Development and optImisation of a
prefabricated modular house for the Porto region
Lucas Matheus Caldas Vicente Lopes
Uminho | 2021

Universidade do Minho
Escola de Engenharia

Lucas Matheus Caldas Vicente Lopes

Development and optImisation of a prefabricated modular house for the Porto region

agosto de 2021

Universidade do Minho
Escola de Engenharia

Lucas Matheus Caldas Vicente Lopes

Development and optimisation of a prefabricated modular house for the Porto region

Dissertation
International Master in Sustainable Built Environment

Supervisor
Professor Manuela Almeida, PhD
Ricardo Barbosa, PhD

agosto de 2021

DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

Licença concedida aos utilizadores deste trabalho

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along theprocess leading to its elaboration.
I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

ABSTRACT

The building stock is responsible for 40% of the energy consumption and 36% of greenhouse gas emissions in Europe. The European Energy Performance of Building Directive (EPBD) established instructions to promote building energy performance to mitigate this problem. Since its first publication in 2002, energy efficiency has been increasingly promoted. In particular, the 2010 recast introduced the nearly zero energy building concept (nZEB), a cost-effective building with low energy demand while having most of its energy demand supplied by renewable energy sources (RES). The procedure for developing a nZEB building includes a cost-optimal assessment of the elements and systems of the buildings, which is the cost-effective comparison between reference building solutions and the proposed building solutions. The cost-optimal assessment has fomented researches aiming to find more cost-effective and energy-efficient building solutions. Furthermore, building methods such as modular and offsite construction have been studied for their possible contribution to increasing cost-effectiveness, energy efficiency, and sustainability. In this context, this study focused on developing a modular solution for the external walls to be used in prefabricated housing. The methodology developed in this dissertation includes developing a catalogue for existing modular solutions, designing the studied building, simulating, and optimizing results, and the cost-optimal analysis of the achieved results for a single-family housing. The data was gathered through a Building Energy Model (BEM) analysis in the software Design-Builder running the Energy-Plus engine simulation. The cost-optimal analysis was performed by comparing different combinations of optimised external envelope options and building solutions. The study analysis shows that an external building envelope can be achieved with lower initial and global costs and lower energy needs than traditional construction. This study shows that the cost-optimal solution for the designed building is a light steel frame panel with an MDF wood façade panel of 22mm, an internal OSBIII panel of 15mm and 90mm Mineral wool insulation material.

Keywords: modular, prefabricated housing, energy efficiency, housing, cost-optimal.

RESUMO

O ambiente construído é responsável por 40% da energia consumida e 36% das emissões de gases com efeito de estufa na Europa. A Diretiva para o Desempenho Energéticos dos Edifícios (EPBD) estabeleceu instruções para promover o desempenho energético e térmico de edifícios para mitigar este problema. Desde a primeira publicação em 2002, a eficiência energética vem sendo fomentada. Em particular, a reformulação em 2010 introduziu o conceito de edifícios com necessidades quase nulas de energia (nZEB), um edifício custo-eficaz com baixas necessidades energética que tem a maior parte dessas necessidades sendo fornecida por energias renováveis. O procedimento de desenvolvimento de um nZEB inclui a análise de custo óptimo dos sistemas e elementos do edifício, comparando entre a solução de referência e as soluções propostas. A análise de custo óptimo fomenta pesquisas focadas em achar mais soluções de melhor custo eficácia e de eficiência energética. Ademais, métodos de construção como edifícios modulares e pré-fabricados são estudados por possíveis contribuições para aumento de custo eficácia, eficiência energética e sustentabilidade. Neste contexto, este estudo focou-se no desenvolvimento de uma solução modular para paredes externas para ser utilizada em habitações pré-fabricadas. A metodologia desenvolvida nesta dissertação inclui o desenvolvimento de um catálogo para soluções modulares existentes, a criação do projeto de estudo, simulação e optimização, e análise de custo ótimo para uma habitação unifamiliar. Os dados foram recolhidos por meio de uma análise de um modelo energético de construção (BEM) pelo software Design-Builder utilizando o motor de simulação do Energy-Plus. A análise de custo óptimo foi feita comparando diferentes combinações de envolvente externa optimizada. A análise de estudo mostrou que é possível alcançar uma envolvente com custo inicial, custo total e necessidades energéticas menores quando comparada com a construção tradicional que se pratica no contexto português. Este estudo mostra que a solução de custo óptimo para o edifício projetado é um painel com estrutura em construção metálica leve (LSF), com um placa de madeira MDF de 22 mm na fachada, uma placa interna de painel estrutural com fibras orientadas de madeira (OSB) III de 15 mm, e o isolamento em lã mineral de 90 mm.

Palavras-chave: modular, pré-fabricada, eficiência energética, habitação, custo-optimo.

TABLE OF CONTENTS

LIST OF TABLES, FIGURES, AND GLOSSARY

LIST OF ABBREVIATIONS

AC : Air-conditioning

BEM : Building Energy Modeling

BIM : Building Information Modeling

BIPV : Building Intergrated Photovoltaics

DHW : Domestic Hot Water

EE : Embodied Energy

EMS : Environment Management System

EU : European Union

FRP : Fibre Reinforced Plastic

GHG : Greenhouse Gas

GUI : Graphics Used Interface

GWP : Global Warming Potential

HVAC : Heating Ventilation and Air Conditioning

LCA : Life Cycle Assessment

LCC : Life Cycle Cost

LSF : Light Steel Framing

MDF : Medium Density Fibreboard

NRPE : Non-renewable Primary Energy

nZEB : Nearly Zero Energy Building

NZEB : Net Zero Energy Buildings

OSB : Oriented Strand Board

PCM : Phase Changing Materials

PEB : Positive Energy Buildin

PV : Photovoltaic

RECS : Regulation of Energy performance of Commercial and Service Buildiings (PT)

REH : Regulation of Energy Performance of Residential Buildiings (PT)

RES : Renewable Energy Source

SDGs : Sustainable Development Goals

SLCA : Sustainable Life Cycle Assessment

UN : United Nations

WRFP : Waste Reduction Framework Plan

XPS : Extruded Polustyrene insulation

Chapter 1: Introduction

Cities are home to most European populations, which are projected to rise significantly until 2050 [1]. Urban environments occupy only around 2% of the world surface. Nevertheless, they are responsible for 75% of the total energy consumption [2]–[4]. In that context, buildings are recognised as essential contributors to energy consumption and carbon emissions worldwide. The building stock in Europe is responsible for 40% of the total energy consumption [5] and is responsible for approximately 36% of the total CO_2 emission of the European Union member states [6].

For mitigating the building stock impacts, laws and regulations have been developed to decrease energy consumption and carbon emissions. In a United Nations (UN) conference in 2012, goals for sustainable development (SDGs) were set to be globally reached by 2030. Those goals are founded on the three pillars of sustainability: social equity, economic viability, and environmental protection. Furthermore, they are divided into 17 main goals, and each one holds a specific objective supported by more particular sub-targets. In particular, goal 11 focuses on sustainable cities and communities, which is the built environment's sustainable development topic. Its sub-targets 11.1 - safe and affordable housing, and 11.6- reducing the environmental impact of cities, aim to make the building stock more energy efficient and its houses more accessible and affordable [7]. In 2018, the European building stock energy demand raised by 7% compared to 2010. With this significant rise, to achieve the SDGs goals for lowering the energy consumption, the energy consumption of the building stock should decrease by 3% yearly [8]. Furthermore, to achieve the goals of the EU 2050, the energy spent on building thermal comfort is supposed to be negative, achieving a zero-emission goal; thus, achieving a nearly zero carbon building (nZCB) with its emissions lower than $3kgCO_2/m^2yr^1$ [9]. This goal is intended to be achieved by maximising energy efficiency and renewable energy sources [10], [11].

With the need for lowering the built environment energy consumption, the European Union (EU) promoted directives to improve the building stock's energy efficiency. The 2010 recast of the EPBD has introduced the nearly zero energy building concept (nZEB). The nZEB is a building defined by its high energy efficiency and local production of its energy demand by renewable energy sources (RES). The directive stipulated that from January 1st, 2021, all new buildings must be nZEB [6]. In the EU, all member states have already their definition of a nZEB according to their national contexts and climates. Other associated concepts and energy efficiency targets are being promoted in the literature, like net-zero energy buildings (NZEB) [12]. While nZEB has its demand partially supported by local RES, an NZEB has 100% of its energy demand supported by RES. Also, a positive energy building (PEB) produces locally more energy than it consumes. However, the NZEB and the PEB are still considered less economically viable than the nZEB. Achieving those results requires higher initial costs and investment in infrastructure, equipment, and systems for the building [12].

For achieving a nZEB, NZEB, and PEB, some methodologies have to be applied in their design. One of those methodologies is the cost-optimal analysis, which consists of a long-term analysis of buildings elements and energy-efficiency measures compared to a reference building [13]. This assessment ensures the minimum requirement for energy performance of the building elements, meaning a significant improvement in the overall building performance [6]. Furthermore, the calculated costs must consider the lifecycle impacts of the energy-efficiency measures on the global cost, the maintenance cost of those systems, operational costs, and investment costs [14], [15]. In addition, the development of a cost-optimal assessment must focus on two different economic perspectives: a Social macroeconomic level and a private microeconomic level. The microeconomic focus is on the end-users economic perspective, considering taxes and costs related to end-user consumption. In comparison, the macro-economic level includes the costs of CO2 emissions, subsidies and taxes of a societal building [9]. As for the development or renovation of a building, the cost-optimal is an essential methodology for developing a more energy-efficient and cost-effective built environment.

Several studies address renovations and new constructions to obtain high energy efficiency levels in different contexts in Europe [16]–[23]. In Portugal, there are also significant studies developed regarding building energy efficiency and sustainability. One example of a study of a building renovation in Porto that renovates an existing building with prefabricated modular panels aiming to achieve the nZEB level is investigated by Almeida et al. [24]. Another example is the SOLAR XXI building in Lisbon, which aims to be net-zero using passive solutions associated with photovoltaic (PV) panels [25]. In addition, the study of a modular house made of shipping containers by Mendes [26], the analysis of a sustainable modular building made with low environmental impact materials by Freitas [27] and the optimisation of prefabricated modular panel solution for a refurbishment by Silva et al. [28] should be mentioned as references about the energy performance of Portuguese buildings using modular solutions.

An energy-efficient building has a low energy demand in its overall life cycle. This energy demand can be reduced by increasing the building's thermal performance, adopting energy-efficient technical solutions and equipment, and employing more efficient technologies and techniques in the construction phase [17], [21], [29]–[31]. When optimised and designed to be efficient, the prefabricated modular construction can improve energy efficiency while making the building more affordable than the traditional construction methods [32]. Furthermore, the modular prefabricated construction system takes advantage of using an industrialised assembly line, which means a faster, cheaper and better-quality product [32], [33]. Thus, this technique offers many advantages that will be discussed in the literature review.

Several studies approach energy efficiency in the built environment in Europe [16], [17], [34], [35]. However, the approach cannot be considered mainstream in southern European countries, as most research on this topic focuses on central and northern Europe.

The early consideration of the building location climate and energy demand in its design stage is essential for achieving a high level of energy efficiency. Research studies about the effects of prefabrication, modularity, and optimisation techniques and how they affect the built environment can be helpful in future development in the area. Thus, this dissertation was focused on the development of a modular solution for Portugal, using the climate characteristics of a specific region in the north of the country. Although literature that discusses the impacts of modularisation and prefabrication on the energy efficiency and sustainability of buildings in Portugal, those types of building methods are not well diffused in the Portuguese building stock, let alone in housing. The addition of studies such as Leal [36] that study the impacts of the form factor and orientation of a building in its thermal performance. Silva et al.[28] with the study of a prefabricated renovation solution to decrease as much as possible the building energy consumption. Machado et al.[37] study of the modular building will be reviewed for better development of the projected building and its analysis.

The main objective of the dissertation study is to address the research gap of investigating the effects of the prefabrication and modularisation on building cost- effectiveness and energy consumption in the reality of a southern European climate, specifically the climate of the northern part of Portugal, in Porto region climate. This objective was achieved by developing and analysing a single-family residential building. This typology was chosen for this study because of its simplicity and comparability with the reviewed literature [22]–[24], [35], [38]–[58]. Furthermore, the building was proposed considering cost-optimisation and the impacts of an optimised architecture design, keeping it affordable and cost-effective while still replicable and adaptable. Furthermore, this dissertation also aims to study and point out the advantages of using building energy modelling (BEM) optimisation to design energy-efficient buildings with this analysis.

This research project is structured in the following chapters:

Chapter 1 develops the introduction and the general context for the work developed in the dissertation, as well as the research objectives;

Chapter 2 presents the literature review regarding the topics relevant to the dissertation, including energy efficiency in buildings, embodied energy, modular and offsite construction, modular nZEB buildings, modular energy-efficient buildings in Portugal, technology overview, and tools and methods for sustainable energy-efficient modular construction. The chapter concludes with the problem identification that leads to the definition of this dissertation;

Chapter 3 explains the methodology used, those being: cataloguing building solutions, architectural design, simulation and optimisation, and cost-optimal analysis;

Chapter 4 discuss the found results and their applicability for the European building stock.

Chapter 2: Literature review

2.1 Energy efficiency in buildings

Energy efficiency and sustainability are increasingly necessary to building stock development. New policies and measures were introduced to promote energy savings and CO_2 emission reductions over the last decade. In this context, the European effort is clearly observed in the Energy Performance of Buildings Directive recast [6], which introduced the nearly Zero Energy Building (nZEB). The nZEB is defined as "a building that has a very high energy performance (...) the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". The nearly zero-energy concept reduces the energy demand to almost zero, coupled with the energy supply from renewable sources [6]. The measures necessary to ensure that the minimum energy performance requirements are defined to achieve the cost-optimal levels, should be calculated according to the European Commission's comparative methodology [59]. A nZEB building is also associated with several co-benefits such as thermal comfort, noise reduction, and a decrease in building physics related problems, such as common pathologies related to insulation deficiencies [60].

