	0.00	-3.00	19.00	24.00	2.00	13.00	1.00			2.00	47.00	48.00	55.00	65.00
		PPD (Mean %)	22.29	0.57	1.04	0.00	2.09	1.01	1.01	0.00	1.52	0.94			1.37	0.57	0.74	0.00	0.00
V2		Energy (kWh/year)	2948.10	4.10	0.10	13.90	10.90	41.80	26.90	4.60	9.80	-0.30			20.60	63.60	66.50	87.50	108.60
mid	Case 7	CO2 (kgCO2)	650.00	1.00	0.00	3.00	3.00	10.00	6.00	1.00	2.00	0.00			5.00	15.00	15.00	20.00	25.00
		PPD (Mean %)	26.29	-0.05	0.43	-0.91	1.02	0.44	0.44	0.25	-0.38	0.38			1.40	-0.05	0.00	0.00	0.00
V1		Energy (kWh/year)	4433.70	18.00	0.50	59.20	-41.70	9.50	-71.40	-36.70	0.00	20.60	359.40		138.40	-45.70	-45.70	-57.80	-54.40
top	Case 8	CO2 (kgCO2)	988.00	4.00	0.00	13.00	-10.00	2.00	-17.00	-9.00	0.00	4.00	82.00		31.00	-11.00	-11.00	-14.00	-13.00
		PPD (Mean %)	30.17	2.27	2.24	2.78	3.62	2.24	2.24	2.10	0.00	2.11	4.03		1.63	2.27	2.27	0.00	0.00
V2		Energy (kWh/year)	3229.00	0.00	0.00	0.00	0.00	18.70	-144.30	0.00	0.00	0.00	0.00	0.00	0.00	-133.80	-133.80	-12.60	-5.00
top	Case 9	CO2 (kgCO2)	684.00	0.00	0.00	0.00	0.00	4.00	-34.00	0.00	0.00	0.00	0.00	0.00	0.00	-31.00	-31.00	-3.00	-1.00
		PPD (Mean %)	26.63	1.33	0.00	0.88	0.75	0.00	0.00	0.22	1.71	0.90	1.13	0.00	0.57	1.33	2.20	0.00	0.00
V1		Energy (kWh/year)	2427.10	0.00	0.00	0.00	0.00	68.00	72.40	0.00	0.00	0.00			0.00	125.30	125.30	239.10	268.00
mid	Case 10	CO2 (kgCO2)	555.00	0.00	0.00	0.00	0.00	16.00	17.00	0.00	0.00	0.00			0.00	29.00	29.00	55.00	61.00
		PPD (Mean %)	17.43	0.01	0.01	0.00	0.75	0.00	0.00	0.23	0.26	-0.02			0.35	0.01	0.75	0.00	0.00

		Potential Savings						
Variant	Case	Total (kWh/year)	Total (€/year) 2013	Total (%)	Lighting (kWh/year)	Lighting (€/year) 2013	Standby (kWh/year)	Standby (€/year) 2013
V3b mid	Case 1	404.58	69.91	17.89	78.84	13.62	70.22	12.14
V3b top	Case 2	1152.62	199.17	18.85	263.44	45.51	222.70	38.49
V3a top	Case 3	726.05	125.46	27.04	246.54	42.60	79.28	13.70
V4 top	Case 4	322.93	55.80	8.38	0.00	0.00	22.38	3.87
V4 mid	Case 5	1215.57	210.05	20.46	442.85	76.52	214.42	37.05
V3a mid	Case 6	1877.81	324.49	46.57	290.37	50.17	148.30	25.63
V2 mid	Case 7	586.60	101.36	29.09	141.96	34.44	67.90	10.83
V1 top	Case 8	737.89	127.51	42.25	251.33	44.64	83.28	14.35
V2 top	Case 9	455.96	78.79	31.03	166.73	31.48	31.67	5.99
V1 mid	Case 10	328.68	56.80	16.81	35.04	6.06	42.00	7.26

Case 1

Project File: Case1_Base2.mit
Sim File: case1_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps	case1_base2.aps
Summed total	0	1.5689	1.5689	0.0131	2.1374	1.4579	3.5953	2.1374	3.0401	5.1776

Project File: Case1_Future.mit
Sim File: case1_future.aps 24/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0	1.4795	1.4795	0.0131	2.1374	1.4579	3.5954	2.1374	2.9506	5.088
	↔	↘	↘	↔	↔	↔	↔	↔	↘	↘

Case 2

Project File: Case2_Base2.mit
Sim File: case2_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.6964	2.5032	3.1996	0.0847	1.0686	2.0595	3.128	1.0686	5.344	6.4126

Project File: case2_Future.mit
Sim File: case2_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.2561	2.5033	2.7594	0.0847	1.0686	2.1503	3.2188	1.0686	4.9943	6.0629
	↘	↔	↘	↔	↔	↗	↗	↔	↘	↘

Case 3

Project File: Case3_Base2.mit
Sim File: case3_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.2894	2.1314	2.4208	0.0788	3.2058	0.9276	4.1332	3.2058	3.4271	6.6329

Project File: Case3_Future.mit
Sim File: case3_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.1629	2.1313	2.2943	0.0788	3.2058	0.9276	4.1334	3.2058	3.3006	6.5064
	↘	↔	↘	↔	↔	↔	↔	↔	↘	↘

Case 4

Project File: Case4_Base2.mit
Sim File: case4_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.6821	1.4301	2.1121	0.2117	0.8549	1.3438	2.1986	0.8549	3.6676	4.5225

Project File: Case4_Future.mit
Sim File: case4_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.2959	1.4301	1.7259	0.2117	0.8549	1.3438	2.1987	0.8549	3.2814	4.1363
	↘	↔	↘	↔	↔	↔	↔	↔	↘	↘

Case 5

Project File: Case5_Base2b.mit
Sim File: case5_base2b.aps 10/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.0932	2.6905	2.7837	0.0847	3.2058	2.421	5.6268	3.2058	5.2894	8.4953

Project File: Case5_Future.mit
Sim File: case5_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.0464	2.6486	2.695	0.0847	3.2058	2.4956	5.7014	3.2058	5.2753	8.4811
	↘	↘	↘	↔	↔	↗	↗	↔	↘	↘

Case 6

Project File: Case6_Base2.mit
Sim File: case6_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.235	1.0386	1.2736	0.1051	2.1372	2.6621	4.7994	2.1372	4.041	6.1783

Project File: Case6_Future.mit
Sim File: case6_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.1453	1.0386	1.1839	0.1051	2.1372	2.6716	4.8088	2.1372	3.9607	6.098
	↘	↔	↘	↔	↔	↗	↗	↔	↘	↘

Case 7

Project File: Case7_Base2.mit
Sim File: case7_base2.aps 07/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0.2208	0.6956	0.9163	0.0726	0.9739	0.9854	1.9593	0.9739	1.9742	2.9481

Project File: Case7_Future.mit
Sim File: case7_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps	case7_future.aps
Summed total	0.0669	0.6956	0.7624	0.0726	0.9739	0.9854	1.9593	0.9739	1.8204	2.7942
	↘	↔	↘	↔	↔	↔	↔	↔	↘	↘

Case 8

Project File: Case8_Base2.mit
Sim File: case8_base2.aps 08/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	2.0199	0.5981	2.618	0.1008	1.0247	0.6904	1.7151	1.0247	3.4091	4.4337

Project File: Case8_Future.mit
Sim File: case8_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	1.1432	0.5981	1.7413	0.1008	1.0247	0.6904	1.7151	1.0247	2.5325	3.5571
	↘	↔	↘	↔	↔	↔	↔	↔	↘	↘

Case 9

Project File: Case9_Base2.mit
Sim File: case9_base2.aps 08/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0	0.4049	0.4049	0.0218	2.2001	0.6022	2.8024	2.2001	1.0289	3.229

Project File: Case9_Future.mit
Sim File: case9_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip LPG (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total LPG (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0	0.4049	0.4049	0.0218	2.2001	0.6042	2.8043	2.2001	1.0309	3.231
	↔	↔	↔	↔	↔	↗	↗	↔	↗	↗

Case 10

Project File: Case10_Base2.mit
Sim File: case10_base2.aps 08/May/2013
Weather File: PortoIWEC.fwt

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0	0.9711	0.9711	0.307	1.1491	1.1491	2.4271	2.4271

Project File: Case10_Future.mit
Sim File: case10_future.aps 25/May/2013
Weather File: PRT_PORTO_HadCM3-A2-2080.epw

	Ap Sys boilers space cond'g energy (MWh)	Ap Sys boilers DHW energy (MWh)	System electricity (MWh)	Lights electricity (MWh)	Equip electricity (MWh)	Total equip energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Summed total	0	0.9711	0.9711	0.307	1.1491	1.1491	2.4271	2.4271
	↔	↔	↔	↔	↔	↔	↔	↔

Design Scenarios **Building modelling**

Scenario	measure	modelling in IES-VE
Baseline		
1	Draughtproofing windows and doors	reduce crack flow in doors and windows (MacroFlo)
2	Improve single glazing with insulating film	model in glazed constructions
3a	Use of internal shutters	model in external glazed elements (internal shade)
3b	use internal shutters and change profile	model in external glazed elements (internal shade)
4	Reduce DHW temperature from 60 to 55 C	model in DHW system
5	Upgrade DHW storage tank insulation (to 100mm)	model in DHW system
6	Introduce double glazing	model in glazed constructions
7	Introduce secondary glazing	model in glazed constructions
8a	Introduce insulation in floors and ceilings	model in floor/ceiling constructions
8b	Introduce insulation in roofs	model in roof constructions
9	introduce exterior insulation in party walls	model in external wall constructions
10	scenario 9 + introduce exterior indulation in facades	model in external wall constructions
11	Introduce PCM in the rooms (inside)	not modelled
1_4_5	Composite scenario (1, 4 and 5)	
1_4_5_3	Composite scenario (1, 4, 5 and 3)	

Design Scenarios **equipment modelling**

Scenario	measure	modelling in Excel table
1	nulling equipment standby	
2	replace existing lamps with more efficient ones	replace incandescent and halogen lamps with CFL equivalent
3	replace existing equipment with more efficient one	replace identified inefficient equipmet with efficient equivalent models

Design Scenario 1

		Baseline	Scenario 1	gain total	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	157.44	3037.04	0.01	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6391.5	21.1	3.65	105.24	28.86	0.33	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1440**	1435	5				0.35		
Case 3	**Energy (kWh/year)**	**6632.9**	6611.5	21.4	3.70	151.99	41.10	0.32	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1437**	1433	4				0.28		
Case 4	**Energy (kWh/year)**	**4522.5**	4460.9	61.6	10.64	101.55	9.54	1.36	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1013**	999	14				1.38		
Case 5	**Energy (kWh/year)**	**8495.3**	8429.1	66.2	11.44	111.00	9.70	0.78	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1863**	1848	15				0.81		
Case 6	**Energy (kWh/year)**	**6178.3**	6137.3	41	7.08	163.85	23.13	0.66	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**1360**	1350	10				0.74		
Case 7	**Energy (kWh/year)**	**2948.1**	2944	4.1	0.71	35.09	49.53	0.14	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**650**	649	1				0.15		
Case 8	**Energy (kWh/year)**	**4433.7**	4415.7	18	3.11	294.73	94.76	0.41	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**988**	984	4				0.40		
Case 8B	**Energy (kWh/year)**	**4436.4**	4418.2	18.2	3.14	294.73	93.72	0.41	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**989**	985	4				0.40		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	81.59	na	0.00	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00	44.28	na	0.00	non-weatherstripped doors and windows	weatherstripped doors and windows
	CO2 (kgCO2)	**555**	555	0				0.00		

Design Scenario 2

		Baseline	Scenario 2	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	10.09	194.64	0.01	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6409.6	3	0.52	25.42	49.04	0.05	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1440**	1439	1				0.07		
Case 3	**Energy (kWh/year)**	**6632.9**	6633.2	-0.3	-0.05	16.29	na	0.00	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1437**	1438	-1				-0.07		
Case 4	**Energy (kWh/year)**	**4522.5**	4519.9	2.6	0.45	11.22	24.97	0.06	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1013**	1012	1				0.10		
Case 5	**Energy (kWh/year)**	**8495.3**	8495.3	0	0.00	16.70	na	0.00	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1863**	1863	0				0.00		
Case 6	**Energy (kWh/year)**	**6178.3**	6177.8	0.5	0.09	27.71	320.72	0.01	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**1360**	1360	0				0.00		
Case 7	**Energy (kWh/year)**	**2948.1**	2948	0.1	0.02	4.41	255.21	0.00	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**650**	650	0				0.00		
Case 8	**Energy (kWh/year)**	**4433.7**	4433.2	0.5	0.09	50.11	579.98	0.01	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**988**	988	0				0.00		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	na	na	0.00	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00	na	na	0.00	simple glazing	Improve simple glazing with insulating film
	CO2 (kgCO2)	**555**	555	0				0.00		

Design Scenario 3

		Baseline	Scenario 3a	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	73.85	1424.58	0.01	open day /closed night (20-8h)	same
	CO2 (kgCO2)	**1131**	1131	0				0.00		introduced shutter in kitchen
Case 2	**Energy (kWh/year)**	**6412.6**	6349.4	63.2	10.92	1905.00	174.44	0.99	always open	open day /closed night (20-8h)
	CO2 (kgCO2)	**1440**	1425	15				1.04		introduced shutter in all exterior openings
Case 3	**Energy (kWh/year)**	**6632.9**	6601.5	31.4	5.43	2279.00	420.02	0.47	no shutters	open day /closed night (20-8h)
	CO2 (kgCO2)	**1437**	1430	7				0.49		introduced shutter in all exterior openings
Case 4	**Energy (kWh/year)**	**4522.5**	4464	58.5	10.11	1485.00	146.90	1.29		open day /closed night (20-8h)
	CO2 (kgCO2)	**1013**	999	14				1.38	no shutters	introduced shutter in all exterior openings
Case 5	**Energy (kWh/year)**	**8495.3**	8495.1	0.2	0.03		na	0.00	winter - open all day, closed in the night (21-6.30h)	open day /closed night (20-8h)
	CO2 (kgCO2)	**1863**	1863	0				0.00	summer - open all night closed all day (6.30-21h)	
Case 6	**Energy (kWh/year)**	**6178.3**	6178.3	0	0.00		na	0.00	open day /closed night (21-7.30h)	same
	CO2 (kgCO2)	**1360**	1360	0				0.00		
Case 7	**Energy (kWh/year)**	**2948.1**	2934.2	13.9	2.40	667.00	277.69	0.47	exterior blinders - 75% open during day, closed during night and when away	introduce shutters - open day /closed night (20-8h)
	CO2 (kgCO2)	**650**	647	3				0.46	no shutters	removed exterior blinders
Case 8	**Energy (kWh/year)**	**4433.7**	4374.5	59.2	10.23	1538.00	150.35	1.34	shutters in 3rd floor - closed continuously 75%	open day /closed night (20-8h)
	CO2 (kgCO2)	**988**	975	13				1.32	no shutters in 4th floor	introduced shutter in all exterior openings
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	2213.40	na	0.00	no shutters	open day /closed night (20-8h)
	CO2 (kgCO2)	**684**	684	0				0.00		introduced shutter in all exterior openings
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00		na	0.00	open day /closed night (19.30-7.30h)	same
	CO2 (kgCO2)	**555**	555	0				0.00		introduced shutter in all exterior openings

Design Scenario 3B

		Baseline	Scenario 3b	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	73.85	1424.58	0.01	open day /closed night (20-8h)	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**1131**	1131	0				0.00		summer - open all night closed all day (6.30-21h)
Case 2	**Energy (kWh/year)**	**6412.6**	6340.1	72.5	12.53	1905.00	152.06	1.13	always open	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**1440**	1423	17				1.18		summer - open all night closed all day (6.30-21h)
Case 3	**Energy (kWh/year)**	**6632.9**	6614.9	18	3.11	2279.00	732.70	0.27	no shutters	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**1437**	1433	4				0.28		summer - open all night closed all day (6.30-21h)
Case 4	**Energy (kWh/year)**	**4522.5**	4489	33.5	5.79	1485.00	256.53	0.74		winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**1013**	1005	8				0.79	no shutters	summer - open all night closed all day (6.30-21h)
Case 5	**Energy (kWh/year)**	**8495.3**	8495.3	0	0.00		na	0.00	winter - open all day, closed in the night (21-6.30h)	same
	CO2 (kgCO2)	**1863**	1863	0				0.00	summer - open all night closed all day (6.30-21h)	
Case 6	**Energy (kWh/year)**	**6178.3**	6193.7	-15.4	-2.66		na	-0.25	open day /closed night (21-7.30h)	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**1360**	1363	-3				-0.22		summer - open all night closed all day (6.30-21h)
Case 7	**Energy (kWh/year)**	**2948.1**	2937.2	10.9	1.88	667.00	354.12	0.37	exterior blinders - 75% open during day, closed during night and when away	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**650**	647	3				0.46	no shutters	summer - open all night closed all day (6.30-21h)
Case 8	**Energy (kWh/year)**	**4433.7**	4475.4	-41.7	-7.21	1538.00	-213.44	-0.94	shutters in 3rd floor - closed continuously 75%	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**988**	998	-10				-1.01	no shutters in 4th floor	summer - open all night closed all day (6.30-21h)
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00		na	0.00	no shutters	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**684**	684	0				0.00		summer - open all night closed all day (6.30-21h)
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00		na	0.00	open day /closed night (19.30-7.30h)	winter - open all day, closed in the night (21-6.30h)
	CO2 (kgCO2)	**555**	555	0				0.00		summer - open all night closed all day (6.30-21h)

Design Scenario 4

		Baseline	Scenario 4	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5056.5	121.1	20.93			2.34	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1131**	1103	28				2.48		
Case 2	**Energy (kWh/year)**	**6412.6**	6169.8	242.8	41.96			3.79	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1440**	1384	56				3.89		
Case 3	**Energy (kWh/year)**	**6632.9**	6431.7	201.2	34.77			3.03	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1437**	1391	46				3.20		
Case 4	**Energy (kWh/year)**	**4522.5**	4407.4	115.1	19.89			2.55	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1013**	987	26				2.57		
Case 5	**Energy (kWh/year)**	**8495.3**	8253.1	242.2	41.85			2.85	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1863**	1808	55				2.95		
Case 6	**Energy (kWh/year)**	**6178.3**	6098.3	80	13.82			1.29	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**1360**	1341	19				1.40		
Case 7	**Energy (kWh/year)**	**2948.1**	2906.3	41.8	7.22			1.42	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**650**	640	10				1.54		
Case 8	**Energy (kWh/year)**	**4433.7**	4424.2	9.5	1.64			0.21	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**988**	986	2				0.20		
Case 9	**Energy (kWh/year)**	**3229**	3210.3	18.7	3.23			0.58	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**684**	680	4				0.58		
Case 10	**Energy (kWh/year)**	**2427.1**	2359.1	68	11.75			2.80	DHW at 60°C	DHW at 55°C
	CO2 (kgCO2)	**555**	539	16				2.88		

Design Scenario 5

		Baseline	Scenario 5	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5020	157.6	27.23	17.00	0.62	3.04	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1131**	1095	36				3.18		
Case 2	**Energy (kWh/year)**	**6412.6**	5983.8	428.8	74.10	17.00	0.23	6.69	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1440**	1342	98				6.81		
Case 3	**Energy (kWh/year)**	**6632.9**	6286.9	346	59.79	17.00	0.28	5.22	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1437**	1358	79				5.50		
Case 4	**Energy (kWh/year)**	**4522.5**	4362.2	160.3	27.70	17.00	0.61	3.54	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1013**	976	37				3.65		
Case 5	**Energy (kWh/year)**	**8495.3**	8101.5	393.8	68.05	17.00	0.25	4.64	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1863**	1773	90				4.83		
Case 6	**Energy (kWh/year)**	**6178.3**	6074.9	103.4	17.87	17.00	0.95	1.67	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**1360**	1336	24				1.76		
Case 7	**Energy (kWh/year)**	**2948.1**	2921.2	26.9	4.65	17.00	3.66	0.91	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**650**	644	6				0.92		
Case 8	**Energy (kWh/year)**	**4433.7**	4505.1	-71.4	-12.34	17.00	-1.38	-1.61	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**988**	1005	-17				-1.72		
Case 9	**Energy (kWh/year)**	**3229**	3373.3	-144.3	-24.94	17.00	-0.68	-4.47	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**684**	718	-34				-4.97		
Case 10	**Energy (kWh/year)**	**2427.1**	2354.7	72.4	12.51	17.00	1.36	2.98	DHW tank with 40mm insulation (0.7 efficiency)	DHW tank with 100mm insulation (loose jacket - 0.9 efficiency)
	CO2 (kgCO2)	**555**	538	17				3.06		

Design Scenario 6

		Baseline	Scenario 6	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	185.00	3568.67	0.01	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6320.1	92.5	15.98	466.00	29.15	1.44	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1440**	1418	22				1.53		
Case 3	**Energy (kWh/year)**	**6632.9**	6629.6	3.3	0.57	299.00	524.34	0.05	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1437**	1437	0				0.00		
Case 4	**Energy (kWh/year)**	**4522.5**	4454.7	67.8	11.72	316.00	26.97	1.50	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1013**	997	16				1.58		
Case 5	**Energy (kWh/year)**	**8495.3**	8495.6	-0.3	-0.05	306.00	-5902.78	0.00	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1863**	1863	0				0.00		
Case 6	**Energy (kWh/year)**	**6178.3**	6169.8	8.5	1.47	508.00	345.86	0.14	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**1360**	1358	2				0.15		
Case 7	**Energy (kWh/year)**	**2948.1**	2943.5	4.6	0.79	81.00	101.90	0.16	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**650**	649	1				0.15		
Case 8	**Energy (kWh/year)**	**4433.7**	4470.4	-36.7	-6.34		na	-0.83	PVC with double glazing (4+12+4mm)	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**988**	997	-9				-0.91		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00		na	0.00	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00		na	0.00	wood frame with single glass 4mm	wood frame double glass (4+6+4)
	CO2 (kgCO2)	**555**	555	0				0.00		