Tools such as energy simulation and building information modelling software are used to analyse the building project and aid during the design stage to help achieve high energy efficiency. Although energy efficiency during its lifecycle is significant to a building, the initial costs must also be considered when designing it. In order to achieve this result, a cost-optimal assessment should be developed between the solutions of the building envelope, heating, ventilation and air-conditioning (HVAC) systems, domestic hot water (DHW) systems and renewable energy sources (RES), taking into account not only the initial costs but also their life cycle costs. Moreover, the cost-optimal assessment is a requirement for a nZEB building. It can balance the parameters initial cost and energy consumption and the building lifecycle cost to achieve efficient results in all the parameters.

The energy spent on DHW and HVAC systems represents most of the overall consumption in the building stock energy consumption [61]. As seen in figure 1, in Europe, this percentage achieves 67% of household energy consumption [62]. For that reason, the energy demand to achieve thermal comfort is the selected parameter determined for evaluating the energy efficiency of the building stock.

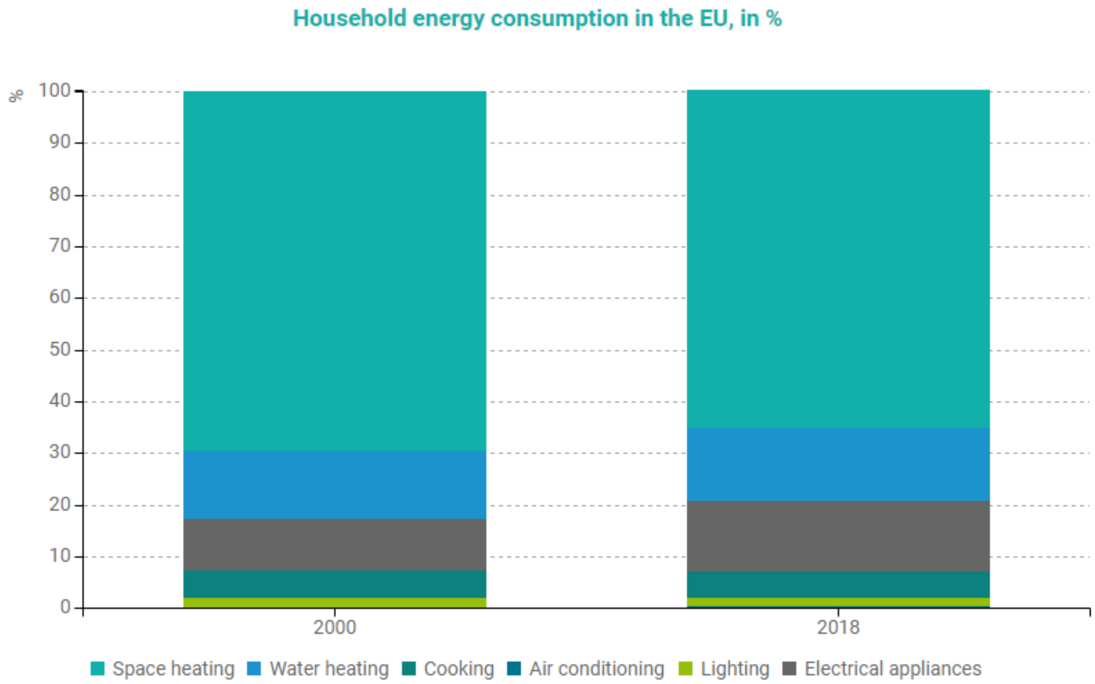


Figure 1 Household energy consumption in the EU

Source: Adapted from [63]

In Portugal, the directive has been ratified and consequently implemented in the Regulation of Energy Performance of Residential Buildings (REH) and Regulation of Energy Performance of Commercial and Service Buildings (RECS) [64]–[70]. Those regulations describe the nZEB as a highly efficient building with low energy demand, with the remaining energy needs supported by local RES [64]. The percentage of locally produced energy might vary for each country. In Portugal, it is mandatory to have at least 50% of the building energy demand made by renewable sources on the building or in its proximities for achieving a nZEB level [69]. Moreover, the best-recommended strategy for addressing the renewable energy source is implementing photovoltaic panels and thermal solar systems since sunlight is an abundant form of energy in Portugal [69]. The directive also has stipulated that new buildings constructed after January 1st of 2021 will be obliged to fit the nZEB definition, thus including in their design high energy efficiency materials, HVAC systems, and RES, while the combination of those inclusions has to fulfil cost-optimality criteria [64], [67], [71].

Becchio et al.[43] developed a study about a nZEB house in northern Italy regarding its sustainability. It was concluded by comparing sustainability and cost-effectiveness that achieving the nZEB level is possible using high-performance building elements. This study suggests that the cost-optimal solutions tend to have smaller RES due to the high initial cost. In addition, the HVAC systems tend to be mainly based on natural gas boiler systems due to their lower initial cost and high efficiency. However, more sustainable solutions tend to have larger RES due to low non-renewable energy consumption. The mixture between PV and Solar Thermal panels systems were found to present the best results in terms of sustainability.

Moreover, there are other options for decreasing energy consumption. Silva [72] concludes that passive solutions in buildings design are crucial in southern Europe. For example, a building could increase its efficiency by reducing heat loss and increasing heat gains in winter, promoting ventilation, and reducing heat gains in summer [25], [40], [44], [56], [73].

Identifying the connection between non-renewable energy production and energy demand can explain why energy-efficient buildings are considered sustainable [3]. A study by Becchio et al.[43] concluded that the cost-optimal solutions tend to have small RES coverage over the overall building energy demand, about 20% to 30%. In comparison, the rate of RES production in nZEB buildings is around 60% to 90%. The amount of energy produced on-site decreases the emissions related to non-renewable energy. If the EU goals are to be met in 2050, the building environment will increase the percentage of the buildings energy demand produced on site.

2.2 Embodied energy on the built environment

The embodied energy (EE) represents the energy consumed in the process of acquiring, processing, manufacturing, transporting, constructing, disassembling, and disposing of a material [74]. Efficient and sustainable materials are vital to keeping the building embodied energy low [32]. Traditionally, the embodied energy in a conventional building is lower than the operational energy consumption in its lifecycle [39]. A study that analyses 73 buildings across 13 countries [75] presented that the operational phase represents 80-90% of its lifecycle energy consumption. Another study about traditional construction in China by Wu et al.[76] had the operational cost responsible for 85.99% of the building 50-year lifecycle. However, as buildings become more efficient in energy use, several studies indicate that embodied energy can be increasingly relevant [77]. A research study in a highly energy-efficient building by Crawford et al.[54], resulted in the operational consumption representing 32% of the total energy consumption, making the embodied energy higher than the operational energy consumption. In addition, the high energy demand in the operational phase of the construction is researched mainly in traditional construction methods. Using alternative construction methods such as prefabrication and modularity could decrease construction energy consumption considering the advantages of industrialisation [32]. The prefabrication of the construction elements would reduce the waste, decrease the construction time and centralise the transportation [32], [46]. All those measures would lower the total embodied energy of the building, thus reducing its total energy consumption.

There is plenty of relevant research on energy efficiency and sustainability focusing on the building sector [31]. However, studies addressing the integration of both concepts are still scarce. This interaction could be analysed in its environmental impact dimension during all energy consumption phases in a building. For example, Stephan et al.[57] approached this subject by analysing a passive house with 100 years of lifecycle energy consumption. The conclusion reached was that only 16.9% of the building energy consumption was related to operational costs. In this study, the higher energy consumption stage was the embodied energy. This result was due to the excess of material used in the construction of the house to achieve a high energy efficiency level. Crawford et al.[78] suggest that the energy efficiency regulations promote an increase of insulation thickness without considering the potential increase in embodied energy. Therefore, the increase in insulation materials usage should consider the whole building lifecycle, including the embodied energy spent.

Yang et al.[79] defend that the solution to deal with the energy consumption impact on the environment issue is to have more energy-efficient buildings and reasonable building energy conservation regulations. The optimised balance between energy consumption during its life cycle and construction dramatically impacts the environment, and both factors can be reduced using energy-saving methodologies, techniques and technologies.

2.3 Modular and offsite construction

Prefabricated buildings are growing in most developed countries [32]. It is often a more sustainable and more efficient construction technique [24]. Modular building and prefabrication have many qualities over the traditional construction method [32]. Moreover, this construction method can make necessary improvements in the building stock.

The construction process developed in a factory results in inbuilt quality advantages, waste reduction, low energy consumption on fabrication, and faster construction [46]. Tam et al. [33] explained the most indicated advantages and disadvantages for construction companies in their research. The most referred benefits in their study were the better supervision of the quality of the prefabricated products, an un-adaptable early design and reduced construction costs. Moreover, prefabrication allows time-saving at the on-site preparation phase, and modules construction operations can run simultaneously [32], [80], [81]. This process also impacts other areas, such as the health and safety of the construction workers, by having a more controlled work environment [46], [82]. Furthermore, cost improvement of the construction technique can be noticed due to the manufacturer's possibility of purchasing materials in large quantities, transport expenses, and reducing the on-site labour cost by 25% [32], [33]. In addition, the overall quality is improved over the traditional construction technique due to its consistency and automation [32], [46].

Case studies about modular offsite building investigate its advantages over the traditional construction method. Lopez et al.[83] studied the benefits of modular panel construction; the conclusion was that it uses faster, lighter and quicker transportation while needing more lightweight equipment. Those results were attributed to the lightness of the panels used in the construction, thus saving construction time, energy spending and emissions during transport and assembly. These benefits were observed in a research comparison between a modular, panelised system vs a pre-assembled module. However, the pre-assembled modular construction has other qualities over the panelised construction, such as lower assembly time and higher construction quality. In another study, Tavares et al.[47] concluded that, even when the prefabricated components were only 38% of the total building substantial volume, the advantages were a decrease of resource depletion of 36%, a reduction of environmental damage by 5%, and a decrease in health damage by 7%. Quale et al. [84] concluded in their analysis that on-site construction has greenhouse gas emissions 20-70% higher than the modular construction technique. Overall the literature points out that modular construction can benefit from a more sustainable and cost-effective building by reducing waste production, consuming less energy in the construction stage, and being faster than traditional construction. Therefore, the benefits associated with modular offsite construction have a significant potential for cost-optimality when compared with the so-called traditional construction techniques [33][69][70][22][71].

Modular construction has a more sustainable result when comparing the results from the life cycle assessment (LCA), life cycle costing (LCC), and sustainable life cycle assessment (SLCA) to the conventional construction method [80]. In another study carried out in India, Nanyam et al.[51] researched the cost viability of modular energy-efficient housing as a more affordable option to live. The studied building was conceived, aiming to have better material supervision, finishing quality, reduced labour requirement since it is produced offsite, and better test facilities to ensure the design efficiency of the project solution. The article's offsite modular construction technique analysis showed an accentuated result in sustainability requirements, design efficiency, cost-saving, and time-saving parameters. Another case study evaluated the Moby house's greenhouse gas emission and embodied energy [47]. The project followed a cradle-to-site construction method, which means that the modules were produced in a factory and transported to be installed on-site. The study observed that the embodied energy of the house is directly proportional to the distance between the construction site and the factory. Therefore, the site should be as close to the production line as possible to achieve an optimised environmental impact. Hsu et al.[85] say that practitioners of modular buildings should consider the transportation, storage, and assembly process to develop modular construction. The process of planning a modular building assembly should account for the probability of getting weather interference, workforce productivity, transport delays, and equipment breakdown. Suppose those interferences happened during the assembly phase of the project, the building embodied energy consumed during the construction and costs would significantly increase.

Construction waste is one of the main issues to be considered regarding the sustainability of the built environment. The construction waste is building material unused that was discarded. Therefore, it is necessary to adopt a waste management strategy for the building lifecycle [33]. The city of Hong Kong addressed in 1989 an issue that promotes a sense of environmental protection [86]. The case included implementing a Waste Reduction Framework Plan (WRFP) and an Environmental Management System (EMS). This is pertinent in this context because, in Hong Kong, modular offsite construction is viewed by local companies as a technique that can improve the building while applying a waste management plan. Several authors, such as Begum et al.[87] state that adopting the prefabrication technique is essential for reducing waste. Through waste reduction, more sustainable buildings can be achieved, and this improvement is attributed to the modularisation and industrialisation of the construction process.

A possible way to make sustainable offsite buildings is the reuse of materials to develop the building. Schiavoni et al.[22] studied the project of modular homes made with end-of-life shipping containers. The study reports on the HPP project (Housing Push & Pull) in its three case studies projects XXS, XS, and S, characterised by its floor area. In the environmental aspect of the buildings analysed, using an end-of-life shipping container as a base material to the house properly utilises a vital structure made for resisting loads and harsh weather conditions. Another study also investigated shipping containers as a sustainable modular base material for construction [88]. In this case, the study suggests that based on Malaysia's available material, the best material for the project of an office building analysed in the study is the shipping container due to its sustainable and structural features.

In general, the literature shows that modular and prefabricated techniques construction has benefits over the standard construction technique. The main benefits being costs reduction, more sustainable building, and low construction time. Moreover, if used intentionally to reach a better overall cost-optimal solution, those advantages would positively impact the building environment.

2.4 Modular nZEB buildings

The nZEB building is currently the standard to follow in most of the Member States [6]. The right balance between energy efficiency, architectural quality, and global costs are vital to achieving the nZEB level. In addition, it was found that the modular prefabricated construction benefits can improve the viability of the nZEB.