Design Scenario 7

		Baseline	Scenario 7	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	2095.00	40412.81	0.01	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6331.2	81.4	14.07	2221.00	157.90	1.27	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1440**	1421	19				1.32		
Case 3	**Energy (kWh/year)**	**6632.9**	6606.1	26.8	4.63	2459.00	530.98	0.40	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1437**	1431	6				0.42		
Case 4	**Energy (kWh/year)**	**4522.5**	4400.6	121.9	21.06	3206.00	152.20	2.70	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1013**	985	28				2.76		
Case 5	**Energy (kWh/year)**	**8495.3**	8429.1	66.2	11.44	2571.00	224.75	0.78	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1863**	1848	15				0.81		
Case 6	**Energy (kWh/year)**	**6178.3**	6120.9	57.4	9.92	5201.00	524.36	0.93	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**1360**	1347	13				0.96		
Case 7	**Energy (kWh/year)**	**2948.1**	2938.3	9.8	1.69	720.00	425.17	0.33	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**650**	648	2				0.31		
Case 8	**Energy (kWh/year)**	**4433.7**	4433.7	0	0.00		na	0.00	Double glazed PVC	same
	CO2 (kgCO2)	**988**	988	0				0.00		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00		na	0.00	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00		na	0.00	single glazed wood frame (4mm)	secondary glazing (50+6mm)
	CO2 (kgCO2)	**555**	555	0				0.00		

Design Scenario 8

		Baseline	Scenario 8	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	574.00	11072.53	0.01	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6336.9	75.7	13.08	1308.80	100.05	1.18	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1440**	1422	18				1.25		
Case 3	**Energy (kWh/year)**	**6632.9**	6616.6	16.3	2.82	460.00	163.32	0.25	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1437**	1434	3				0.21		
Case 4	**Energy (kWh/year)**	**4522.5**	4440.3	82.2	14.20	778.67	54.82	1.82	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1013**	994	19				1.88		
Case 5	**Energy (kWh/year)**	**8495.3**	8490.1	5.2	0.90	519.00	577.59	0.06	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1863**	1862	1				0.05		
Case 6	**Energy (kWh/year)**	**6178.3**	6175.1	3.2	0.55	886.00	1602.29	0.05	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**1360**	1359	1				0.07		
Case 7	**Energy (kWh/year)**	**2948.1**	2948.4	-0.3	-0.05	237.68	na	-0.01	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**650**	650	0				0.00		
Case 8	**Energy (kWh/year)**	**4433.7**	4413.1	20.6	3.56	1575.00	442.46	0.46	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**988**	984	4				0.40		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	171.01	na	0.00	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00	425.59	na	0.00	uninsulated floors and ceilings	Introduce insulation in floors and ceilings
	CO2 (kgCO2)	**555**	555	0				0.00		

Design Scenario 8B

		Baseline	Scenario 8b	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**					na	0.00	na	na
	CO2 (kgCO2)	**1131**						0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6360.3	52.3	9.04	816.70	90.37	0.82	Uninsulated roof	Introduce insulation in roof
	CO2 (kgCO2)	**1440**	1428	12				0.83		
Case 3	**Energy (kWh/year)**	**6632.9**	6616.6	16.3	2.82	951.00	337.64	0.25	Uninsulated roof	Introduce insulation in roof
	CO2 (kgCO2)	**1437**	1434	3				0.21		
Case 4	**Energy (kWh/year)**	**4522.5**	4441.7	80.8	13.96	1175.00	84.16	1.79	Uninsulated roof	Introduce insulation in roof
	CO2 (kgCO2)	**1013**	994	19				1.88		
Case 5	**Energy (kWh/year)**	**8495.3**					na	0.00	na	na
	CO2 (kgCO2)	**1863**						0.00		
Case 6	**Energy (kWh/year)**	**6178.3**					na	0.00	na	na
	CO2 (kgCO2)	**1360**						0.00		
Case 7	**Energy (kWh/year)**	**2948.1**					na	0.00	na	na
	CO2 (kgCO2)	**650**						0.00		
Case 8	**Energy (kWh/year)**	**4433.7**	4074.3	359.4	62.10	1348.00	21.71	8.11	Uninsulated roof	Introduce insulation in roof
	CO2 (kgCO2)	**988**	906	82				8.30		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00		na	0.00	Uninsulated roof	Introduce insulation in roof
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**					na	0.00	na	na
	CO2 (kgCO2)	**555**						0.00		

Design Scenario 9

		Baseline	Scenario 9	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	669.80	12920.52	0.01	uninsulated exterior walls	50mm EPS in back and party walls
	CO2 (kgCO2)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6273.9	138.7	23.97	561.00	23.41	2.16	uninsulated exterior walls	50mm EPS in party walls
	CO2 (kgCO2)	**1440**	1408	32				2.22		
Case 3	**Energy (kWh/year)**	**6632.9**	6596.5	36.4	6.29	7191.00	1143.26	0.55	uninsulated exterior walls	50mm EPS in party walls
	CO2 (kgCO2)	**1437**	1429	8				0.56		
Case 4	**Energy (kWh/year)**	**4522.5**	4099.8	422.7	73.04	5546.00	75.93	9.35	uninsulated exterior walls	50mm EPS in exterior walls
	CO2 (kgCO2)	**1013**	916	97				9.58		
Case 5	**Energy (kWh/year)**	**8495.3**					na	0.00	no exterior party walls	na
	CO2 (kgCO2)	**1863**						0.00		
Case 6	**Energy (kWh/year)**	**6178.3**					na	0.00	no exterior party walls	na
	CO2 (kgCO2)	**1360**						0.00		
Case 7	**Energy (kWh/year)**	**2948.1**					na	0.00	no exterior party walls	na
	CO2 (kgCO2)	**650**						0.00		
Case 8	**Energy (kWh/year)**	**4433.7**					na	0.00	no exterior party walls	na
	CO2 (kgCO2)	**988**						0.00		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	1908.00	na	0.00	uninsulated exterior walls	50mm EPS in party walls
	CO2 (kgCO2)	**684**	684	0	0.00			0.00		
Case 10	**Energy (kWh/year)**	**2427.1**					na	0.00	no exterior party walls	na
	CO2 (kgCO2)	**555**						0.00		

Design Scenario 10

		Baseline	Scenario 10	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5177.3	0.3	0.05	1090.60	21037.81	0.01	uninsulated exterior wall	25mm EPS in main facade + 50mm EPS in back and party walls
	CO_2 ($kgCO_2$)	**1131**	1131	0				0.00		
Case 2	**Energy (kWh/year)**	**6412.6**	6091	321.6	55.57	2729.00	49.11	5.02	uninsulated exterior wall	25mm EPS in facades + 50mm EPS in party walls
	CO_2 ($kgCO_2$)	**1440**	1366	74				5.14		
Case 3	**Energy (kWh/year)**	**6632.9**	6596.6	36.3	6.27	7845.00	1250.67	0.55	uninsulated exterior wall	25mm EPS in facades + 50mm EPS in party walls
	CO_2 ($kgCO_2$)	**1437**	1429	8				0.56		
Case 4	**Energy (kWh/year)**	**4522.5**	4099.8	422.7	73.04	5546.00	75.93	9.35	uninsulated exterior wall	50mm EPS in exterior walls (same as simulation 9)
	CO_2 ($kgCO_2$)	**1013**	916	97				9.58		
Case 5	**Energy (kWh/year)**	**8495.3**	8490.5	4.8	0.83	571.00	688.42	0.06	uninsulated exterior wall	25mm EPS in main facade
	CO_2 ($kgCO_2$)	**1863**	1862	1				0.05		
Case 6	**Energy (kWh/year)**	**6178.3**	6170.9	7.4	1.28	506.00	395.71	0.12	uninsulated exterior wall	25mm EPS in back facade
	CO_2 ($kgCO_2$)	**1360**	1358	2				0.15		
Case 7	**Energy (kWh/year)**	**2948.1**	2927.5	20.6	3.56	2381.00	668.88	0.70	uninsulated exterior wall	25mm EPS in facades
	CO_2 ($kgCO_2$)	**650**	645	5				0.77		
Case 8	**Energy (kWh/year)**	**4433.7**	4295.3	138.4	23.92	4347.00	181.76	3.12	uninsulated exterior wall	25mm EPS in facades
	CO_2 ($kgCO_2$)	**988**	957	31				3.14		
Case 9	**Energy (kWh/year)**	**3229**	3229	0	0.00	3986.00	na	0.00	uninsulated exterior walls	25mm EPS in facades + 50mm EPS in party walls
	CO_2 ($kgCO_2$)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0	0.00	3715.00	na	0.00	uninsulated exterior wall	25mm EPS in facades
	CO_2 ($kgCO_2$)	**555**	555	0				0.00		

Design Scenarios 1, 4 and 5

		Baseline	Scenarios 1 4 5	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	4925.9	251.7	43.49	174.44	4.01	4.86	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1131**	1073	58				5.13		
Case 2	**Energy (kWh/year)**	**6412.6**	5774.1	638.5	110.33	122.24	1.11	9.96	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1440**	1294	146				10.14		
Case 3	**Energy (kWh/year)**	**6632.9**	6108.9	524	90.55	168.99	1.87	7.90	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1437**	1318	119				8.28		
Case 4	**Energy (kWh/year)**	**4522.5**	4211.1	311.4	53.81	118.55	2.20	6.89	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1013**	942	71				7.01		
Case 5	**Energy (kWh/year)**	**8495.3**	7847	648.3	112.03	128.00	1.14	7.63	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1863**	1715	148				7.94		
Case 6	**Energy (kWh/year)**	**6178.3**	5971.8	206.5	35.68	181.85	5.10	3.34	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**1360**	1313	47				3.46		
Case 7	**Energy (kWh/year)**	**2948.1**	2884.5	63.6	10.99	52.09	4.74	2.16	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**650**	635	15				2.31		
Case 8	**Energy (kWh/year)**	**4433.7**	4479.4	-45.7	-7.90	311.73	-39.47	-1.03	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**988**	999	-11				-1.11		
Case 9	**Energy (kWh/year)**	**3229**	3362.8	-133.8	-23.12	98.59	-4.26	-4.14	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**684**	715	-31				-4.53		
Case 10	**Energy (kWh/year)**	**2427.1**	2301.8	125.3	21.65	61.28	2.83	5.16	baseline	Conjunction of scenarios 1, 4 and 5
	CO2 (kgCO2)	**555**	526	29				5.23		

Design Scenarios 1, 4, 5 and 3

		Baseline	Scenarios 1 4 5 3	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	4925.9	251.7	43.49	248.29	5.71	4.86	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**1131**	1073	58				5.13		
Case 2	**Energy (kWh/year)**	**6412.6**	5702.7	709.9	122.67	2027.24	16.53	11.07	Baseline	Conjunction of scenarios 1, 4, 5 and 3b
	CO2 (kgCO2)	**1440**	1277	163				11.32		
Case 3	**Energy (kWh/year)**	**6632.9**	6077	555.9	96.06	2447.99	25.48	8.38	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**1437**	1310	127				8.84		
Case 4	**Energy (kWh/year)**	**4522.5**	4157.3	365.2	63.11	1603.55	25.41	8.08	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**1013**	929	84				8.29		
Case 5	**Energy (kWh/year)**	**8495.3**	7850.1	645.2	111.49	128.00	1.15	7.59	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**1863**	1716	147				7.89		
Case 6	**Energy (kWh/year)**	**6178.3**	5968.2	210.1	36.31	181.85	5.01	3.40	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**1360**	1312	48				3.53		
Case 7	**Energy (kWh/year)**	**2948.1**	2881.6	66.5	11.49	719.09	62.58	2.26	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**650**	635	15				2.31		
Case 8	**Energy (kWh/year)**	**4433.7**	4479.4	-45.7	-7.90	1849.73	-234.23	-1.03	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**988**	999	-11				-1.11		
Case 9	**Energy (kWh/year)**	**3229**	3362.8	-133.8	-23.12	2311.99	-100.00	-4.14	Baseline	Conjunction of scenarios 1, 4, 5 and 3
	CO2 (kgCO2)	**684**	715	-31				-4.53		
Case 10	**Energy (kWh/year)**	**2427.1**	2301.8	125.3	21.65	270.18	12.48	5.16	Baseline	Conjunction of scenarios 1, 4, 5 and 3b
	CO2 (kgCO2)	**555**	526	29				5.23		