In Italy, Tumminia et al.[89] explored the performance of a modular building that reached a net-zero-energy building (NZEB) certification. Due to the modularity and prefabrication of the structure and building solutions, the total building impact on the energy consumption and the environment was significantly lower than a traditional building. Tumminia et al.[90] also studied solutions in a house located in Messina, Italy. The project was conceived with modular panels made of fibre-reinforced plastic (FRP) and insulated with polyester fibre. The wall solution has 25cm in total thickness and is considered to have high thermal efficiency. The primary purpose of his project is to make an easily replicable nZEB modular housing. Therefore, the designed building used the modularity associated with high-efficiency materials and solutions to achieve the nZEB level. The renovation scenario by Pielo et al. [34] researched the nZEB renovation of a building with modular panels. This research involved designing an external panel to insulate the building while testing other functional parameters such as ventilation, heat recovery, and hygrothermal performance. The external panel designed to achieve nZEB level in building renovations had a 0.10 W/(m2.K) thermal transmittance. The panel performance would require a smart vapour retarder to better control the panel hygrothermal performance. The study concluded that when renovating a building with a high thermal-resistance panel to achieve the nZEB level, its initial state must be considered to ensure the best results. In another case study, Antonini et al.[91] researched the optimisation of a light steel frame modular housing. The building modules were designed to be light, transportable, easily assembled on-site, sustainable and energy-efficient. The opaque envelope options considered for the study had between 0.19 and 0.14 W/m^2.K. The study concludes that the modular approach to the project design increases sustainability. It also concludes that the light steel frame positively impacts the building design due to its recyclability, longevity, and lightness. In addition, the study by Pinto et al.[92] studied the prefabricated modular construction with high thermal insulation. The studied building was a single-family housing with a system wall with 0.22 W/m^2.K thermal transmittance and roofing and flooring with a thermal transmittance of 0.30 W/m^2.K. It is concluded that the high thermal performance is not enough to fulfil the nZEB requirements; thus, it also considered windows, openings, HVAC systems, and RES. In a paper by Pulakka et al.[93] it assessed Finland's economics, energy efficiency, environmental impacts, and user satisfaction of two lean wooden modular nZEB. Since the buildings were designed for a cold climate, adopting the modular approach helped prevent moisture-related risks for the building. The wooden building structure and opaque envelope provided a high thermal transmittance. This measure associated with RES usage, a nZEB compatible HVAC, and shadings for solar gain control is responsible for achieving the nZEB targets.

The literature about the nZEB relationship with modularity explains that the nZEB level can be reached more comfortably when adopting the prefabrication and modular design approach since the early design stage. Thus, its benefits can be seen in the whole building lifecycle, although primarily more beneficial in the cost and sustainability of the building.

2.5 Modular energy efficient buildings in Portugal

The performed literature review allowed to identify several studies addressing the energy-efficient modular construction developed for Portugal. The case studies on modular prefabricated buildings in Portugal also research the differences of the technique over the traditional construction system using improvements in energy efficiency, total cost, and thermal performance as main indicators.

The current modular prefabricated approach to construction in Portugal was studied by Macieirinha [94]. It was analysed the development of modular architecture in Portugal in terms of how it is being developed, what techniques and materials are being used and how it differs from the traditional construction method. The study concludes that it requires more time to plan the project than traditional on-site construction. Its adoption can mean a more agile construction, with better overall quality and adaptability, thus reducing waste, discourage unneeded demolition and influencing the building sustainability. Another modular building study in Portugal was carried by Mendes [26] analysing the energy efficiency of a modular building that used containers as a structural material. The study provides a critical approach to how modular buildings are related to energy efficiency in Portugal. The study analyses a single-family home located in Covilhã, Portugal, built with ISO' 20' and ISO' 40' containers. The building's insulation materials were chosen according to the climate of the region where it was implanted. As a result, the shipping container house achieved low primary energy calculation, classifying the building with an A grade in energy efficiency. A different approach can be found in the study performed by Almeida et al. [24], where a modular panel was developed for an energy renovation project in Vila Nova de Gaia, in the north of Portugal. Results suggest that, if mass-produced, the approach would reduce production costs by 70%, considering the Portuguese industrial market. The cost reduction of the mass production of this building element would make it the best cost-optimal solution for the renovation scenario. In addition, energy improvements can reach 86% on average. Patinha et al.[58] analysed the development of a modular building project based on the concept of flat-pack furniture. This project had the objective of being low-cost, easy to build, reusable and upgradable according to the family needs and changes. The analysis concluded that the construction and mass production were responsible for a significant decrease in the module cost. Moreover, a study by Pinto et al.[92] studied a modular nZEB designed for the Portugal climate. The external envelope had an excellent thermal performance compared to the regulated. The building also had to account for windows with solar control, passive solutions, an efficient HVAC system, and a RES to be considered nZEB. It was concluded that only having a high thermal performance is not enough to achieve the nZEB level. In another study, Freitas [27] studied how the modular construction associated with the material can influence sustainability and energy efficiency. The research is developed by analysing the same modular structure in four building typologies: a sales spot, a studio like home building, a single room house, and a two-room house. After analysing the best materials to develop the building systems, it was concluded that the modular prefabricated building has lower costs than traditional construction while having a better environmental performance and energy efficiency. The study also affirms that Portugal can provide high-performance materials produced locally. This material quality associated with the modular construction method can be excellent for developing a highly efficient building.

Moreover, using the passive design on a modular building could also benefit energy consumption and sustainability in southern Europe. When adjusted to the specific climate, a passive design is responsible for better thermal performance. For example, natural sunlight to gain heat in winter decreases the energy needed to achieve thermal comfort. The same can be said for the summer, where the avoidance of the heat gains contribute to low energy demand from the air-conditioning system [72]. The SOLAR XXI building in Lisbon, where PV panels helped reach the net-zero level, used PV panels as shading elements in the façade [25]. The adoption of PV panels as passive design solutions was the cause of the building high thermal performance. This case study shows the benefits of aligning passive design with renewable energy sources to enhance building efficiency.

Modular construction in Portugal has proven results similar to the rest of the literature. Those results prove the modular prefabricated building to be a better option in terms of sustainability and global cost. The adoption of prefabrication, modularity and a passive design could significantly increase the energy efficiency and sustainability of the built environment.

2.6 Technology overview

The use of technology for improving the built environment has been a focus for researchers since energy efficiency and sustainability were popularised as issues. The energy spent on thermal comfort represents 67% of the building's total energy consumption [62]. Henceforth thermal comfort directly impacts the productivity, health, and well-being of the building occupants. Therefore, the technologies that address that issue must be highly efficient and sometimes deviate from the obvious path.

The building envelope is a crucial element to the energy efficiency of a building. Its performance may vary due to thermal transmittance, thermal capacity, the behaviour of the transparent envelope, and the radiative proprieties of the coatings [95]. Therefore, it is crucial to the building thermal performance to improve the envelope elements [60]. An improved building envelope affects the thermal performance, but other results will be achieved, such as noise reduction and a more climate-resilient building [96]. One key point for this improvement is related to the type and thickness of insulation used. In the study of Pihelo et al.[34] the addition of an extra 32.8cm of insulation brought by the wood panel insulated with mineral wool made the pre-existing building reach the energy demand level of a nZEB. In the study by Mendes [26] it was possible to achieve the nZEB energy demand level by adding 6cm of mineral wool, 1.5cm of plasterboard, 1.5cm of a non-ventilated air gap, and 1.5cm of an insulating panel to the container steel structure. Those additions improved the thermal transmittance from 0,526 W/(m2.°C) to 0,363 W/(m2.°C) to the walls of the modular building. Silva et al.[28] optimised a prefabricated module for the renovation of a building using black cork as insulation material. In designing a modular sustainable house by Freitas [27], the insulation material used was a cellulosic fibre called Isofloc. This material usage in the building contributed positively to the overall building energy demand. Caseiro [97] used in the study of a modular architecture the MDF panel from MDFachada as façade material and cellulosic fibre as insulation material. The insulation material is associated with the high thermal-performance materials used that were responsible for the project good environmental performance. Although the addition of insulation material is beneficial for building energy efficiency, Rauf et al. [98] discuss the impacts of adding insulation to a building without concern about its embodied energy or the effect of the added insulation.

Several studies are pointing out the use of wood elements, such as Caseiro et al.[97] that developed a wooden modular building, Freitas [27] that proposes a prefabricated wooden building with high thermal performance, and Pulakka et al.[93] that assessed two wooden modular nZEB. Both studies also use wood as a façade element due to its thermal performance and sustainability. Other studies such as Almeida et al.[24], [34] and Pihelo et al.[34] point out the wood as a structural element used in the fabrication of modular panels used in renovations. Both studies refer to the wood structure as a good option due to its thermal performance. Other materials are often pointed out as sustainable for the built environment. Materials such as aluminium and steel have high recyclability and durability. Those materials are used in the study by Silva et al.[28] as façade element and structure for the developed renovation panels. In the study by Antonini et al.[91] it was also considered the usage of the steel frame structure. However, the LSF was used in a new nZEB building and is considered only a sustainable material due to its high recyclability and as a light material that can make possible the prefabrication and modularisation of a nZEB. The approach about the steel as the structure was addressed in other literature [22], [26], [47], [99].

Regarding building-integrated technical systems, such as HVAC systems and renewable energy sources, there are significant differences concerning the climate where the modular construction will be implemented. A study carried by Ma et al.[44] displayed the most used solutions for space heating, space cooling, and renewable energy sources is the Solar decathlon. The most used HVAC was the electric heat pump, which can vary in air-to-air, water-to-source, and ground thermal. This choice was due to the efficiency of the systems and their resilience. Other reviewed literature also incorporated the heat pump, such as Becchio et al.[43], Barthelmes et al.[16], Hamdy et al.[13], and Wu et al.[100]. In a case study by Kurnitsky et al.[20] the HVAC solution used was a ground thermal heat pump that used heated floors as a dissipation method. The study by Barthelmes et al.[16] used a water-to-water heat pump also associated with heated floors; a split air-conditioning system was used with an external wall compressor for the cooling system. It is worth mentioning that some literature used emerging technologies such as phase-changing materials (PCM) and desiccant dehumidification [44]. However, those techniques are still not broadly used in the construction industry; thus, they have a high initial cost, and their usage cannot be considered cost-optimal yet. Ma et al.[44] also described the most used renewable energy source solution in the Solar Decathlon. The solar-thermal hybrid panel was the most used RES for its combination of photovoltaic panelled for generating energy and solar-thermal for DHW or space heating. This solution has good efficiency and availability in the market and such solutions are encouraged by the Portuguese regulations [71]. The use of efficient renewable energy sources (RES) is a crucial aspect of building energy efficiency. RES are a defining attribute of the nZEB and have a significant impact on sustainability. A Building-integrated photovoltaic (BIPV) is one of the most suitable building techniques to comply with the nZEB requirements [73]. BIPV indicates when a photovoltaic panel is integrated with the building construction elements, which can be on the envelope, on roof facades, in the atria, or acting as shading elements. Literature examples of the development of such technologies are extensive. The PV panels can also be hybrid and associated with a solar thermal system to assist indoor thermal comfort. The hybrid BIPV has excellent potential for payback and co-benefits, such as the influence of job production, tax reduction, investment payback, and energy generation impacts of investment in PV panels in a building [21], [56].

2.7 Tools and methods for sustainable energy efficient modular construction

Several tools, methods and methodologies were used in the literature to assess the energy efficiency and sustainability of a building in terms of energy consumption, thermal performance, cost-optimality, and environmental performance.

A key tool found in studies addressing modular construction relates to energy simulation. The building energy modelling tool calculates energy demand, energy consumption, and building material optimisation via simulation. This tool utilises information about the materials, systems efficiency, systems power, solutions composition, building location, regional climate, sunlight gains, building orientation, and other data to estimate how the building will behave when finished accurately. The results expected through the use of this software are: how the solar gains will influence the thermal performance, how the solar gain can be for the optimal building opening and shadings, how its envelope can influence heat losses or gains, what envelope solution provides better performance over cost and material usage, how much energy is demanded to achieve a set thermal comfort, and how much will be the overall energy demand [101]. The BEM software was broadly used in the literature [14], [16], [19], [22], [24], [26], [34], [43], [102]. This software is also used for financial incentives, policy analysis, asset rating, code compliance and model predictive control [103]. The most used BEM software in the literature was Energy-Plus[101], a free, open-source, cross-platform software [101]. Ascione et al.[95], used the software Energy-Plus associated with MATLAB to optimise and identify the solutions that were not dominated by other results, thus setting the Pareto front line. The Pareto front options were sorted in their thermal and comfort performance to identify the optimal building element for the study. Tumminia et al.[90] also used Energy-Plus for the modular home case study project, thus using the software to predict the building thermal behaviour and test HVAC solutions for their cost-optimality.

In a case study, two quasi-steady-state methodologies were compared to their consistent results when applied in a Northern and Southern European climate [50]. One methodology is the guideline published by the Portuguese decree-law [64]. The other is the monthly results of the simulations as recommended by the PassivHaus Institute. The paper concluded that the most significant criteria on the methodologies were the climate data used for each simulation. It further concludes that the methodology used on the simulation would be more assertive if the methodology and the climate data were appropriate for the site location.

A methodology that is crucial for developing a nZEB building and a cost-effective building is the cost-optimal assessment. The method used in most literature analysed is the suggested reference by the EU Delegated Regulation [15]. This methodology involves calculating the global costs in a pre-determinate time. This tool was created to assess the overall costs, including the initial, operational and maintenance costs. Its results are of great importance to the literature. The assessment is developed by comparing a set of solutions with a reference building. The reference solutions are constituted of a building using the traditional building materials and solutions to the region. The cost-optimal solutions are the ones that have lower primary energy consumption and global cost when compared with the reference building. Therefore, as shown in Figure 2, the results in the graphs that are lower than the curve and consume less primary energy will be considered cost-optimal.