Design Scenario Solar DHW

		Baseline	Scenario Solar Thermal	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	4804.6	373	64.45	4147.30	64.34	7.20	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1131**	1046	85				7.52		
Case 2	**Energy (kWh/year)**	**6412.6**	5679.6	733	126.66	4147.30	32.74	11.43	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1440**	1271	169				11.74		
Case 3	**Energy (kWh/year)**	**6632.9**	6014	618.9	106.95	4147.30	38.78	9.33	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1437**	1296	141				9.81		
Case 4	**Energy (kWh/year)**	**4522.5**	4063.4	459.1	79.33	4147.30	52.28	10.15	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1013**	908	105				10.37		
Case 5	**Energy (kWh/year)**	**8495.3**	7759.9	735.4	127.08	4147.30	32.64	8.66	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1863**	1695	168				9.02		
Case 6	**Energy (kWh/year)**	**6178.3**	5939.9	238.4	41.20	4147.30	100.67	3.86	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**1360**	1305	55				4.04		
Case 7	**Energy (kWh/year)**	**2948.1**	2860.6	87.5	15.12	4147.30	274.29	2.97	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**650**	630	20				3.08		
Case 8	**Energy (kWh/year)**	**4433.7**	4491.5	-57.8	-9.99	4147.30	-415.23	-1.30	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**988**	1002	-14				-1.42		
Case 9	**Energy (kWh/year)**	**3229**	3241.6	-12.6	-2.18	4147.30	-1904.81	-0.39	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**684**	687	-3				-0.44		
Case 10	**Energy (kWh/year)**	**2427.1**	2188	239.1	41.32	4147.30	100.38	9.85	Baseline	Introduction of solar thermal DHW
	CO2 (kgCO2)	**555**	500	55				9.91		

Design Scenarios Solar DHW and 4

		Baseline	Scenario Solar Thermal and 4	gain	Saving (€)	Measure cost (€)	Payback (years)	saving %	existing	simulated
Case 1	Energy (kWh/year)	**5177.6**	4728.5	449.1	77.60	4147.30	53.44	8.67	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1131**	1028	103				9.11		
Case 2	Energy (kWh/year)	**6412.6**	5513.7	898.9	155.33	4147.30	26.70	14.02	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1440**	1234	206				14.31		
Case 3	Energy (kWh/year)	**6632.9**	5870.5	762.4	131.74	4147.30	31.48	11.49	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1437**	1263	174				12.11		
Case 4	Energy (kWh/year)	**4522.5**	4007.2	515.3	89.04	4147.30	46.58	11.39	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1013**	895	118				11.65		
Case 5	Energy (kWh/year)	**8495.3**	7594.4	900.9	155.68	4147.30	26.64	10.60	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1863**	1657	206				11.06		
Case 6	Energy (kWh/year)	**6178.3**	5894.2	284.1	49.09	4147.30	84.48	4.60	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**1360**	1295	65				4.78		
Case 7	Energy (kWh/year)	**2948.1**	2839.5	108.6	18.77	4147.30	221.00	3.68	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**650**	625	25				3.85		
Case 8	Energy (kWh/year)	**4433.7**	4488.1	-54.4	-9.40	4147.30	-441.19	-1.23	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**988**	1001	-13				-1.32		
Case 9	Energy (kWh/year)	**3229**	3234	-5	-0.86	4147.30	-4800.12	-0.15	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**684**	685	-1				-0.15		
Case 10	Energy (kWh/year)	**2427.1**	2159.1	268	46.31	4147.30	89.55	11.04	Baseline	Introduction of solar thermal DHW with scenario 4
	CO2 (kgCO2)	**555**	494	61				10.99		

Design Scenario Future Weather 2080

		Baseline	Scenario Future Weather 2080	gain	Saving (€)	Measure cost (€)	Payback (years)	**saving %**	existing	simulated
Case 1	**Energy (kWh/year)**	**5177.6**	5088	89.6				1.73	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1131**	1111	20				1.77		
Case 2	**Energy (kWh/year)**	**6412.6**	6062.9	349.7				5.45	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1440**	1360	80				5.56		
Case 3	**Energy (kWh/year)**	**6632.9**	6506.4	126.5				1.91	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1437**	1409	28				1.95		
Case 4	**Energy (kWh/year)**	**4522.5**	4136.3	386.2				8.54	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1013**	925	88				8.69		
Case 5	**Energy (kWh/year)**	**8495.3**	8481.1	14.2				0.17	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1863**	1860	3				0.16		
Case 6	**Energy (kWh/year)**	**6178.3**	6098	80.3				1.30	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**1360**	1341	19				1.40		
Case 7	**Energy (kWh/year)**	**2948.1**	2794.2	153.9				5.22	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**650**	615	35				5.38		
Case 8	**Energy (kWh/year)**	**4433.7**	3557.1	876.6				19.77	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**988**	788	200				20.24		
Case 9	**Energy (kWh/year)**	**3229**	3231	-2				-0.06	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**684**	684	0				0.00		
Case 10	**Energy (kWh/year)**	**2427.1**	2427.1	0				0.00	Baseline	Future weather 2080 simulation
	CO2 (kgCO2)	**555**	555	0				0.00		

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Equipment	model	brand	Power (Kw)	Equipment	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR20010	Hall	lighting	3 halogen lamps			0.1050	CFL	0.0330	1 hour/day	365	38.33	12.05	ERSE (35W); Topten equals CFL 11W
FLR20024	Corridor	lighting	1 compact fluorescent lamp			0.0110	same		0.5 hours/day	182.5	2.01	2.01	ERSE (11w); efficient
FLR20024	Corridor	appliance	1 Washing machine	J853	Samsung	2.0000	Topten		2 washes (1.5hx2)/week	156	312.00	137.00	ERSE (2000w) - ver net; Topten efficient appliance - 137kWh
FLR20018	Living Room	lighting	1 compact fluorescent lamp			0.0110	same		4 hours/day	1460	16.06	16.06	ERSE (11w); efficient
FLR20018	Living Room	entertainment	1 TV		Philips	0.0900	TV (Topten)	0.0300	3 hours/day	1095	98.55	32.85	ERSE (90w); Topten efficient appliance - 30W
FLR20018	Living Room	entertainment	1 TV in standby		Philips	0.0025	no standby		21 hours/day	7665	18.86	0.00	Deco Proteste Internet simulator
FLR20018	Living Room	entertainment	1 DVD player			0.2400	Topten	0.0350	0.5 hours/day	182.5	43.80	6.39	ERSE (240w); Topten 35W
FLR20018	Living Room	entertainment	1 DVD player in standby			0.0014	no standby		23.5 hours day	8577.5	11.84	0.00	Deco Proteste Internet simulator
FLR20019	Bedroom 3	lighting	1 compact fluorescent lamp			0.0110	same		0.5 hours/day	182.5	2.01	2.01	ERSE (11w); efficient
FLR20013	Bedroom 2	lighting	1 compact fluorescent lamp			0.0110	same		1 hour/day	365	4.02	4.02	ERSE (11w); efficient
FLR20013	Bedroom 2	entertainment	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w); Topten efficient appliance - 30W
FLR20013	Bedroom 2	entertainment	1 TV in standby			0.0025	no standby		23 hours/day	8395	20.66	0.00	Deco Proteste Internet simulator
FLR20013	Bedroom 2	entertainment	1 Desktop computer			0.3000	same		1 hour/day	365	109.50	109.50	ERSE (300w); no information
FLR20009	Bedroom 1	lighting	3 halogen lamps			0.1050	CFL	0.0330	2 hours/day	730	76.65	24.09	ERSE (35w); Topten equal CFL 11W
FLR20025	Kitchen	lighting	2 compact fluorescent lamps			0.0220	same		3 hours/day	1095	24.09	24.09	ERSE (11w); efficient
FLR20025	Kitchen	appliance	1 Dish washer	ZDF211	Zanuzzi	2.0000	efficient		1.5 hours/week	78	156.00	156.00	ERSE (2000w) - ver net; efficient
FLR20025	Kitchen	appliance	1 fridge / freezer	Class A	Whirlpool	0.0392	efficient		On continuously	8760	343.39	343.39	model WTE 3111 W (internet manual) - 0.94w/day; efficient
FLR20025	Kitchen	appliance	1 Microwave	CRS	Worten	0.9000	same		0.5 hours/day	182.5	164.25	165.25	ERSE (900w); no information
FLR20025	Kitchen	appliance	1 Microwave in standby	CRS	Worten	0.0043	same		23.5 hours day	8577.5	37.28	37.28	Deco Proteste Internet simulator; not viable
FLR20025	Kitchen	appliance	1 Electric frying pan	DF 30AW	Electric	2.0000	same		1 hour /week	52	104.00	104.00	in situ; no information
FLR20025	Kitchen	appliance	1 Iron			1.6000	same		4 hours /week	208	332.80	332.80	ERSE (1600w); no information
FLR20025	Kitchen	entertainment	1 TV	Trinitron	Sony	0.0900	TV (Topten)	0.0300	3 hours /day	1095	98.55	32.85	ERSE (90w)
FLR20025	Kitchen	entertainment	1 TV in stand-by	Trinitron	Sony	0.0025	no standby		21 hours/day	7665	18.86	0.00	Deco Proteste Internet simulator
FLR20025	Kitchen	environment	1 Electric hot water cylinder	75 RI	Aparici	2.0000	same		On continuously	8760	448.95	448.95	AKI - 1.23kWh/Day; no information
FLR20004	WC	lighting	1 fluorescent lamp			0.0360	same		2 hours/day	730	26.28	26.28	ERSE (36w); efficient
										TOTAL Electricity	**2541.57**	**2027.81**	**less 20.21%**
										EDP (kWh/Year)	3641.00		
FLR20025	Kitchen	appliance	1 Gas stove/oven						1 bottle (13 Kg) /month	156 Kg/Year	2137.20		Households / 13.7 kWh per Kg

IES VE code	Room	Category	Equipment	model	brand	Baseline Power (Kw)	Simulation Equipment	Simulation Power (Kw)	Operation profile assumed (average usage hours)	Hours per year (52 weeks, 365 days)	Baseline Kwh/year	Simulation Kwh/year	Source
FLR50016	Bedroom Hall	lighting	1 lamp			0.0600	CFL	0.0110	0.5 hours/day	182.5	10.95	2.01	ERSE (60w); Topten equals CFL 11W
FLR50004	Stairs hall	lighting	2 compact fluorescent lamps			0.0220	same		3 hours/day	1095	24.09	24.09	ERSE (11w); efficient
FLR50015	Living room	lighting	3 halogen lamps			0.1050	CFL	0.0330	3 hours/day	1095	114.98	36.14	ERSE (35w)
FLR50015	Living room	entertainment	1 TV		Tecnimagem	0.0900	TV (Topten)	0.0300	3 hours/day	1095	98.55	32.85	ERSE (90w); Topten 30W
FLR50015	Living room	entertainment	1 TV in standby		Tecnimagem	0.0025	no standby		21 hours/day	7665	18.86	0.00	Deco Proteste Internet simulator
FLR50015	Living room	entertainment	1 Cable TV box decoder		Meo Box	0.0162	same		3 hours/day	1095	17.74	17.74	EDP (8w) / **Quercus (16.2w); no information**
FLR50015	Living room	entertainment	1 Cable TV box decoder in standby		Meo Box	0.0094	no standby		21 hours/day	7665	72.05	0.00	Quercus (9.4w)
FLR50023	Bedroom 1	lighting	3 halogen lamps			0.1050	CFL	0.0330	1.5 hours/day	547.5	57.49	18.07	ERSE (35w); Topten equals CFL 11W
FLR50023	Bedroom 1	lighting	2 lamps (table lamps)			0.0800	CFL	0.0160	1.5 hours/day	547.5	43.80	8.76	ERSE (40w); Philipls equal 8W
FLR50023	Bedroom 1	entertainment	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w); Topten 30W
FLR50023	Bedroom 1	entertainment	1 TV in stand-by			0.0025	no standby		23 hours/day	8395	20.66	0.00	Deco Proteste Internet simulator
FLR50023	Bedroom 1	entertainment	1 DVD Player		Nustic or Mustic ?	0.2400	Topten	0.0350	0.5 hours/day	182.5	43.80	6.39	ERSE (240w); Topten
FLR50023	Bedroom 1	entertainment	1 DVD Player in standby			0.0014	no standby		23.5 hours/day	8577.5	12.01	0.00	Deco Proteste Internet simulator
FLR50023	Bedroom 1	entertainment	1 Cable TV box decoder		Meo Box	0.0162	same		1 hour/day	365	5.91	5.91	EDP (8w) / Quercus (16.2w); no information
FLR50023	Bedroom 1	entertainment	1 Cable TV box decoder in standby		Meo Box	0.0094	no standby		23 hours/day	8395	78.91	0.00	Quercus (9.4w)
FLR50023	Bedroom 1	environment	1 Electric Fan			0.1000			all night in summer		0.00		LG (100w)
FLR50024	Bedroom 2	lighting	3 halogen lamps			0.1050	CFL	0.0330	1.5 hours/day	547.5	57.49	18.07	ERSE (35w); Topten equals CFL 11W
FLR50020	Kitchen	lighting	1 fluorescent lamp			0.0580	same		4 hours/day	1460	84.68	84.68	ERSE (58w); efficient
FLR50020	Kitchen	lighting	1 compact fluorescent lamp			0.0110	same		2 hours/day	730	8.03	8.03	ERSE (11w); efficient
FLR50020	Kitchen	appliance	1 Washing machine	HE605 TX	Haier	1.9500	Topten		1.5 hours/day	547.5	416.10	137.00	1 washing/day. Manual in internet; Topten - 137kWh/year
FLR50020	Kitchen	appliance	1 fridge	Predilect	Fagor	0.1500	same		On continuously	8760	223.00	223.00	ERSE (150w) Topten (223 kWh/year); efficient
FLR50020	Kitchen	appliance	1 freezer		Ariston	0.2500	Topten		On continuously	8760	296.00	190.00	ERSE (250w) Topten (296 kWh/year)
FLR50020	Kitchen	appliance	1 Microwave			0.9000	same		0.5 hours/day	182.5	164.25	164.25	ERSE (900w); no information
FLR50020	Kitchen	appliance	1 Microwave in standby			0.0043	same		23.5 hours/day	8577.5	36.88	36.88	Deco Proteste Internet simulator; not viable
FLR50020	Kitchen	appliance	1 Iron			1.6000	same		0.5 hour/day	182.5	292.00	292.00	ERSE (1600w); no information
FLR50020	Kitchen	appliance	1 Extractor hood		Airlux	0.1400	same		2 hours/day	730	102.20	102.20	ERSE (140w); no information
FLR50020	Kitchen	appliance	1 Toaster			1.0000	same		0.25 hours/day	91.25	91.25	91.25	ERSE (1000w); no information
FLR50020	Kitchen	environment	electric hot water cylinder		Spersil	1.0000	same		On continuously	8760	321.20	321.20	50 l - in situ; AKI - 0.88kWh/Day; no information
FLR50032	WC	lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR50019	Storage	lighting	1 lamp			0.0600	CFL	0.0110	0.25 hours/day	91.25	5.48	1.00	ERSE (60w); Topten equals CFL 11W
FLR60034	Bedroom 3 (Floor 6)	lighting	3 halogen lamps			0.1050	CFL	0.0330	1.5 hours/day	547.5	57.49	18.07	ERSE (35w); Topten equals CFL 11W
FLR60034	Bedroom 3 (Floor 6)	entertainment	1 TV			0.0900	TV (Topten)	0.0300	1.5 hours/day	547.5	49.28	16.43	ERSE (90w); Topten 30W
FLR60034	Bedroom 3 (Floor 6)	entertainment	1 TV in standby			0.0025	no standby		22.5 hours/day	8212.5	20.21	0.00	Deco Proteste Internet simulator
FLR60034	Bedroom 3 (Floor 6)	entertainment	1 DVD Player			0.2400	Topten	0.0350	1 hour/day	365	87.60	12.78	ERSE (240w); Topten 35W
FLR60034	Bedroom 3 (Floor 6)	entertainment	1 DVD Player in stand-by			0.0014	no standby		23 hours/day	8395	11.75	0.00	Deco Proteste Internet simulator
FLR60034	Bedroom 3 (Floor 6)	environment	1 Electric oil-filled radiator heater			2.0000			1 h when cold (less 19)		0.00		ERSE (2000w)
FLR60039	Storage (Floor 6)	lighting	3 halogen lamps			0.1050	CFL	0.0330	0.125 hours/day	45.625	4.79	1.51	ERSE (35w); Topten equals CFL 11W
										TOTAL	**3004.21**	**1885.25**	**less 37.25%**
										EDP (kWh/Year)	5978.26		
FLR50020	Kitchen	appliance	1 Gas stove/oven						0.5 bottles (13kg)/month	78 kg/year	1068.60		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR40064	Stairs	Lighting	2 compact fluorescent lamps			0.0220	same		0.5 hours/day	182.5	4.02	4.02	ERSE (11w); efficient
FLR40064	Stairs	Lighting	1 lamp			0.0400	CFL	0.0080	0.5 hours/day	182.5	7.30	1.46	ERSE (40w), Philips equals 8W
FLR40037	Corridor 1	Lighting	1 compact fluorescent lamp			0.0110	same		0.5 hours/day	182.5	2.01	2.01	ERSE (11w); efficient
FLR40009	Corridor 2	Lighting	1 compact fluorescent lamp			0.0110	same		0.5 hours/day	182.5	2.01	2.01	ERSE (11w); efficient
FLR40088	Corridor 3	Lighting	1 lamp			0.0400	CFL	0.0080	0.5 hours/day	182.5	7.30	1.46	ERSE (40w), Philips equals 8W
FLR40022	Livingroom 1	Lighting	5 lamps			0.2000	CFL	0.0400	2 hours/day	730	146.00	29.20	ERSE (40w), Philips equals 8W
FLR40022	Livingroom 1	Entertainment	1 Hi-Fi			0.0600	same		0.125 hours/day	45.625	2.74	2.74	ERSE (60w); no information
FLR40022	Livingroom 1	Entertainment	1 HI-Fi standby			0.0010	no standby		23.875 hours/day	8714.375	8.76	0.00	Deco Proteste Internet simulator
FLR40008	Living Room	Lighting	2 compact fluorescent lamps			0.0220	same		2 hours/day	730	16.06	16.06	ERSE (11w); efficient
FLR40008	Living Room	Entertainment	1 Plasma TV			0.3000	LCD	0.0240	2 hours/day	730	219.00	17.52	ERSE (300w), Topten 24W
FLR40008	Living Room	Entertainment	1 Plasma TV in standby			0.0009	no standby		22 hours/day	8030	7.55	0.00	SELINA
FLR40091	Bedroom 1	Lighting	2 lamps			0.0800	CFL	0.0160	1 hour/day	365	29.20	5.84	ERSE (40w), Philips equals 8W
FLR40091	Bedroom 1	Entertainment	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w); Topten 30W
FLR40091	Bedroom 1	Entertainment	1 TV in standby			0.0025	no standby		23 hours/day	8395	20.99	0.00	Deco Proteste Internet simulator
FLR40091	Bedroom 1	Environment	1 Electric oil-filled radiator heater			2.0000			1h/day with cold (less 19)		0.00		
FLR40092	Bedroom2	Lighting	4 lamps			0.1600	CFL	0.0320	2 hours/day	730	116.80	23.36	ERSE (40w), Philips equals 8W
FLR40092	Bedroom2	Entertainment	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w)
FLR40092	Bedroom2	Entertainment	1 TV in standby			0.0025	no standby		23 hours/day	8395	20.99	0.00	Deco Proteste Internet simulator
FLR40041	Kitchen	Lighting	2 fluorescent lamps			0.0720	same		3 hours/day	1095	78.84	78.84	ERSE (36w); efficient
FLR40041	Kitchen	Appliance	1 Microwave		Taurus	0.8000	same		0.25 hours/day	91.25	73.00	73.00	in situ; no information
FLR40041	Kitchen	Appliance	1 Microwave in standby		Taurus	0.0043	same		23.75 hours/day	8668.75	37.28	37.28	Deco Proteste Internet simulator; not viable
FLR40041	Kitchen	Appliance	1 Fridge / freezer		Balay	0.3000	Topten		On continuously	8760	293.00	219.00	ERSE (300w) Balay internet (293KWh/year)
FLR40041	Kitchen	Appliance	1 Extractor hood			0.1400	same		1 hour/day	365	51.10	51.10	ERSE (140w); no information
FLR40041	Kitchen	Appliance	1 Washing machine	Maxx 7	Bosch	1.1900	Topten		2/3 washes week (2.58 hours each)	335.4	399.13	173.00	Catalog internet
FLR40041	Kitchen	Entertainment	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w)
FLR40041	Kitchen	Entertainment	1 TV in standby			0.0025	no standby		23 hours/day	8395	20.99	0.00	Deco Proteste Internet simulator
FLR40041	Kitchen	Environment	1 electric hot water cylinder		Spersil	1.0000	same		On continuously	8760	321.20	321.20	50 l in situ; AKI - 0.88kWh/Day; no information
FLR40038	WC	Lighting	1 compact fluorescent lamp			0.0110	same		1 hour/day	365	4.02	4.02	ERSE (11w); efficient
FLR40011	Storage	Lighting	1 lamp			0.0400	CFL	0.0080	0.25 hours/day	13	0.52	0.10	ERSE (40w), Philips equals 8W
FLR50021	Floor 5 Front Storage	Lighting	1 lamp			0.0400	CFL	0.0080	0.25 hours/week	13	0.52	0.10	ERSE (40w), Philips equals 8W
FLR50018	Floor 5 Back Storage	Lighting	1 lamp			0.0400	CFL	0.0080	0.25 hours/week	13	0.52	0.10	ERSE (40w), Philips equals 8W
										TOTAL	**1989.36**	**1096.28**	**less 44.89%**
										EDP (kWh/Year)	2950.27		
FLR40041	Kitchen	Appliance	1 Gas stove/oven						1.5 bottles/month	234 kg/year	3205.80		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR40045	Entrance Hall	Lighting	1 compact fluorescent lamp			0.011	same		1 hour /day	365	4.02	4.02	ERSE (11w); efficient
FLR40007	Bedroom Hall	Lighting	1 compact fluorescent lamp			0.011	same		0.25 hours/day	91.25	1.00	1.00	ERSE (11w); efficient
FLR40023	Living Room	Lighting	4 compact fluorescent lamps			0.044	same		4 hours/day	1460	64.24	64.24	ERSE (11w); efficient
FLR40023	Living Room	Entertainment	1 TV	HD TV Digital Plus	Samsung	0.058	same		3hours/day	1095	63.51	63.61	Samsung internet; efficient
FLR40023	Living Room	Entertainment	1 TV in standby	HD TV Digital Plus	Samsung	0.0003	no standby		21 hours/day	7665	2.30	0.00	Samsung internet
FLR40023	Living Room	Environment	1 electric resistance heater			1.5			with cold 3/4 electric resistences		0.00		ERSE (1500w) WC heater high
FLR40000	Bedroom 1	Lighting	3 compact fluorescent lamps			0.033	same		1 hour /day	365	12.05	12.05	ERSE (11w); efficient
FLR40048	Bedroom 2	Lighting	3 compact fluorescent lamps			0.033	same		1 hour /day	365	12.05	12.05	ERSE (11w); efficient
FLR40047	Bedroom 3	Lighting	3 compact fluorescent lamps			0.033	same		1 hour /day	365	12.05	12.05	ERSE (11w); efficient
FLR40003	Kitchen	Lighting	1 fluorescent lamp			0.058	same		10 hours/day	3650	211.70	211.70	ERSE (58w); efficient
FLR40003	Kitchen	Appliance	1 Washing machine	Fuzzy Logic 7Kg	LG	1.19	Topten		3 times/week (2 hours)	312	371.28	173.00	LG internet
FLR40003	Kitchen	Appliance	1 Dish washer	Top dispaner	Ocean	2	Topten		1 time /day (2 hours)	730	383.25	262.00	ERSE (2000w); TopTen (1.05 Kwh each wash)