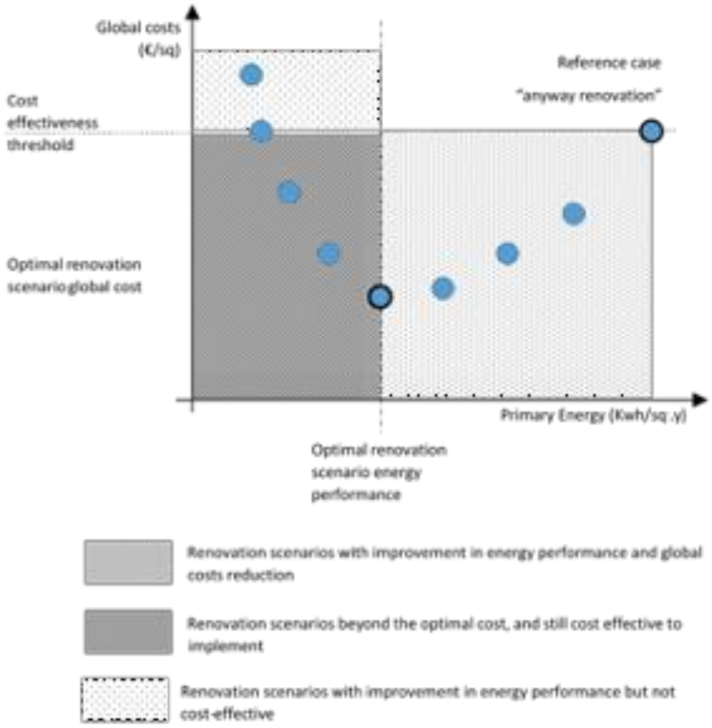


Figure 2 – Cost Optimal analysis graph.

Source: Adapted from [104]

2.8 Problem identification

From the literature review, it is noticeable the importance of the development of sustainable building stock. Since most energy produced globally is not renewable [3], energy consumption affects GHG production [29]. An effort is being made to mitigate this situation through regulations and norms [64]. Although progress is being made, efforts to increase reductions should be further increased to meet the targets for 2050 [8]. This demand for more energy-efficient buildings fomented several studies investigating methods and techniques for achieving better performing construction.

Evidence in the literature suggests that implementing a modular approach can benefit energy efficiency and sustainability [33], [105], [106]. Offsite modular construction can benefit from the industrialisation of the production processes. This type of construction can be cleaner, faster to implement, more economical, and more sustainable [33]. Due to these reasons, this construction approach might increase the building's energy efficiency cost-effectively, particularly when looking at nZEB buildings, which have to integrate energy efficiency measures and renewable energy sources.

Although significant research studies deal with the subject in Northern Europe, China, and the USA, a modular approach in Southern Europe is poorly developed, especially for residential buildings. Scientific studies addressing the subject in this national context are scarce and limited in scope. On the other hand, the literature review also identified space for further development in research that investigates environmental impacts and cost-optimality calculations to achieve more sustainable energy-efficient buildings. Therefore, this dissertation aims to research the design and energy-efficiency optimisation of a prefabricated modular single-family building in Porto, Portugal. The building was designed to achieve high energy efficiency levels; its external envelope was optimised in BEM software and analysed in their cost-optimal aspect. This dissertation aims to elaborate on how optimisation of a modular approach regarding building design and its envelope can influence the building energy efficiency and global cost building in a Southern European country, more specifically Portugal.

Chapter 3: Methodology

This dissertation will develop a modular architectural model, design wall modules compositions, develop its passive solutions optimisation and perform the cost-optimal analysis on the building solutions. The methodological framework adopted in this project was developed in four main steps.

1. Catalogue development: a catalogue of the relevant solutions in the reviewed literature was developed in this first step. The solutions catalogued served as a basis and foundation for the rest of the dissertation project.
2. Project development: in this step, the architectural model and external envelope solutions were designed considering this dissertation's objectives. The project development will consider its openings and shadings optimisations.
3. Energy Simulation and solutions optimisation: in this step, heating loads and energy demand were calculated using the building model for each wall solution composition to optimise the external envelope solutions.
4. Cost-Effectiveness calculation: all the data gathered from previous steps were analysed and compared using a cost-optimal methodology

3.1 Catalogue development

The catalogue development phase – the first step in the methodology in this study - consists of the collection of solutions found through literature review regarding walls, floorings, windows, doors, ceilings, HVAC and RES, used to support modular approaches. In addition, the catalogue intends to gather information regarding solutions materials, thickness, thermal performance, estimated costs, embodied CO_2 emissions and embodied non-renewable energy.

The wall, flooring, and ceiling solutions were catalogued considering composition, structure type, façade material, and thickness. The density and thermal performance of the materials information was predominantly gathered from the ITE50 [107]. Costs of each material considered in the catalogue were estimated per square meter (including maintenance, when available) and gathered from a market-based price generator tool [108]. Considering that the building to be developed in the scope of this dissertation would be, in nature, prefabricated, its fabrication process would have different values for labour cost compared to the traditional construction method. Therefore, for achieving more tangible results of a prefabricated building, the labour costs were not included. Some materials, such as steel structure and aluminium façade, have their material density catalogued since it is needed to calculate the cost, where the unity were euros per kilogram. Since sustainability was considered essential for this study, the embodied CO_2 emissions and [108] non-renewable energy were also collected from the literature [98] to choose the external wall composition materials.

The windows and doors solutions were catalogued accordingly to their availability in the Portuguese market. The availability took into consideration the products where information and costs were widely accessible. The windows options research was primarily done online through the own company product catalogue and website. This measure helps to get a stable standard for pricing and quality while considering companies with product stock near the building construction, thus decreasing the embodied energy for transportation.

The HVAC solutions were catalogued according to their technology, cost, power, efficiency and availability. The availability and cost were defined by the market-based price generator tool used for wall materials [108]. The relevant efficiency and power consumptions considered were gathered from the systems factory manuals. Three types of HVAC combinations were considered to include in the cost-optimal analysis of the project. Those solutions will be designated as a reference, upgraded reference and best practice and were chosen to consider the location and climate of the project. The intention is to investigate the building optimisation performance in the best and reference scenarios and provide a middle ground alternative for this analysis.

All data gathered for the catalogue was introduced in an MS Excel file to be further analysed and used in the dissertation. The results table were organised as shown in Table 1.

Table 1 – Catalog data layout example

SOLUTION NUMBER	Material	Thickness (mm)	Density (kg/m3)	Cost (€/m2)	Maint. (€/m2.year)	Demo. (€/m2)	Cost Unit	U-Value (W/(m2·K))	GWP	NRPE
	Material 1	-	-	€ -	€ -	€ -	Kg	-	-	-
	Material 2	-	-	€ -	€ -	€ -	m2	-	-	-
	...									
	Material n	-	-	€ -	€ -	€ -	-	-	-	-

The solutions designed had its primary materials used recorded on the same table format as Table 1. The final wall composition design was later placed in a table to be displayed in this paper, as shown in Table 2.

Table 2 – Wall solution table

Solution n	
Structure Material	
Internal Material	
External Material	
Insulation Material	
nA	Xmm
nB	Xmm
nC	Xmm
nD	Xmm
nE	Xmm
nF	Xmm
nG	Xmm
nH	Xmm

3.2 Project development

The project development phase considered the architectural design of the house and external envelope solutions to be analysed in this dissertation. The project design was determined by the directives of making an energy-efficient cost-optimal modular prefabricated housing for the region of Porto.

The development of the architectural project was made in the building information model (BIM) format associated with a building energy model (BEM). Those models were developed in BIM software integrated with the data calculated and gathered from the BEM model. The architectural building was also developed considering the literature on actions and strategies that could be taken to reduce energy consumption passively (e.g. [17], [36], [40].).

The software chosen for the BIM development was Archicad24 [109] for its BIM capacities and familiarity with the software. The BIM development consisted of a Level of Detail 100 (LOD100) model with a simple representation for the development of this project [110]. Therefore, further development of the BIM was not considered, for it was not relevant for the development of the dissertation. In addition, the material composition for the external envelope in the BIM was not detailed and considered the maximum thickness of the possible solutions; this decision was taken to avoid losing vital circulation space when considering different external wall thicknesses.

The BEM software chosen was Energy-Plus [101] software [111]. The Energy-Plus model was chosen for its user-friendly interface and optimisation capacities due to its broad usage in the GUI software. For optimisation, the target was set to the lowest values of heating and cooling loads. The changing parameters set were window-to-wall ratio, considering all the building facades. The optimisation tool was also used with different combinations of architectural design to achieve the best-proven form. The U-Value calculation tool integrated into the BEM software was used for simulation wall composition and verification of thermal performance, hygrothermal performance and thermal bridges. The parameters used for the file in both tools is the same as used in the simulation step.

The External wall solutions design were chosen accordingly to the reviewed literature to define efficacy, modularity and availability in the Portuguese market. At the same time, the catalogue developed in the previous phase of the methodology was used to distinguish the solutions based on cost, density, thermal performance, embodied non-renewable energy values and embodied emissions. The objective of a modular prefabricated approach was the defining factor for the wall solutions; materials with low weight per square meter, thermal efficiency, and widely available in the Portuguese market were preferred. A base design solution was chosen. The base solution had different alternatives to material combinations. The combinations were designed to be tested and optimised in the next phase of the methodology.

3.3 Energy simulation and solutions optimization

The simulation generated by the Design-Builder[111] software is considered a sub-hourly simulation with the wall solution optimisation. The simulation was made with a two-time-step per hour with air temperature control. All modelled volumes were considered in the calculations. The solar gain distribution configuration was set to average on all days, according to the pre-set font of the software. Moreover, the solar gains were calculated using the simple diffuse sky model template. The geographic location parameters by latitude and longitude, time and daylight saving, annual weather, and yearly temperatures were set by the weather data drawn from the Energy-Plus[101] database [112] regarding Porto's region in Portugal. The building north orientation was defined by a 90-degree angle from its north façade to simplify the simulation process, as shown in figure 3. Finally, the project location was chosen due to its availability in the simulations templates and its Mediterranean climate [113], enhancing the project's relevance to locations with similar climates.

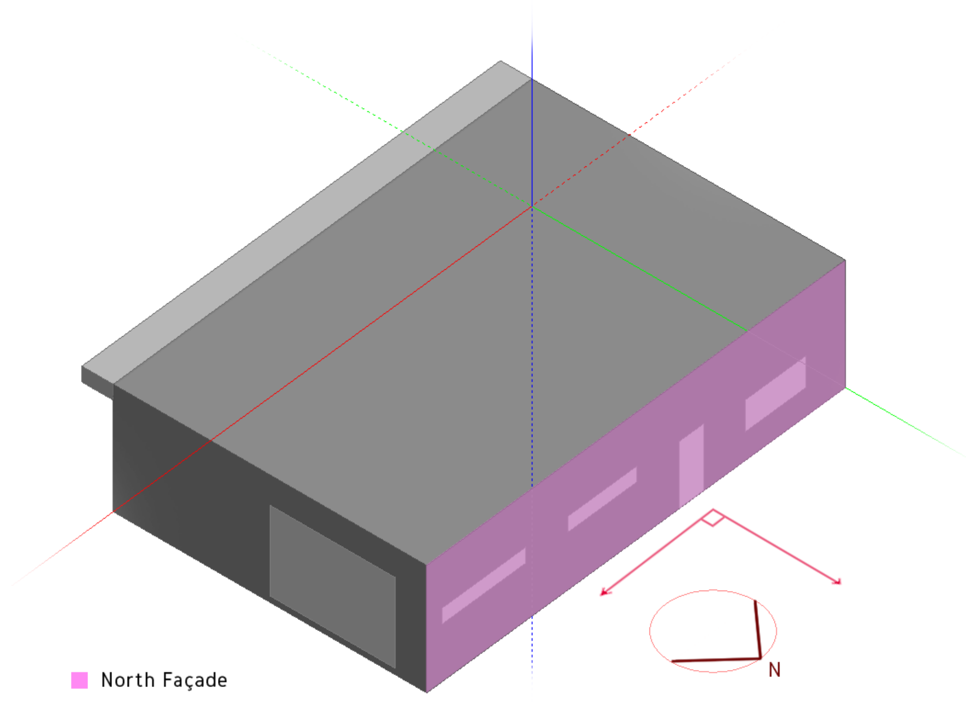


Figure 3 – Project North façade orientation

Some of the building's parameters used in the simulation are represented in table 3. For the building occupancy, the parameters used were the available template for a family of three [114], [115],[26].