FLR40003	Kitchen	Appliance	1 Fridge / freezer	Green Fresh	Balay	0.3	Topten		On continuously	8760	293.00	219.00	ERSE (300w) Balay internet (293KWh/year)
FLR40003	Kitchen	Appliance	1 Microwave	Techno Star		0.9	same		0.5 hours/day	182.5	164.25	164.25	ERSE (900w); no information
FLR40003	Kitchen	Appliance	1 Microwave in standby	Techno Star		0.0043	same		23.5 hours/day	8577.5	36.88	36.88	Deco Proteste Internet simulator; not viable
FLR40003	Kitchen	Appliance	1 Electric Oven			2.4	same		0.25 hours/day	91.25	219.00	219.00	ERSE (2400w); no information
FLR40003	Kitchen	Appliance	1 Extractor hood		Ocean	0.14	same		1 hour /day	365	51.10	51.10	ERSE (140w); no information
FLR40003	Kitchen	Entertainment	1 Mini-TV			0.09	TV (Topten)	0.0300	2 hours/day	730	65.70	21.90	ERSE (90w)
FLR40003	Kitchen	Entertainment	1 Mini-TV in standby			0.0025	no standby		22 hours/day	8030	20.08	0.00	Deco Proteste Internet simulator
FLR40003	Kitchen	Environment	1 electric hot water cylinder		Jucomel	1.5	same		allways on	8760	467.20	467.20	50 l in situ; AKI - 1.28kWh/Day; no information
FLR40002	WC	Lighting	1 compact fluorescent lamp			0.011	same		1.5 hours/day	547.5	6.02	6.02	ERSE (11w); efficient
FLR40019	Storage 1	Lighting	1 compact fluorescent lamp			0.011	same		0.25 hours/week	13	0.14	0.14	ERSE (11w); efficient
FLR40021	Storage 2	Lighting	1 compact fluorescent lamp			0.011	same		0.25 hours/week	13	0.14	0.14	ERSE (11w); efficient
										TOTAL	**2460.95**	**2001.35**	**less 18.68%**
										EDP (kWh/Year)	3896.90		
FLR40003	Kitchen	Appliance	1 Gas stove		Ocean				1 bottle/2.5 months (0.4/month)	62.4 kg/year	854.88		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours)	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
HALL0000	Hall	Lighting	3 lamps			0.12	CFL	0.0240	1.5 hours/day	547.5	65.70	13.14	ERSE (40w), Philips equals 8W
LVNG0000	Living Room	Lighting	7 lamps			0.28	CFL	0.0560	4 hours/day	1460	408.80	81.76	ERSE (40w), Philips equals 8W
LVNG0000	Living Room	Appliance	1 cordless telephone		Siemens	0.003	same		On continuously	8760	26.28	26.28	LG (3w); no information
LVNG0000	Living Room	Entertainement	1 TV		LG	0.09	TV (Topten)	0.0300	4 hours/day	1460	131.40	43.80	ERSE (90w)
LVNG0000	Living Room	Entertainement	1 TV in standby		LG	0.00523	no standby		20 hours/day	7300	38.18	0.00	SELINA (TV CRT 5.23w)
LVNG0000	Living Room	Entertainement	1 Cable TV box decoder		Meo Box	0.0162	same		4 hours/day	1460	23.65	23.65	Quercus (16.2w); no information
LVNG0000	Living Room	Entertainement	1 Cable TV box decoder in standby		Meo Box	0.0094	no standby		20 hours/day	7300	68.62	0.00	Quercus (9.4w)
LVNG0000	Living Room	Entertainement	1 Hi-Fi		Sanyo	0.06	same		0.5 hours / week	26	0.24	0.24	ERSE (60w); no informationh
LVNG0000	Living Room	Entertainement	1 Hi-Fi in standby		Sanyo	0.00205	no standby		167.96 hours/week	8734	17.90	0.00	SELINA (2.05w)
LVNG0000	Living Room	Environment	1 Electric oil-filled radiator heater			2			with cold always on in minimum		0.00		ERSE (2000w)
LVNG0000	Living Room	Environment	1 electric fan			0.1			with hot always on		0.00		LG (100w)
FLR20001	Bedroom	Lighting	1 lamp			0.06	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR20001	Bedroom	Lighting	1 compact fluorescent lamp			0.011	same		1 hour/day	365	4.02	4.02	ERSE (11w); efficient
FLR20001	Bedroom	Entertainement	1 TV			0.09	TV (Topten)	0.0300	0.5 hours / day	182.5	16.43	5.48	ERSE (90w)
FLR20001	Bedroom	Entertainement	1 TV in standby			0.00523	no standby		23.5 hours/day	8577.5	44.86	0.00	SELINA (TV CRT 5.23w)
BDRM0003	Bedroom 1	Lighting	1 lamp			0.06	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
BDRM0003	Bedroom 1	Entertainement	1 TV			0.09	TV (Topten)	0.0300	0.5 hours / day	182.5	16.43	5.48	ERSE (90w)
BDRM0003	Bedroom 1	Entertainement	1 TV in standby			0.00523	no standby		23.5 hours/day	8577.5	44.86	0.00	SELINA (TV CRT 5.23w)
KTCH0000	Kitchen	Lighting	1 fluorescent lamp			0.058	same		4 hours/day	1460	84.68	84.68	ERSE (58w); efficient
KTCH0000	Kitchen	Appliance	1 Washing machine	6 Kg	Samsung	2	Topten		1 wash / day (2 hours)	730	416.10	173.00	ERSE (2000w); Topten (1.14 kWh each cycle)
KTCH0000	Kitchen	Appliance	1 Fridge / freezer		Whirlpool	0.3	Topten		On continuously	8760	354.00	219.00	ERSE (300w); Topten (354 kWh/year)
KTCH0000	Kitchen	Appliance	1 Microwave		Silver	0.9	same		0.5 hours / day	182.5	164.25	164.25	ERSE (900w); no information
KTCH0000	Kitchen	Appliance	1 Microwave in standby		Silver	0.0043	same		23.5 hours/day	8577.5	36.88	36.88	Deco Proteste Internet simulator; not viable
KTCH0000	Kitchen	Appliance	1 Electric Oven	H + 610 ME	Teka	2.693	same		0.25 hours/day	91.25	245.74	245.74	site Teka (2693w) HE610; no information
KTCH0000	Kitchen	Appliance	1 Coffee machine			1.2	same		0.5 hours / day	182.5	219.00	219.00	EDP (1200w); no information
KTCH0000	Kitchen	Appliance	1 Extractor hood			0.14	same		allways off (not in use)	0	0.00	0.00	ERSE (140w)
KTCH0000	Kitchen	Appliance	1 Iron			1.6	same		2 hours /week	104	166.40	166.40	ERSE (1600w); no information
KTCH0000	Kitchen	Appliance	1 Vacuum cleaner			1.6	Topten	1	1 time / week (1.5 hous)	78	124.80	78.00	ERSE (1600w)
KTCH0000	Kitchen	Environment	1 electric hot water cylinder		Arierom	2	same		On continuously	8760	448.95	448.95	AKI - 1.23 kWh/Day; no information
WC__0000	WC	Lighting	1 lamp			0.06	CFL	0.0110	1.5 hours/day	547.5	32.85	6.02	ERSE (60w); Topten equals CFL 11W
WC__0000	WC	Lighting	1 Hair dryer			1.5	same		0.5 hours / day	182.5	273.75	273.75	ERSE (1500w); no information
STRG0000	Storage	Lighting	1 lamp			0.06	CFL	0.0110	0.25 hours/week	13	0.78	0.14	ERSE (60w); Topten equals CFL 11W
										TOTAL	**3519.35**	**2327.69**	**less 33.86%**
										EDP (kWh/Year)	5692.66		
KTCH0000	Kitchen	Appliance	1 Gas stove	H + 610 ME	Teka				1.5 bottles / month	234 kg/year	3205.80		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR20015	Bedroom Hall	Lighting	1 lamp			0.0400	CFL	0.0080	0.5 hours/day	182.5	7.30	1.46	ERSE (40w), Philips equals 8W
FLR20016	Living Room	Lighting	4 halogen lamps			0.1400	CFL	0.0440	3 hours/day	1095	153.30	48.18	ERSE (35W); Topten equals CFL 11W
FLR20016	Living Room	Lighting	2 lamps			0.1200	CFL	0.0220	0.5 hours/day	182.5	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR20016	Living Room	Entertainment	1 Hi-Fi		Sony	0.0600	same		1 hour/week	52	3.12	3.12	ERSE (60w); no information
FLR20016	Living Room	Entertainment	1 Hi-Fi in standby		Sony	0.0021	no standby		167.46 hours/week	8708	17.85	0.00	SELINA (2.05w)
FLR20016	Living Room	Entertainment	1 Plasma TV	HD SRS	Samsung	0.3500	LCD	0.0240	4 hours/day	1460	511.00	35.04	Samsung internet (350w), Topten 24W
FLR20016	Living Room	Entertainment	1 Plasma TV in standby	HD SRS	Samsung	0.0003	no standby		20 hours/day	7300	2.19	0.00	Samsung internet (0.3w)
FLR20016	Living Room	Entertainment	1 Cable TV box decoder	HD - DSR 7151	Zon - Pace	0.0090	same		4 hours/day	1460	13.14	13.14	Quercus (9w); no information
FLR20016	Living Room	Entertainment	1 Cable TV box decoder in standby	HD - DSR 7151	Zon - Pace	0.0083	no standby		20 hours/day	7300	60.59	0.00	Quercus (8.3w)
FLR20016	Living Room	Entertainment	1 DVD Player		Mitsai	0.2400	Topten	0.0350	1 hour/day	365	87.60	12.78	ERSE (240w); Topten 35W
FLR20016	Living Room	Entertainment	1 DVD Player in standby		Mitsai	0.0014	no standby		23 hours/day	8395	11.75	0.00	Deco Proteste Internet simulator
FLR20014	Bedroom 1	Lighting	3 lamps			0.1200	CFL	0.0240	1 hour/day	365	43.80	8.76	ERSE (40w), Philips equals 8W
FLR20014	Bedroom 1	Lighting	2 lamps (side bed)			0.0800	CFL	0.0160	1 hour/day	365	29.20	5.84	ERSE (40w), Philips equals 8W
FLR20014	Bedroom 1	Entertainment	1 Plasma TV	HD SRS	Samsung	0.3500	LCD	0.0240	3 hours/day	1095	383.25	26.28	Samsung internet (350w), Topten 24W
FLR20014	Bedroom 1	Entertainment	1 Plasma TV in standby	HD SRS	Samsung	0.0003	no standby		21 hours/day	7665	2.30	0.00	Samsung internet (0.3w)
FLR20014	Bedroom 1	Environment	1 electric fan heater			2.0000			1 hour/day when cold		0.00		ERSE (200w)
FLR20014	Bedroom 1	Environment	1 electric fan			0.1000			1 hour/day when hot		0.00		LG (100w)
FLR20013	Bedroom 2	Lighting	3 lamps			0.1200	CFL	0.0240	1 hour/day	365	43.80	8.76	ERSE (40w), Philips equals 8W
FLR20013	Bedroom 2	Lighting	2 lamps (side bed)			0.0800	CFL	0.0160	1 hour/day	365	29.20	5.84	ERSE (40w), Philips equals 8W
FLR20013	Bedroom 2	Entertainment	1 TV	14''	Beko	0.0300	same		0.5 hours/day	182.5	5.48	5.48	Beko Manual (30w); already efficient
FLR20013	Bedroom 2	Entertainment	1 TV in standby	14''	Beko	0.0040	no standby		23.5 hours/day	8577.5	34.31	0.00	Beko Manual (4w)
FLR20013	Bedroom 2	Entertainment	1 DVD Player		Samsung	0.2400	Topten	0.0350	0.5 hours/day	182.5	43.80	6.39	ERSE (240w); Topten 35W
FLR20013	Bedroom 2	Entertainment	1 DVD Player in standby		Samsung	0.0014	no standby		23.5 hours/day	8577.5	12.01	0.00	Deco Proteste Internet simulator
KTCH0003	Kitchen	Lighting	2 Fluorescent lamps			0.0720	same		4 hours/day	1460	105.12	105.12	ERSE (36w); efficient
KTCH0003	Kitchen	Appliance	1 Washing machine	AWO / D8409	Whirlpool	2.0000	Topten		3 times/week (1.5 hours)	234	212.16	173.00	ERSE (2000w); Manual (1.36 kWh each washing cycle); Toptten 173kWh/year
KTCH0003	Kitchen	Appliance	1 Microwave	MW2717	Fairline	0.7000	same		0.25 hours/day	91.25	63.88	63.88	Internet (max 700w); no information
KTCH0003	Kitchen	Appliance	1 Microwave in standby	MW2717	Fairline	0.0043	same		23.75 hours/day	8668.75	37.28	37.28	Deco Proteste Internet simulator; not viable
KTCH0003	Kitchen	Appliance	1 Fridge / freezer		no brand identificable	0.0255	same		On continuously	8760	223.00	223.00	Top ten (223 hWh/year); efficient
KTCH0003	Kitchen	Appliance	1 Electric Oven	Princess	Milano	0.7000	same		0.5 hours/day	182.5	127.75	127.75	in situ; no information
KTCH0003	Kitchen	Appliance	1 Extractor hood		Arjero	0.1050	same		when cooking (2hours/day)	730	76.65	76.65	nominal power 105 W; no information
KTCH0003	Kitchen	Appliance	1 Iron			1.6000	same		2 times/week (1.5 hours)	156	249.60	249.60	ERSE (1600w); no information
KTCH0003	Kitchen	Entertainment	1 Plasma TV	small	Samsung	0.2300	LCD	0.0240	4 hours/day	1460	335.80	35.04	Samsung internet (230w); Topten 24W
KTCH0003	Kitchen	Entertainment	1 Plasma TV in standby	small	Samsung	0.0010	no standby		20 hours/day	7300	7.30	0.00	Samsung internet (1w)
KTCH0004	Kitchen - Laundry	Lighting	1 Lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
KTCH0004	Kitchen - Laundry	Appliance	1 Freezer	HC150	Tensai	0.0292	Topten		On continuously	8760	256.00	145.00	Tensai internet (256 kWh/year); Topten 145 kWh/year
KTCH0004	Kitchen - Laundry	Environment	1 electric hot water cylinder			1.5000	same		On continuously	8760	321.20	321.20	in situ; AKI - 0.88 kWh/Day (50l, 1200w); no information