Table 3 – Additional simulation configurations

Simulation configuration		
Location	Template Design-Builder for Porto/Pedras Rubras	
Site Location	Latitude	41,23
	Longitude	-8,68
	ASHRAE climate zone	3C
Site details	Elevation above sea-level	77
	Exposure to wind	2 - Normal
	Site Orientation	0
	Site level variation	No
Ground	Template	Granulated Gray 453M
	Surface solar and visible reflectance	0,2
	Snow reflected solar and daylight multiplier	2
Outiside air definition method		4 - Min fresh air (Sum per person + per area)
Ventilation	Model infiltration	Yes
	Constant air ration (ac/h)	1
	Schedule	On 24/7
HVAC template		Portugal
Mechanical ventilation		On
Heating	Heated	Yes
	Fuel	1 - Electricity from the grid
	Heating system seasonal CoP	1
	Mec. Vent. load	1-Met by zone equipment
Cooling	Cooled	Yes
	Cooling system	Default
	Fuel	1 - Electricity from the grid
	Cooling system seasonal CoP	1
DHW	DHW system	On
	DHW template	Project DHW
	Type	Same as HVAC
	Delivery temperatures	65
	Main supply temperature	10
Lightning and appliances energy consumption		4W/m2

Temperature considered in simulations								
Monthly Design Dry Bulb	Jan.	17,4	Mean Coincident wet bulb temperatures	Jan.	12,5	Monthly Minimum dry-bulb temperatures	Jan.	10,2
	Feb.	20,2		Feb.	13,2		Feb.	10,7
	Mar.	24,7		Mar.	13,6		Mar.	12,7
	Apr.	25,9		Apr.	16,3		Apr.	14,7
	May	29,2		May	17,4		May	17,3
	June	31,4		June	18,9		June	18,8
	July	33,3		July	19,9		July	19,9
	Aug.	33,3		Aug.	19,3		Aug.	20,2
	Sept.	30,2		Sept.	18,6		Sept.	18,4
	Oct.	26,6		Oct.	17,4		Oct.	16,3

	Nov.	22		Nov.	15,5		Nov.	13,7
	Dec.	18		Dec.	13,2		Dec.	11,2

The model simulation considered the "Ideal Loads" configuration for the HVAC model, which was set to simple. This measure was adopted to simulate the thermal behaviour of the building in ideal energy load conditions. Other configurations that could alter the energy demand results were configurable to simple and set to the default Portuguese template. Simulations were conducted to increase the energy efficiency by optimising the building envelope, and therefore, renewable energy sources were not considered in the simulation, although they are necessary for the achievement of the nZEB level, as discussed previously.

The model uses a single thermal zone approach in order to simplify calculations and reduce computation time. Shadings were modelled as building components. The windows and door proprieties were defined according to the chosen window in the catalogue step. All the external envelope options were modelled and had their attributes inputted in the software using the information contained in the catalogue. The simulation was run in the software Design-Builder[111] version 6.1.7.007. The outputs from the simulation were the annual sub-hourly heating load and cooling load. The building was simulated in its reference solution and the alternative external envelope possible combinations in the optimisation step for comparison purposes. Since the quasi-steady-state methodology is required in the Portuguese regulation [64]. The steady-state method was considered as a calculation methodology for the software Pernigotto [116]

For the optimisation of the model, the tool optimisation of Design-Builder[111] and Energy-Plus[101] was used. For the analysis configuration, the category considered for the simulated options were the combination of wall compositions. The rest of the building was tested as defined by the catalogue. The optimisation results were displayed in a table that was later included in the cost-effectiveness calculation step.

3.4 Cost-effectiveness calculation

For the cost-effectiveness calculation, the following methodology was used. The global material costs were calculated in a Microsoft Excel sheet, the data used was extracted from the catalogue. The time considered for the building lifetime was 30 years, intending to compare the results with the reviewed literature. The cost was calculated according to the equation as it follows:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right]$$

where:

- τ means the calculation period;
- Cg(τ) means global cost (referred to starting year τ 0) over the calculation period;
- CI means initial investment costs for a measure or set of measures j;
- Ca,I (j) means annual cost during year i for a measure or set of measures j;
- Vf,τ (j), means the residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ 0).
- Rd (i) means discount factor for the year i based on discount rate r to be calculated, were:

$$R_d(p) = \left(\frac{1}{1 + r/100} \right)^p$$

Where p means the number of years from the starting period, and r means the actual discount rate.

Each simulated solution option had its global cost and initial cost calculated. The HVAC system's efficiency values were added to the cost-effectiveness table to simplify the simulation step. Those values were later added to the cost-optimal MS Excel tool and were accounted for in the assessment. Finally, all the global costs, initial costs, and primary energy consumption were displayed in scatter graphs with all the possible 577 combinations for analysing and comparing the results with the reference solution.

Chapter 4: Results

In this chapter, it will be discussed the results of the processes explained in the methodology. Then, the results are displayed according to the latest findings of the development process of each step and the conclusions that can be obtained from them.

4.1 Catalogue

The catalogue contemplated building solutions used in the reviewed literature. However, not every material had all of its categories filled due to information availability and time constraints. The complete catalogue is available in Annex 1. The solutions for this research were selected from the reviewed literature. Aspects of some relevant literature influenced the wall, roof, ground floor and foundation solutions designed.

The most meaningful projects for developing the opaque envelope were the prefabricated modular housing and renovation systems such as Almeida et al.[24], Pihelo et al.[34], and Silva et al.[28]. Although some of the solutions were used for renovation scenarios, their approach on the panel design raised the possibility of developing a thermally efficient building only using those panels in a cost-efficient way. Furthermore, new buildings solutions such as Barthelmes et al.[16], Becchio et al. [43], Caseiro [97], and Mendes [26] influenced the design by modular design, logistics, and materials. In addition, other projects such as Freitas [27], Leal [36], and Tavares et al.[72] influenced the construction technique and materials.

The wall solutions designed were divided into the structure, external façade, internal element, and insulation. The first choice for the structure was the light steel framing (LSF), which can contribute to the building's sustainability considering its 100% recyclability and reduction potential of construction debris [26], [117] structure also contributes to the building's sustainability and cost-effectiveness [26]. The second structure option analysed in this project is a wood-frame panel. This solution was chosen for its low environmental impact and lightness[47], [118], [119]. For the external facade, as in the Silva et al.[28], Tavares et al.[47] the options were an OSBIII panel proper for the external environment, and an Aluminium plate façade was selected for its sustainability and thermal performance. The aluminium was chosen for its lightness, low maintenance cost, and recyclability. For the internal material, OSB III panel. Finally, the insulation materials chosen were black cork, XPS and mineral wool. According to what is considered a common application in the Portuguese market, these solutions were simulated in different thicknesses, making a total of 8 options for each insulation. Thus, in total, the wall combinations considered 192 different options, as shown in table 4. The organisation of those walls is visible in Figure 4.

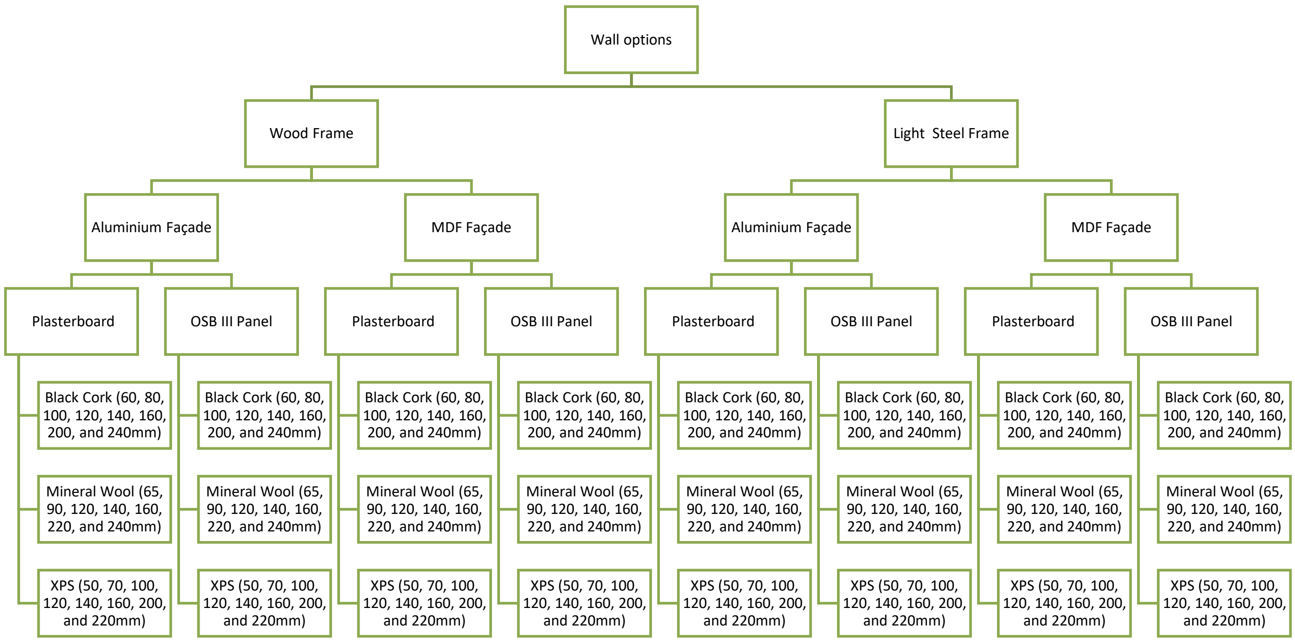


Figure 4 - Wall options and possible combinations

Table 4 - *Wall solutions primary materials and compositions*

Solution 1		Solution 2		Solution 3		Solution 4		Solution 5	
Steel Frame		Steel Frame		Steel Frame		Steel Frame		Steel Frame	
OSB III 15mm board Boards		OSB III 15mm board Boards		OSB III 15mm board Boards		Plaster board		Plaster board	
Aluminium Façade		Aluminium Façade		Aluminium Façade		MDF Façade		MDF Façade	
Black cork		XPS		Mineral Wool		Black cork		XPS	
1A	60mm	2A	50mm	3A	65mm	4A	60mm	5A	50mm
1B	80mm	2B	70mm	3B	90mm	4B	80mm	5B	70mm
1C	100mm	2C	100mm	3C	120mm	4C	100mm	5C	100mm
1D	120mm	2D	120mm	3D	140mm	4D	120mm	5D	120mm
1E	140mm	2E	140mm	3E	160mm	4E	140mm	5E	140mm
1F	160mm	2F	160mm	3F	180mm	4F	160mm	5F	160mm
1G	200mm	2G	200mm	3G	220mm	4G	200mm	5G	200mm
1H	240mm	2H	220mm	3H	240mm	4H	240mm	5H	220mm
Solution 6		Solution 7		Solution 8		Solution 9		Solution 10	
Steel Frame		Steel Frame		Steel Frame		Steel Frame		Steel Frame	
Plaster board		Plaster board		Plaster board		Plaster board		OSB III 15mm board Boards	
MDF Façade		Aluminium Façade		Aluminium Façade		Aluminium Façade		MDF Façade	
Mineral Wool		Black cork		XPS		Mineral Wool		Black cork	
6A	65mm	7A	60mm	8A	50mm	9A	65mm	10A	60mm
6B	90mm	7B	80mm	8B	70mm	9B	90mm	10B	80mm
6C	120mm	7C	100mm	8C	100mm	9C	120mm	10C	100mm
6D	140mm	7D	120mm	8D	120mm	9D	140mm	10D	120mm
6E	160mm	7E	140mm	8E	140mm	9E	160mm	10E	140mm
6F	180mm	7F	160mm	8F	160mm	9F	180mm	10F	160mm
6G	220mm	7G	200mm	8G	200mm	9G	220mm	10G	200mm
6H	240mm	7H	240mm	8H	220mm	9H	240mm	10H	240mm

Solution 11		Solution 12		Solution 13		Solution 14		Solution 15	
Steel Frame		Steel Frame		Wood Frame		Wood Frame		Wood Frame	
OSB III 15mm board Boards		OSB III 15mm board Boards		OSB III 15mm board Boards		OSB III 15mm board Boards		OSB III 15mm board Boards	
MDF Façade		MDF Façade		Aluminium Façade		Aluminium Façade		Aluminium Façade	
XPS		Mineral Wool		Black cork		XPS		Mineral Wool	
11A	50mm	12A	65mm	13A	60mm	14A	50mm	15A	65mm
11B	70mm	12B	90mm	13B	80mm	14B	70mm	15B	90mm
11C	100mm	12C	120mm	13C	100mm	14C	100mm	15C	120mm
11D	120mm	12D	140mm	13D	120mm	14D	120mm	15D	140mm
11E	140mm	12E	160mm	13E	140mm	14E	140mm	15E	160mm
11F	160mm	12F	180mm	13F	160mm	14F	160mm	15F	180mm
11G	200mm	12G	220mm	13G	200mm	14G	200mm	15G	220mm
11H	220mm	12H	240mm	13H	240mm	14H	220mm	15H	240mm

Solution 16		Solution 17		Solution 18		Solution 19		Solution 20	
Wood Frame		Wood Frame		Wood Frame		Wood Frame		Wood Frame	
Plaster board		Plaster board		Plaster board		Plaster board		Plaster board	
MDF Façade		MDF Façade		MDF Façade		Aluminium Façade		Aluminium Façade	
Black cork		XPS		Mineral Wool		Black cork		XPS	
16A	60mm	17A	50mm	18A	65mm	19A	60mm	20A	50mm
16B	80mm	17B	70mm	18B	90mm	19B	80mm	20B	70mm
16C	100mm	17C	100mm	18C	120mm	19C	100mm	20C	100mm
16D	120mm	17D	120mm	18D	140mm	19D	120mm	20D	120mm
16E	140mm	17E	140mm	18E	160mm	19E	140mm	20E	140mm
16F	160mm	17F	160mm	18F	180mm	19F	160mm	20F	160mm
16G	200mm	17G	200mm	18G	220mm	19G	200mm	20G	200mm
16H	240mm	17H	220mm	18H	240mm	19H	240mm	20H	220mm

Solution 21		Solution 22		Solution 23		Solution 24	
Wood Frame		Wood Frame		Wood Frame		Wood Frame	
Plaster board		OSB III 15mm board Boards		OSB III 15mm board Boards		OSB III 15mm board Boards	
Aluminium Façade		MDF Façade		MDF Façade		MDF Façade	
Mineral Wool		Black cork		XPS		Mineral Wool	
21A	65mm	22A	60mm	23A	50mm	24A	65mm
21B	90mm	22B	80mm	23B	70mm	24B	90mm
21C	120mm	22C	100mm	23C	100mm	24C	120mm
21D	140mm	22D	120mm	23D	120mm	24D	140mm
21E	160mm	22E	140mm	23E	140mm	24E	160mm
21F	180mm	22F	160mm	23F	160mm	24F	180mm
21G	220mm	22G	200mm	23G	200mm	24G	220mm
21H	240mm	22H	240mm	23H	220mm	24H	240mm

The reference external wall solution was a double hollowed 15cm brick wall with an air gap between layers. This option was chosen according to its standard practice in the Portuguese market [120] and availability in the *gerador de preços* [108] database. The reference roof solution chosen was a non-accessible non-ventilated plane concrete slab with dry expanded clay as covering. This solution was selected in *gerador de preços* [108] as a standard roof practice [121].