WC__0001	WC	Lighting	1 lamp			0.0600	CFL	0.0110	1.5 hours/day	547.5	32.85	6.02	ERSE (60w); Topten equals CFL 11W
										TOTAL	**3587.37**	**1752.64**	**less 51.14%**
										EDP (kWh/Year)	4139.04		
KTCH0003	Kitchen	Appliance	1 Gas stove	Princess	Milano				1 bottle/month	156 kg/year	2137.20		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR10012	Livingroom	Lighting	3 lamps			0.1200	CFL	0.0240	4 hours/day	1460	175.20	35.04	ERSE (40w), Philips equals 8W
FLR10012	Livingroom	Entertainment	1 TV	old model	Panasonic	0.0900	TV (Topten)	0.0300	8 hours/day	2920	262.80	87.60	ERSE (90w)
FLR10012	Livingroom	Entertainment	1 TV in standby	old model	Panasonic	0.00523	no standby	0.0000	16 hours/day	5840	30.54	0.00	SELINA (TV CRT 5.23w)
FLR10012	Livingroom	Entertainment	1 VCR	Express programming system	JVC	0.0200	same	0.0000	no use	0	0.00	0.00	ERSE (20w); no use
FLR10012	Livingroom	Entertainment	1 Hi-Fi	old model	Sanyo	0.0600	same	0.0000	no use	0	0.00	0.00	ERSE (60w); no use
FLR10012	Livingroom	Appliance	1 cordless telephone	Gigaset A160	Siemens	0.0030	same	0.0030	On continuously	8760	26.28	26.28	LG (3w); no information
FLR10012	Livingroom	Environment	1 Electric oil-filled radiator heater	HR 1500	Fidelis	1.5000			3 hours when cold		0.00		in situ
FLR10013	Bedroom	Lighting	3 compact fluorescent lamps			0.0330	same	0.0330	4 hours /day	1460	48.18	48.18	ERSE (11w); efficient
FLR10013	Bedroom	Lighting	2 lamps in bed side			0.0800	CFL	0.0160	1 hour/day	365	29.20	5.84	ERSE (40w); Philips equals 8W
FLR10013	Bedroom	Entertainment	1 small TV		Philips	0.0300	same	0.0300	2 hours/day	730	21.90	21.90	same as BEKO; efficient
FLR10013	Bedroom	Entertainment	1 small TV in standby		Philips	0.0040	no standby	0.0000	22 hours/day	8030	32.12	0.00	same as BEKO
FLR10006	Kitchen	Lighting	2 Fluorescent lamps			0.0720	same	0.0720	8 hours/day	2920	210.24	210.24	ERSE (36w)
FLR10006	Kitchen	Appliance	1 Washing machine	TKX 85	Teka	2.0000	same		2 washes / week (1.5 hours)	156	118.56	118.56	Top ten (1.14 kWh each washing cycle); efficient
FLR10006	Kitchen	Appliance	1 Microwave	Grill	LG	0.9000	same	0.9000	0.25 hours/day	91.25	82.13	82.13	ERSE (900w); no information
FLR10006	Kitchen	Appliance	1 Microwave in standby	Grill	LG	0.0043	same	0.0043	23.75 hours/day	8668.75	37.28	37.28	Deco Proteste Internet simulator; not viable
FLR10006	Kitchen	Appliance	1 Fridge	Cooler	Bosch	0.0346	Topten		On continuously	8760	303.00	216.00	Bosch manual (KIL 38A40 IE Cooler - 303 kWh/year); Topten 216 kWh/year
FLR10006	Kitchen	Appliance	1 Toaster		Silver	0.7500	same	0.7500	0.25 hours/day	91.25	68.44	68.44	in situ; no information
FLR10006	Kitchen	Appliance	1 Electric Oven	Mini oven grill	Tefal	2.4000	Topten	0.9100	0.25 hours/day	91.25	219.00	83.04	ERSE (2400w); Topten
FLR10006	Kitchen	Appliance	1 Electric Oven in standby	Mini oven grill	Tefal	0.0040	same	0.0040	23.75 hours/day	8668.75	34.68	34.68	EDP (4w); no information
FLR10006	Kitchen	Environment	1 Electric hot water cylinder	CB 50 -N1	Fagor	1.6000	same	1.6000	On continuously	8760	467.20	467.20	Fagor internet; AKI - 1.28 kWh/Day (50l, 2000w); no information
FLR10007	WC	Lighting	1 lamp			0.0600	CFL	0.0110	2 hours/day	730	43.80	8.03	ERSE (60w); Topten equals CFL 11W
										TOTAL	**2210.54**	**1550.42**	**less 29.86%**
										EDP (kWh/Year)	1796.81		
FLR10006	Kitchen	Appliance	1 Gas stove		Ruby				1 bottle / 1.5 months (0.66)	102.96 kg/year	1410.55		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR30022	Hall/Stairs - Floor 3	Lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR30017	Livingroom - floor 3	Lighting	5 lamps			0.2000	CFL	0.0400	2 hours/day	730	146.00	29.20	ERSE (40w), Philips equals 8W
FLR30017	Livingroom - floor 3	Entertainmnet	1 TV			0.0900	TV (Topten)	0.0300	1 hour/day	365	32.85	10.95	ERSE (90w)
FLR30017	Livingroom - floor 3	Entertainmnet	1 TV in standby			0.0052	no standby	0.0000	23 hours/day	8395	43.91	0.00	SELINA (TV CRT 5.23w)
FLR30017	Livingroom - floor 3	Environment	1 old Electric oil-filled radiator heater		Forster	1.0000			1.5 hours/day when cold		0.00		in situ
FLR30011	Bedroom 2 - Floor 3	Lighting	1 lamp			0.0600	CFL	0.0110	0.25 hours/week	13	0.78	0.14	ERSE (60w); Topten equals CFL 11W
FLR30013	Bedroom 1 - Floor 3	Lighting	3 lamps			0.1200	CFL	0.0080	0.25 hours/week	13	1.56	0.10	ERSE (40w), Philips equals 8W
FLR30013	Bedroom 1 - Floor 3	Lighting	2 side bed lamps			0.0800	CFL	0.0160	no use	0	0.00	0.00	ERSE (40w), Philips equals 8W
FLR30013	Bedroom 1 - Floor 3	Entertainmnet	1 TV			0.0900	TV (Topten)	0.0300	no use	0	0.00	0.00	ERSE (90w)
FLR30013	Bedroom 1 - Floor 3	Entertainmnet	1 TV in standby			0.0052	no standby	0.0000	no use	0	0.00	0.00	SELINA (TV CRT 5.23w)
FLR30019	WC - Floor 3	Lighting	1 lamp			0.0600	CFL	0.0110	0.25 hours/day	91.25	5.48	1.00	ERSE (60w); Topten equals CFL 11W
FLR30019	WC - Floor 3	Environment	1 Electric hot water cylinder		Arierom	2.0000	same		On continuously	8760	448.95	448.95	AKI - 1.23 kWh/Day (like case 5); no information
FLR40031	Hall/Stairs - Floor 4	Lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR40015	Bedroom 1 - Floor 4	Lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR40015	Bedroom 1 - Floor 4	Lighting	2 bed side lamps			0.0800	CFL	0.0080	1 hour/day	365	29.20	2.92	ERSE (40w), Philips equals 8W
FLR40015	Bedroom 1 - Floor 4	Entertainmnet	1 TV			0.0900	TV (Topten)	0.0300	3.5 hours/day	1277.5	114.98	38.33	ERSE (90w)
FLR40015	Bedroom 1 - Floor 4	Entertainmnet	1 TV in standby			0.0052	no standby	0.0000	20.5 hours/day	7482.5	39.13	0.00	SELINA (TV CRT 5.23w)
FLR40015	Bedroom 1 - Floor 4	Environment	1 old Electric oil-filled radiator heater		Century	1.0000			allways on when cold		0.00		in situ
FLR40021	Bedroom 2 - Floor 4	Lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
FLR40016	Kitchen - Floor 4	Lighting	2 Fluorescent lamps			0.0720	same	0.0720	4 hours/day	1460	105.12	105.12	ERSE (36w); Efficient
FLR40016	Kitchen - Floor 4	Appliance	1 Washing machine	C40T Jolly	Candy	2.0000	same		1 wash/week (1.5 hours)	78	59.28	59.28	Top ten (1.14 kWh each washing cycle); not necessary
FLR40016	Kitchen - Floor 4	Appliance	1 Fridge / freezer		Indesit	0.0404	Topten		On continuously	8760	354.00	219.00	Top ten (354 kWh/year): Topten 219 kWh/Year
FLR40016	Kitchen - Floor 4	Appliance	1 Electric Oven		Tecnogas	2.4000	Topten	0.9100	0.25 hours/day	91.25	219.00	83.04	ERSE (2400w); Topten
FLR40016	Kitchen - Floor 4	Appliance	1 Electric Oven in standby		Tecnogas	0.0040	same		23.75 hours/day	8668.75	34.68	34.68	EDP (4w)
FLR40035	WC - Floor 4	Lighting	1 lamp			0.0600	CFL	0.0110	2 hours/day	730	43.80	8.03	ERSE (60w); Topten equals CFL 11W
FLR40019	Storage - Floor 4	Lighting	1 lamp			0.0400	CFL	0.0080	0.125 hours/day	45.625	1.83	0.37	ERSE (40w), Philips equals 8W
										TOTAL	**1768.13**	**1057.17**	**Less 41.21%**
										EDP (kWh/Year)	3421.76		
FLR40016	Kitchen - Floor 4	Appliance	1 Gas stove		Tecnogas				0.5 bottles/month	78 kg/year	1068.60		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
HALL0000	Hall	Lighting	1 lamp			0.0600	CFL	0.0110	0.125 hours/day	45.625	2.74	0.50	ERSE (60w); Topten equals CFL 11W
LVNG0000	Living Room	Lighting	3 lamps			0.1200	CFL	0.0240	3 hours/day	1095	131.40	26.28	ERSE (40w), Philips equals 8W
LVNG0000	Living Room	Entertainment	1 Plasma TV		Samsung	0.1180	LCD	0.0240	2 hours/day	730	86.14	17.52	Samsung internet (118w), Topten 24W
LVNG0000	Living Room	Entertainment	1 Plasma TV in standby		Samsung	0.0003	no standby	0.0000	22 hours/day	8030	2.41	0.00	Samsung internet (0.3w)
LVNG0000	Living Room	Entertainment	1 Hi-FI			0.0600	same	0.0600	1 hour/day	365	21.90	21.90	ERSE (60w); no information
LVNG0000	Living Room	Entertainment	1 Hi-FI in standby			0.0021	no standby	0.0000	23 hours/day	8395	17.21	0.00	SELINA (2.05w)
LVNG0000	Living Room	Entertainment	1 Radio			0.0070	same	0.0070	1 hour/day	365	2.56	2.56	LG (7w); no information
LVNG0000	Living Room	Entertainment	1 Radio in standby			0.0015	no standby	0.0000	23 hours/day	8395	12.59	0.00	SELINA (1.5w)
LVNG0000	Living Room	Entertainment	1 Modem Router			0.0052	same	0.0052	On continuously	8760	45.38	45.55	SELINA (5.18w); no information
LVNG0000	Living Room	Entertainment	1 Laptop computer			0.0500	same	0.0500	2 hours/day	730	36.50	36.50	LG (50w); no information
LVNG0000	Living Room	Environment	1 Electric fan			0.1000			On with hot temperature		0.00		LG (100w)
BDRM0000	Bedroom 1	Lighting	1 lamp			0.0600	CFL	0.0110	1 hour/day	365	21.90	4.02	ERSE (60w); Topten equals CFL 11W
BDRM0000	Bedroom 1	Lighting	1 side bed lamp			0.0400	CFL	0.0080	1 hour/day	365	14.60	2.92	ERSE (40w), Philips equals 8W
BDRM0000	Bedroom 1	Entertainment	1 Plasma TV		Samsung	0.1180	LCD	0.0240	2 hours/day	730	86.14	17.52	Samsung internet (118w), Topten 24W
BDRM0000	Bedroom 1	Entertainment	1 Plasma TV in standby		Samsung	0.0003	no standby	0.0000	22 hours/day	8030	2.41	0.00	Samsung internet (0.3w)
KTCH0000	Kitchen	Lighting	1 Fluorescent lamp			0.0580	same	0.0580	3 hours/day	1095	63.51	63.51	ERSE (58w); efficient
KTCH0000	Kitchen	Appliance	1 Fridge	Cooler	Bosch	0.0346	topten		On continuously	8760	303.00	216.00	Bosch manual (KIL 38A40 IE Cooler - 303 kWh/year); Topten 216 kWh/year
KTCH0000	Kitchen	Appliance	1 Microwave			0.9000	same	0.9000	0.25 hours/day	91.25	82.13	82.13	ERSE (900w); no information
KTCH0000	Kitchen	Appliance	1 Microwave in standby			0.0043	same	0.0043	23.75 hours/day	8668.75	37.28	37.28	Deco Proteste Internet simulator; not viable
KTCH0000	Kitchen	Appliance	1 Extractor hood		Tecnogas	0.1400	same	0.1400	2 hours/day	730	102.20	102.20	ERSE (140w); no information
KTCH0000	Kitchen	Environment	1 Electric hot water cylinder		Termobrasa	1.5000	same	1.5000	On continuously	8760	321.20	321.20	50 l in situ; AKI - 0.88 kWh/Day (1200w, 50L); no information
WC1_0000	WC 1	Lighting	1 lamp			0.0400	CFL	0.0080	0.75 hours/day	273.75	10.95	2.19	ERSE (40w), Philips equals 8W
WC2_0000	WC 2 - Balcony	Lighting	1 Compact fluorescent lamp			0.0110	same	0.0110	2 hours/day	730	8.03	8.03	ERSE (11w); efficient
FLR40000	Storage 1	Lighting	1 lamp			0.0400	CFL	0.0080	0.125 hours/day	45.625	1.83	0.37	ERSE (40w), Philips equals 8W
STRG0001	Storage 2 - Balcony	Lighting	1 lamp			0.0400	CFL	0.0080	1 hour/day	365	14.60	2.92	ERSE (40w), Philips equals 8W
STRG0001	Storage 2 - Balcony	Appliance	1 Washing machine		Balay	2.0000	same		2 washes/week (1.5 hours)	156	118.56	118.56	ERSE (2000w); Top ten (1.14 kWh each washing cycle); efficient
STRG0002	Storage 3 - Balcony	Lighting	1 lamp			0.0400	CFL	0.0080	1 hour/day	365	14.60	2.92	ERSE (40w), Philips equals 8W
STRG0003	Storage 4 - Balcony curve	Lighting	1 lamp			0.0400	CFL	0.0080	1 hour/day	365	14.60	2.92	ERSE (40w), Philips equals 8W
										TOTAL	**1576.35**	**1135.48**	**Less 27.97%**
										EDP (kWh/Year)	804.13		
KTCH0000	Kitchen	Appliance	1 Gas stove						1.5 bottles/month	234 kg/year	3205.80		Households / 13.7 kWh per Kg

						Baseline	Simulation		Operation profile assumed	Hours per year	Baseline	Simulation	
IES VE code	Room	Category	Appliance	model	brand	Power (Kw)	Equipment	Power (Kw)	(average usage hours	(52 weeks, 365 days)	Kwh/year	Kwh/year	Source
FLR20010	Living Room	Lighting	1 fluorescent lamp			0.0580	same		3 hours/day	1095	63.51	63.51	ERSE (58w); efficient
FLR20010	Living Room	Lighting	5 lamps			0.2000	CFL	0.0400	no use	0	0.00	0.00	ERSE (40w), Philips equals 8W
FLR20010	Living Room	Entertainment	1 TV		Sony	0.0900	TV (Topten)	0.0300	2 hours/day	730	65.70	21.90	ERSE (90w); Topten 30W
FLR20010	Living Room	Entertainment	1 TV in standby		Sony	0.0052	no standby		22 hours/day	8030	42.00	0.00	SELINA (TV CRT 5.23w)
FLR20010	Living Room	Appliance	1 Fridge			0.0255	same		On continuously	8760	223.00	223.00	Top ten (223 kWh/year); efficient
FLR20010	Living Room	Appliance	1 Cordless telephone			0.0030	same		On continuously	8760	26.28	26.28	LG (3w); no information
FLR20002	Bedroom 1	Lighting	1 lamp			0.0400	CFL	0.0080	1 hour/day	365	14.60	2.92	ERSE (40w), Philips equals 8W
FLR20012	Bedroom 2	Lighting	1 lamp			0.0400	CFL	0.0400	no use	0	0.00	0.00	ERSE (40w), Philips equals 8W
FLR20013	Kitchen	Lighting	1 fluorescent lamp			0.0580	same		allways on with house occupied (13 hours)	4745	275.21	275.21	ERSE (58w); efficient
FLR20013	Kitchen	Appliance	1 washing machine			2.0000	same		1 wash/week (1.5 hours)	104	59.28	59.28	Top ten (1.14 kWh each washing cycle); not necessary
FLR20013	Kitchen	Appliance	Electric stove		Leco	2.4000	Topten	0.9100	2 hours/day	730	1752.00	664.30	ERSE (2400w); Topten
FLR20011	WC	Lighting	1 lamp			0.0400	CFL	0.0080	2 hours/day	730	29.20	5.84	ERSE (40w), Philips equals 8W
FLR20011	WC	Environment	1 Electric hot water cylinder			1.5000	same		On continuously	8760	321.20	321.20	50 l in situ; AKI - 0.88 kWh/Day (1200w, 50L)
										TOTAL	**2871.98**	**1663.44**	**Less 42.08%**
										EDP (kWh/Year)	2605.74		