The windows chosen were double glazed windows with 13mm of air gap between sheets and a U-Value of 1.96 W/m^2-K. The chosen door is a simple painted wood model, widely available in the Portuguese market with a U-Value of 2.823 W/m^2-K. Both opening solutions values were accounted for in all the building simulations to limit the final options to be accessed in the cost-optimal analysis.

The flooring solutions considered for the development of this dissertation were a simple LSF or wood frame structure accordingly to the wall structure composition. Therefore, the flooring was composed of a 140mm structure with mineral wool insulation, smart vapour barrier, OSB III panel structure purpose for both panel sides, and a wood plank finishing. The reference flooring solution was a concrete slab with 100mm of thickness with 50mm mineral wool insulation, screed, vapour retarder, and wood plank flooring. Moreover, to limit the optimisation results, it was not considered other insulation materials or thicknesses on the flooring solutions.

For the roof solutions, the most relevant literature was the study of Capozzoli et al.[122] and Perini et al.[123]. The chosen option was an extensive green roof with an LSF structure and a solar panel roofing with an LSF structure. Both solutions were designed to have high thermal performance while being relatively light and easy to transport and assembled on site. The lightness can be attributed to the composition of materials. The mobility can be attributed to the module size and its capacity to be fabricated in smaller parts. The roof module size depends on the fabrication method and transportation equipment. Since those factors were not on the scope for this dissertation, the panel final size was not defined. An assembly image can be seen in figure 5. The ground floor and foundation design considered standard methods. That being a standard LSF or Wood Frame slab with a concrete foundation. The structure on the roof and flooring will vary accordingly to the wall option simulated. Those practices are widely available on the Portuguese market [36].

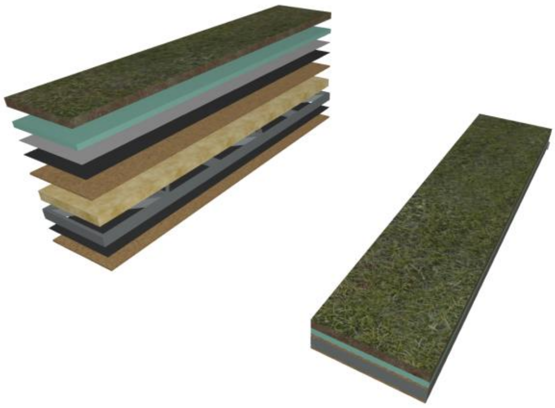


Figure 5 - Roof module representation

Three HVAC systems combinations were chosen as part of the solutions packages to develop the cost-optimal calculations. The number of system options was chosen to limit the final number of combinations in the optimisation step by 577 options. The reference solution was constituted by a combination of a gas boiler for domestic hot water (DHW), an electric heater, and an air conditioning (AC) split unity, which is also the default setup considering in the national building code [64]–[66]. The second system improved the reference solution's heating system; composed a wall-mounted water radiator, gas boiler for DHW and heating system, and AC split with an external condenser. Finally, the best practice solution was a water-to-water geothermal reversible heat pump in the heating, cooling, and DHW. The best practice system solution was selected due to its high performance [44]. All systems models costs were selected according to the price generator tool, CYPE, availability [108], and their efficiency was gathered from the manufacturer's website.

The results obtained from the cataloguing of solutions and materials are that various materials are used in the literature for structure, façade and isolation material. Those materials mainly being:

- Wood structure: considered for its low LCA values, good thermal performance and lightness [27], [34], [93], [118], [124].
- Light Steel Frame: considered for its lightness and high recyclability [36], [37], [47].
- MDF Wood façade: considered for high thermal performance and sustainability [27], [97].
- Aluminium façade: considered for its low maintenance and high recyclability [28].
- Mineral wool insulation: considered for its large availability in the market, low cost, and good thermal performance [26], [34].
- Cork insulation: considered for its high thermal performance and availability in Portugal [28], [89], [125].

The designed and catalogued solutions were the base for the development of the following methodologies steps.

4.2 Project

The development of this project considered the principle that it should be a small modular house that can fit different inhabitants needs. A module can serve as a studio dwelling with all housing needs integrated into the same space. The modules can also form an ampler housing to accommodate different family sizes and configurations comfortably. For the basic model, it was considered a 5-meter for 10-meter building footprint. Therefore, the housing is a studio apartment with basic needs, as seen in figure 6. This basic model defined the two-bedroom and 3-bedroom building architecture, as seen in figures 7, 8, 9, 10, and 11. For this dissertation, the simulations, optimisation and analysis were made around the building with three rooms for the average family size in Portugal of 3 inhabitants [114], [115]. The final architecture was a product of an iterative development between designing and simulating the optimal building design.

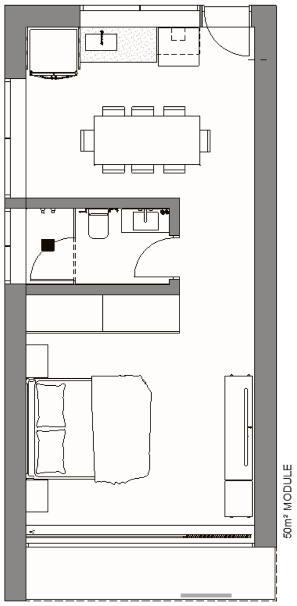


Figure 6 - Building Module 1 Bedroom

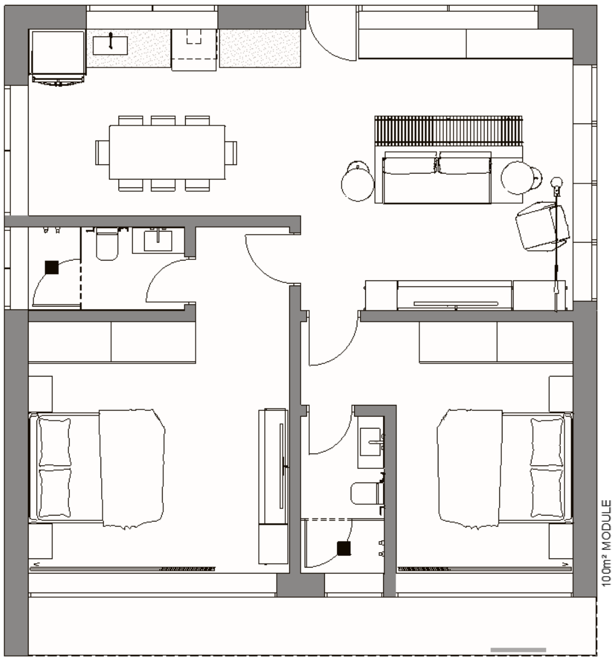


Figure 7 - Building Module 2 Bedroom

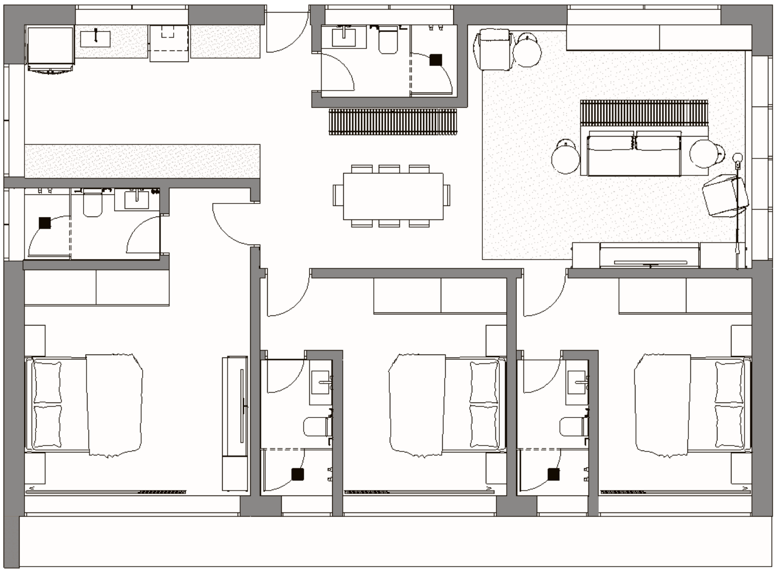


Figure 8 - 3 Bedroom Module

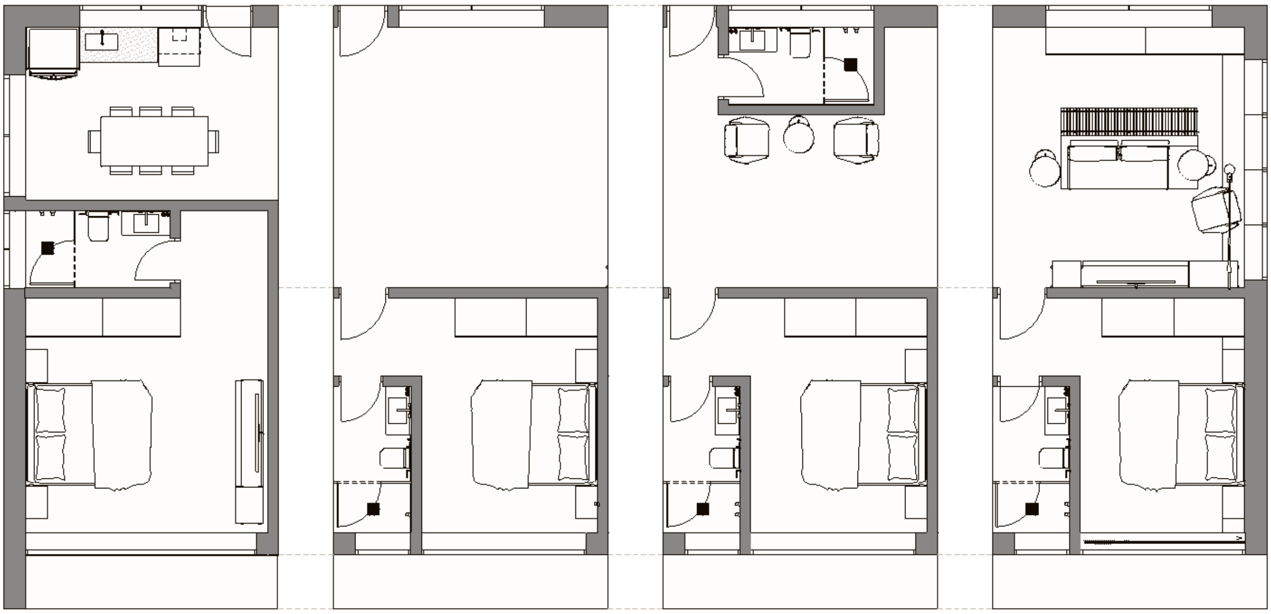


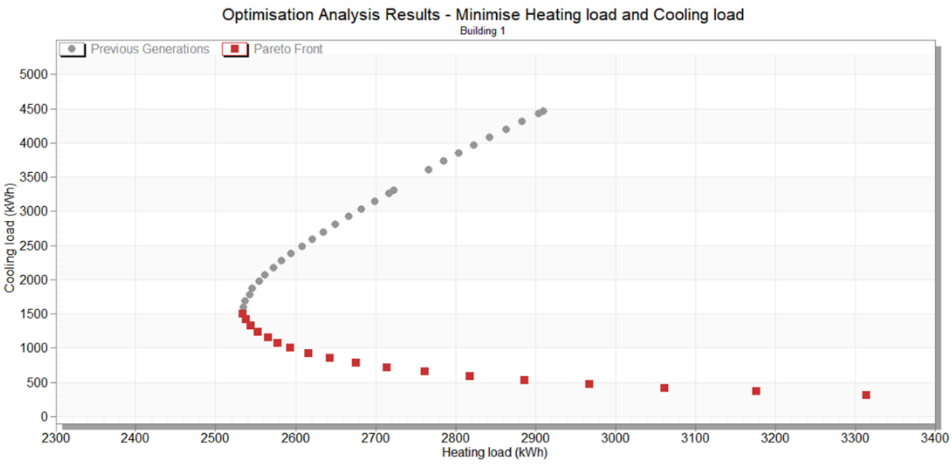
Figure 9 - Modules plan view

Figure 10 - Modules 3D view

Figure 11 - Isometric rendered view of the separated modules

During the design of the modules, the plan room organisation and building orientation were decided considering the rooms' function and the best orientation for passive heat gains. The orientation follows the recommended pattern observed in the Solar Decathlon in Spain [40], [44], [52]. The buildings with the best thermal performance results had their more permeable façade oriented to the south. The functional rooms were placed with a north orientation, and the living rooms were placed facing south to use the heat gains in favour of the rooms with more usage time.

The buildings openings were optimised for the three bedrooms model. In the software Design-Builder[111], the module's volumetric model and each wall were tested under the optimisation setting to the window to wall ratio, with the objective targeted to heating load and cooling load. The whole building optimisation average of optimal solutions, those dominant in each result category, resulted in a 27% window to wall ratio. Figure 12 shows the results of the whole building simulation, the Pareto front being the dominant solution and the Previous generations being simulations that resulted in non-dominant results. The final building design contemplated a 54m² translucent envelope of the entire 200m² façade available, thus achieving the target. The translucent envelope had 34.77m² for the south façade, 11.40m² for the east façade, 3.13m² for the west façade, and 4.70m2 for the north façade. The south façade represent 64% of the total building window to wall ratio, relating to the study by Yu et al.[40] about the projects developed for the Solar Decathlon Madrid, the best performing projects had a 40% to 70% windows to wall ratio facing the south façade.



Window to Wall Ration optimization results			
Info	Objective	Objective	Variable
Category	Heating load (kWh)	Cooling load (kWh)	Window to Wall %
Optimal Designs	2616,10	924,86	30
Optimal Designs	2643,13	852,50	28
Optimal Designs	2537,87	1415,28	42
Optimal Designs	2967,73	473,34	16
Optimal Designs	2761,93	651,96	22
Optimal Designs	3314,68	315,53	10
Optimal Designs	2817,89	589,93	20
Optimal Designs	2565,80	1156,74	36
Optimal Designs	2675,66	782,32	26
Optimal Designs	2593,60	999,73	32
Optimal Designs	3062,36	419,32	14
Optimal Designs	2886,23	530,84	18
Optimal Designs	2577,47	1077,20	34
Optimal Designs	2714,39	716,21	24
	2682,43	3031,44	74
	2717,29	3259,50	78
	2635,53	2697,19	68
	2537,87	1415,28	42
	2572,58	2174,03	58
	2717,29	3259,50	78
	...	...	...

Figure 12 - Optimisation Graphs and Result from Building Volume Simulation

With the building opening optimised, the heat gains during summer would be high due to the building south opening orientation. The possible shading models were simulated in Design-Builder[111] to improve the building passive thermal performance. It compared the basic simulation model with the optimised openings heating loads and cooling loads with the shading options simulation results to achieve such results. The shading considered for the development of this project was a simple marquise overhang and lateral brise soleil. The shading elements have a 1-meter distance from the main body of the building. This size was defined to keep the shading in the pattern of 1m by 1m of the modules. The solar chart of the Porto City was also considered to choose the overhang distance, aiming to protect the south façade from direct sunlight between midday.

Shading solution 1 is a simple overhang option over the south wall. Its implantation resulted in the reduction of 25,3% of the Heating Load and Cooling Load sum. Shading 2, 3, and 4 tested the addition of a lateral shading in the side of the building, those being in the west, west and east, and east, respectively. Shading 3 had the best result, although it had a minimal difference between shading 2, making shading number 2 the best option by reducing the construction material used in the building. Solutions 5 and 6 tested just the impact of the lateral shading on the west and east façade, respectively. The result was not favourable since they did not block most of the direct sunlight during the day. Shading 7 and 8 tested an overhang shading in the east façade, it had some impacts over the main building, but they were not significant compared to their material usage addition. Shading 9 tested a small 40cm overhang directly above the north windows. As predicted, the North shading had little impact. The result and choice for shading used in the project's development were Shading 2, which has the most impact using less material than the other options, as seen in figure 13.

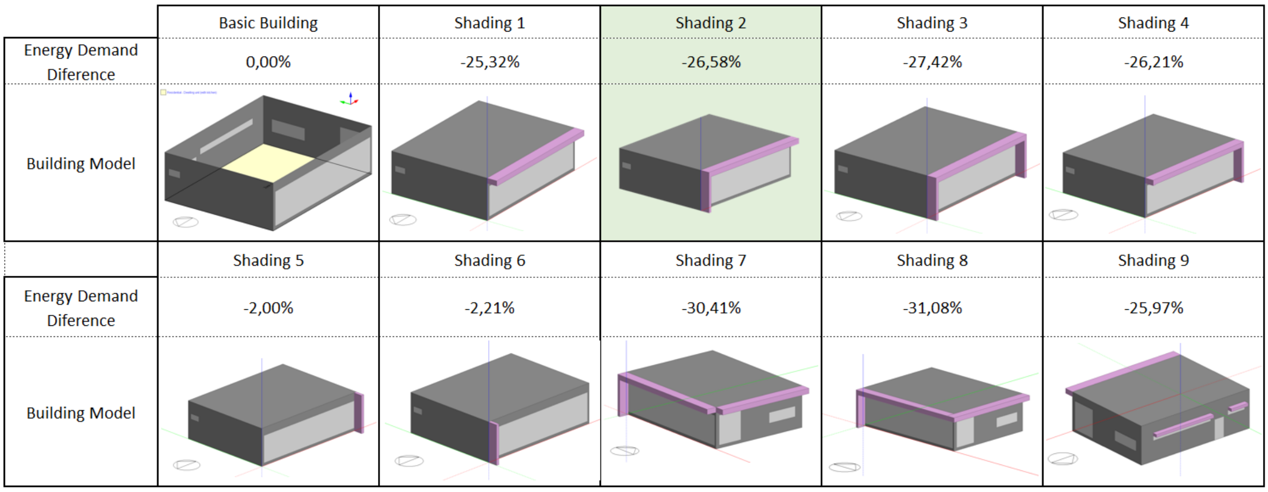


Figure 13 - Shading Building Model and Energy Demand Difference

After modelling the optimised shading, the building was modelled in a Building Information Model (BIM). The software used was Archicad [109]. The model was used to finalise the plan, account for material use and design the building wall module of the prefabrication process. The building construction is a prefabricated, panelised construction. The panelised construction was selected for its light transport, lightweight, and fast assembly [32], [83]. The panel for this dissertation is made of four primary materials, as seen in Figure 14. The development of the architectural project the module considered was its thickest variation, with 277 millimetres thick. Using the thickest solutions tested would allow the project to maintain its functional spaces while optimising the possible external wall solutions. The panels' organisation are shown in figure 15 in the form of an isometric diagram.

Figure 14 - LSF panel exploded view

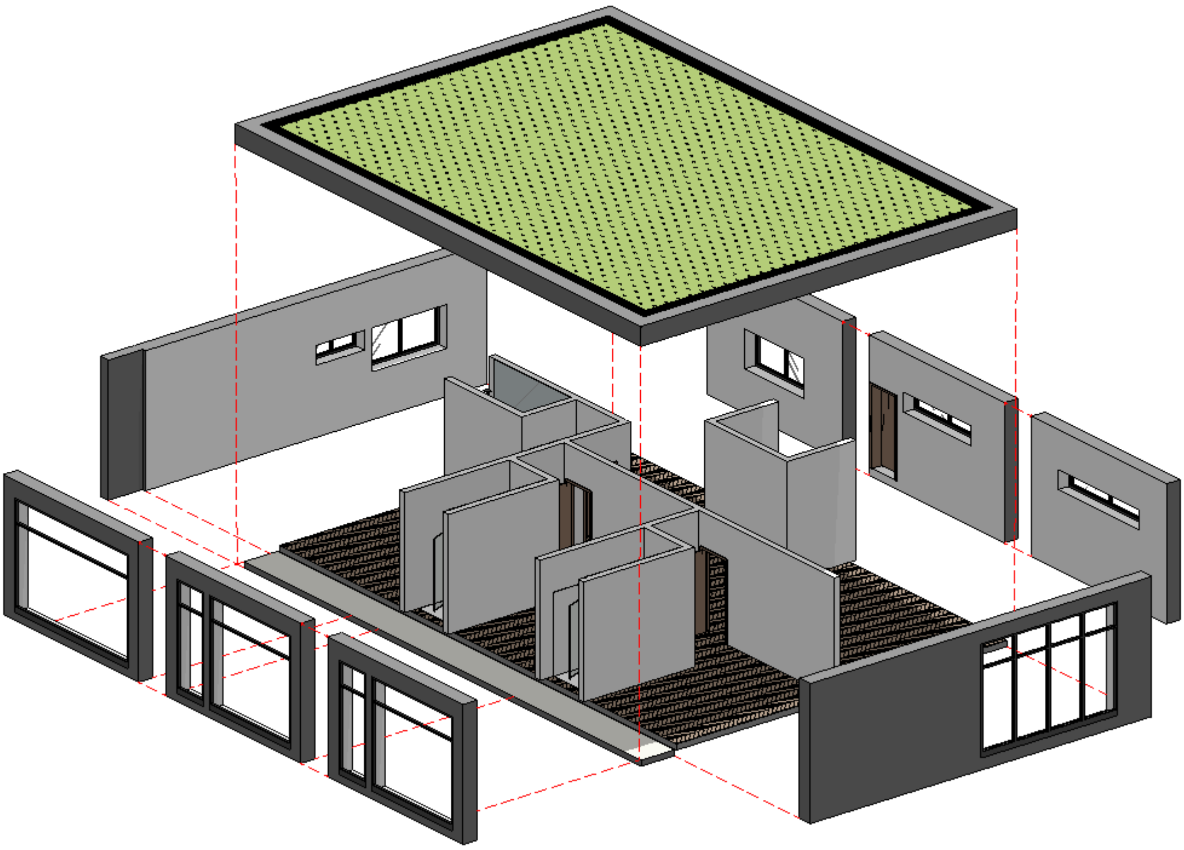


Figure 15 - Three-bedroom house exploded panel diagram

In its possible material finishings, the designed project has a function-driven aesthetic, and it was modelled to comply with the objective of this dissertation. That being: be cost-optimal, prefabricated, modular, light, and sustainable. The final aesthetics of the three-bedroom house is as shown in figures 16, 17, 18, and 19.

Figure 16 - Rendered aluminium façade South and East view

Figure 17 - Rendered aluminium façade North view

Figure 18 - Rendered Wooden South façade view

Figure 19 - Rendered Wooden North façade view

It was concluded on the development of the project that although the precise number was not calculated, the optimisation of the windows to wall ratio had a positive effect on the project energy demand. The optimisation of the shading element decreased by 33% of the building energy demand. Although this decrease was expected, adopting the simulation and optimisation in the early stages of the project development was vital for choosing the shading element with the most impactful results. This decision has increased the efficiency of the shading while maintaining its efficacy.

4.3 Simulation

The building designed in the previous step had its thermal performance simulated in every category accounted for in the dissertation. The results displayed some early results on the best options when considering only their thermal performance. The difference between the results of the simulated solutions is expected since their thermal performance was a category catalogued in the first step of this dissertation. Although most of the results were expected, the closeness of the results demonstrated the importance of the optimisation procedure. The cost-optimal analysis could determine optimal solutions that were not expected.

The wall options, as catalogued, were simulated as explained in the methodology. The results were displayed in a table available in Annex 1. The simulations showed an average heating load of 14.1 kWh/m^2.year and an average cooling load of 5.2 kWh/m^2.year, not considering the reference building. Although the results of the simulated solutions were very similar, on average, the solutions with LSF displayed a better result than the wood structure. The best performing insulation material overall was the black cork due to its better thermal performance. Nevertheless, as expected, all insulation materials had a similar result since their thickness was chosen to give a similar thermal performance. The façade with the MDF panel had shown better results than the aluminium façade. However, the closeness of their results shows that it is more relevant to the insulation material's thermal performance than the external element. It was also possible to identify the wall solution's thermal performance with OSB III panel than the plasterboard solution.

The basic simulation of the reference building was tested with the standard materials for the construction. As expected, the result was low energy efficiency compared to the other catalogued solutions. The heat gain result was 50.14 kWh/m^2.year, and the cooling gain result was 19.02 kWh/m^2.year. Compared to the optimised solutions, the reference solution is 355% and 365% above the average heating and cooling load, respectively. This difference can be seen in figures 20 and 21 when comparing the yearly energy demand graph.

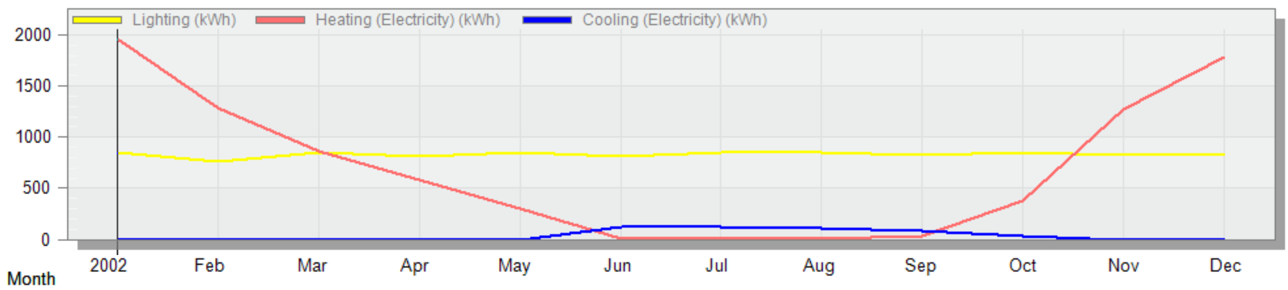


Figure 20 - Yearly energy demand simulation graph, Reference Solution

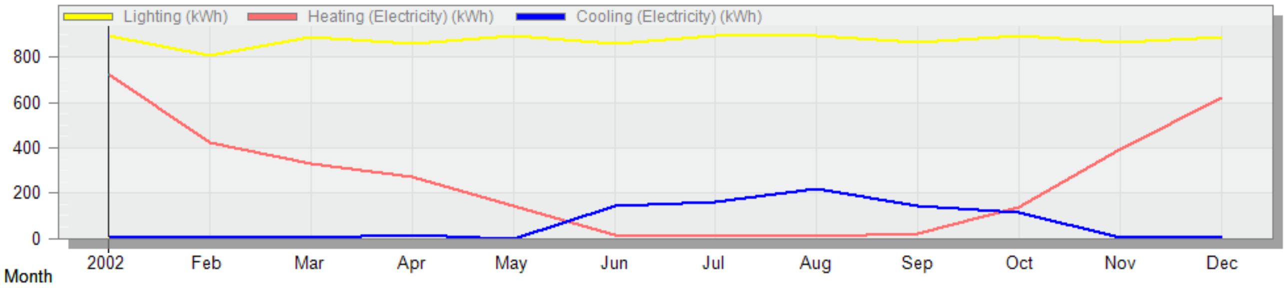


Figure 21 - Yearly energy demand graph, 12B Solution

Although the results demonstrated exciting results that are mostly predictable, as shown in figure 22, the simulation results alone do not appoint the optimal solutions. The graph in figure 22 was developed using the results obtained in the simulation of the wall options; the results are shown in order from 1A to 24G and reference. It demonstrates how similar the solutions behaved and how this behaviour was expected. The thickness of the insulation materials was chosen and tested in Design-Builder[111] to achieve similar thermal transmittance values; therefore, the expected similar results. Moreover, it displayed a similarity in the results that prove the importance of the optimisation process to avoid unnecessary insulation elements to achieve a similar result that might be cost-optimal.

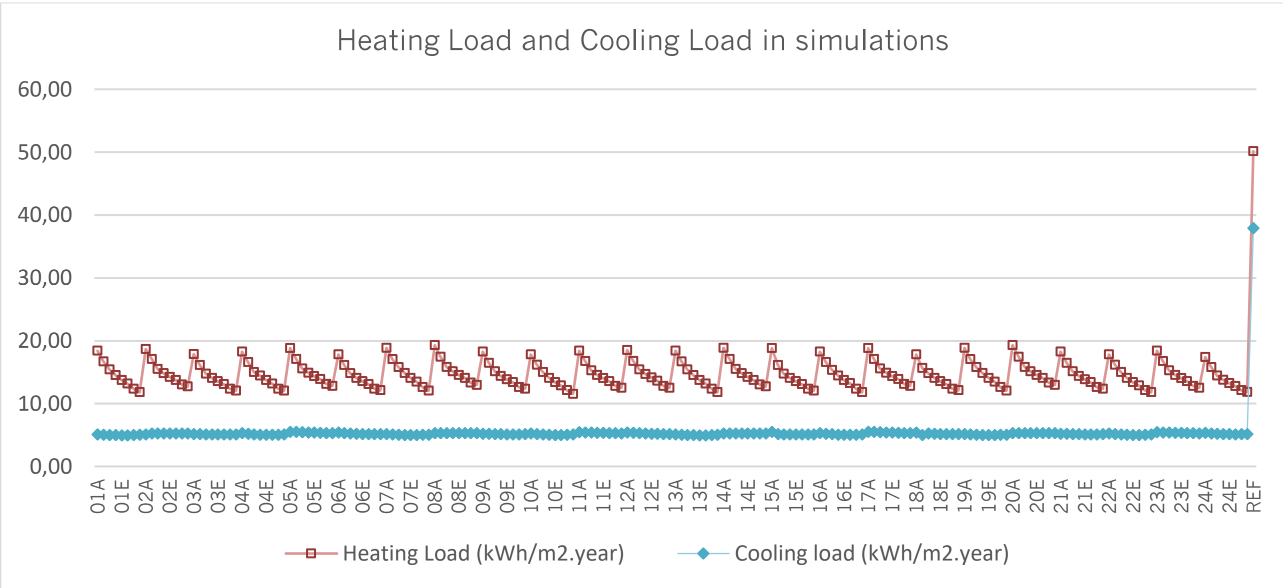


Figure 22 - Yearly energy demand based on the simulated cooling loads and heating loads parameters—results of 24 main combinations varying from (nA to nG) and reference solution (REF).

4.4 Cost-optimal analysis

The cost-optimal assessment was developed with the results obtained from previous steps. The costs considered the 577 combinations of systems for the optimisation. Their values were considered as a private investment which included taxes accordingly to the Portuguese regulation. As well, the simulation results considered the results from the software Design-Builder[111]. Finally, the solutions variations and efficiency were set accordingly to the catalogue solutions.

The results were then displayed in graphics. As shown in Table 6, the graphics were colour-coded to promote a better understanding of the results. The solutions were separated in their structure element, façade material and HVAC system. Solutions 1 to 24 are displayed in table 3. The HVAC system 1 (S1) represents the traditional solution. The HVAC system 2 (S2) represents the middle-ground solution. Finally, the HVAC system 3 (S3) represents the best practice solution.

Table 5 - Colour coding of the compositions of the solutions

System 1 - (reference system) + LSF Structure + Aluminium Facade	System 2 - (middle-ground system) + LSF Structure + Aluminium Facade	System 3 - (Best-practice system) + LSF Structure + Aluminium Facade
System 1 - (reference system) + LSF Structure + Wood Facade	System 2 - (middle-ground system) + LSF Structure + Wood Facade	System 3 - (Best-practice system) + LSF Structure + Wood Facade
System 1 - (reference system) + Wood Structure + Aluminium Facade	System 2 - (middle-ground system) + Wood Structure + Aluminium Facade	System 3 - (Best-practice system) + Wood Structure + Aluminium Facade
System 1 - (reference system) + Wood Structure + Wood Facade	System 2 - (middle-ground system) + Wood Structure + Wood Facade	System 3 – (Best-practice system) + Wood Structure + Wood Facade

The graph illustrated in figure 23 shows the results of the cost-optimal analysis. This graph compares the global cost in $€/m^2$ and primary energy consumption in $kW/h.m^2$. The reference building solution is the point of the main comparison. Solutions with lower energy consumption and global costs in comparison with the reference solution are cost-optimal.

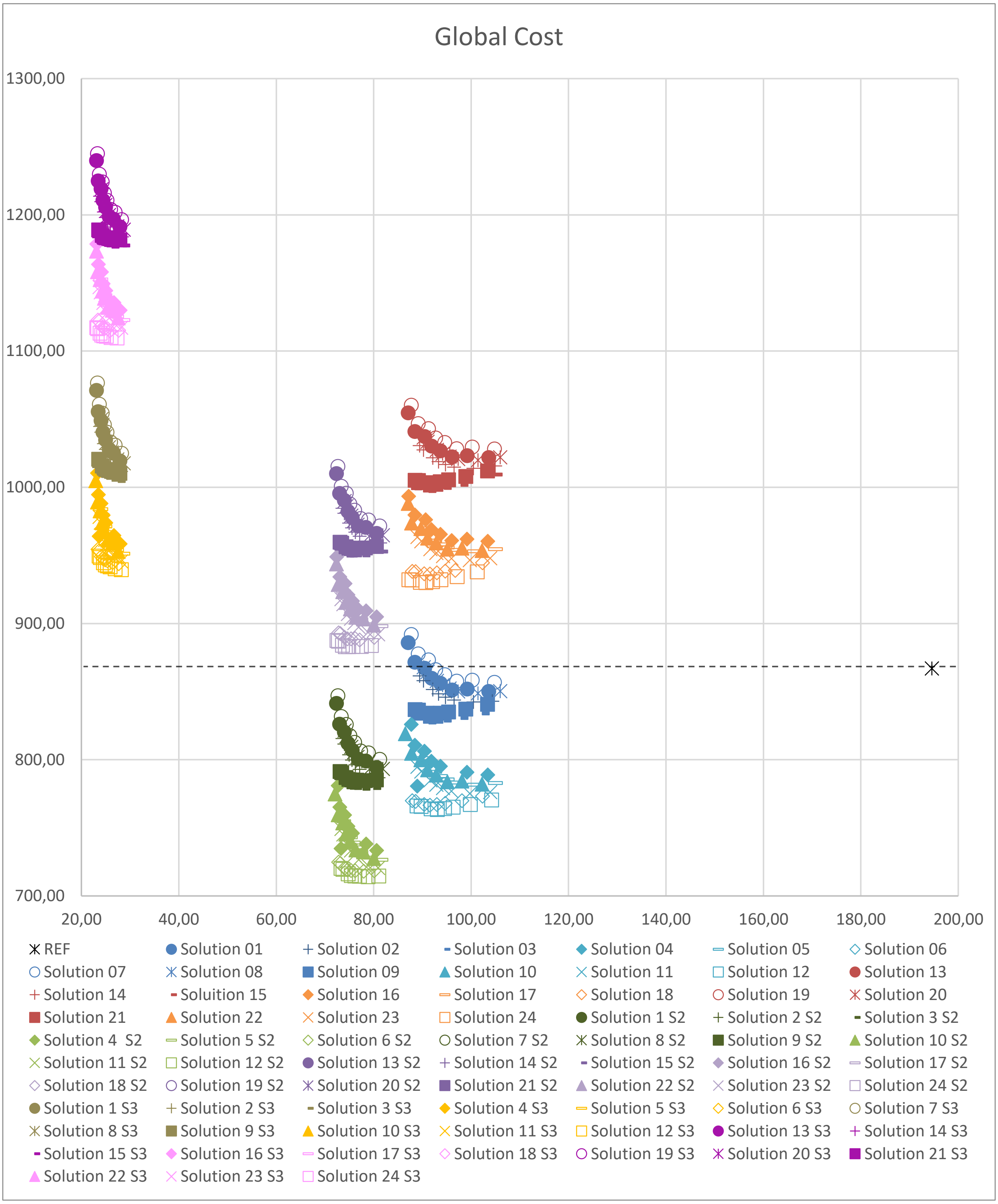


Figure 23 - Cost Optimal Graph 1 – Cost optimal solutions

The second graph is represented by figure 24, a graph considering the initial cost and primary energy consumption. This graph was developed considering the initial private costs of all options, and it aims to show how the initial costs relate to the global costs. This comparison displays the importance of global cost analysis. The importance being, a low initial cost does not imply that a solution will have a lower cost during the building lifecycle. Therefore, the building solution with the lowest initial cost in this study, 12B S2, is not the best cost-optimal solution.

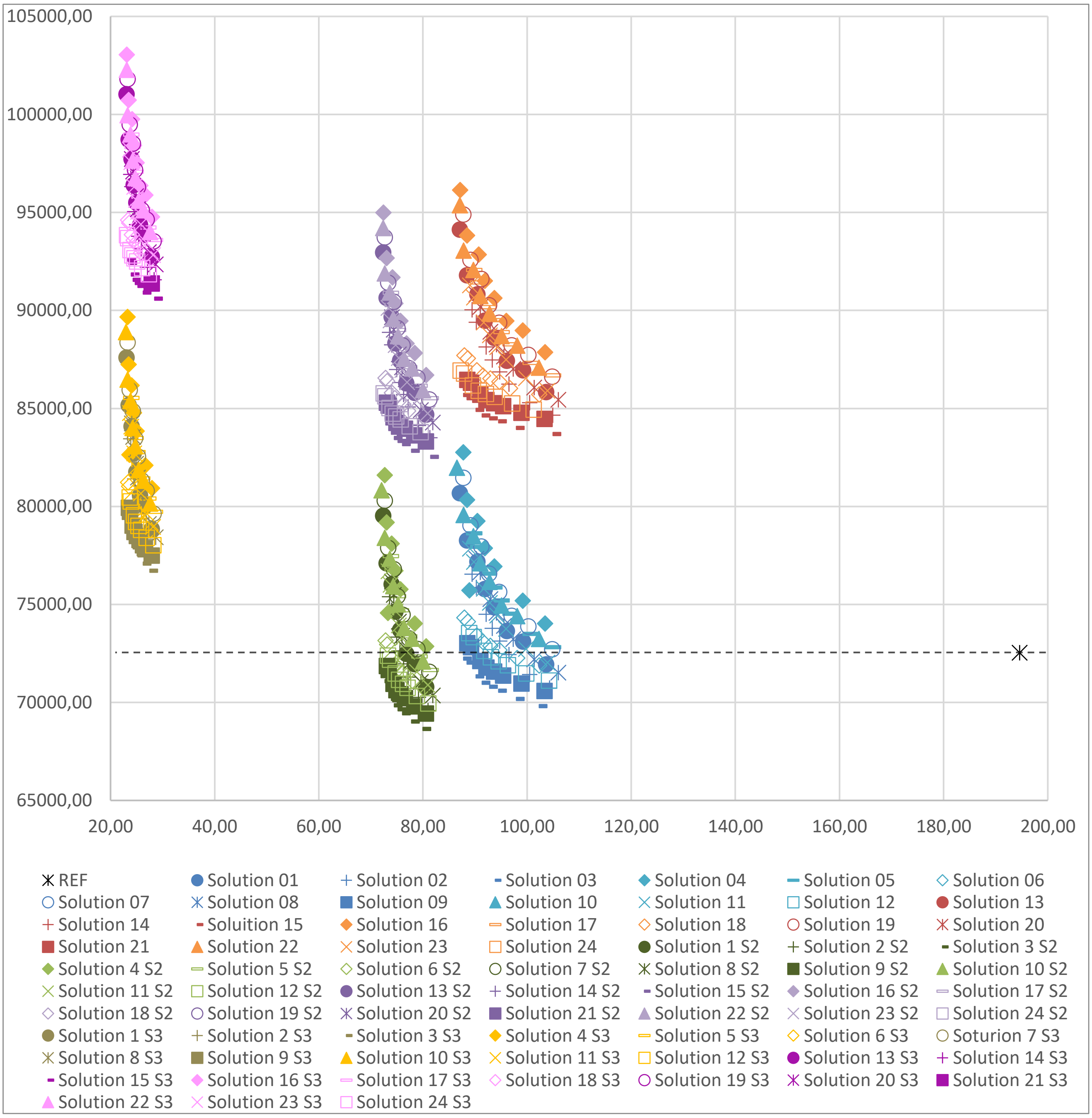


Figure 24 - Cost Optimal Graph 2 – Initial cost

The third graph, figure 25, represents the best insulation thickness of all possible combinations in terms of private global costs. The main objective of this graph is to reduce the tested option number from 577 to 73, displaying more clearly the disparity between combinations.

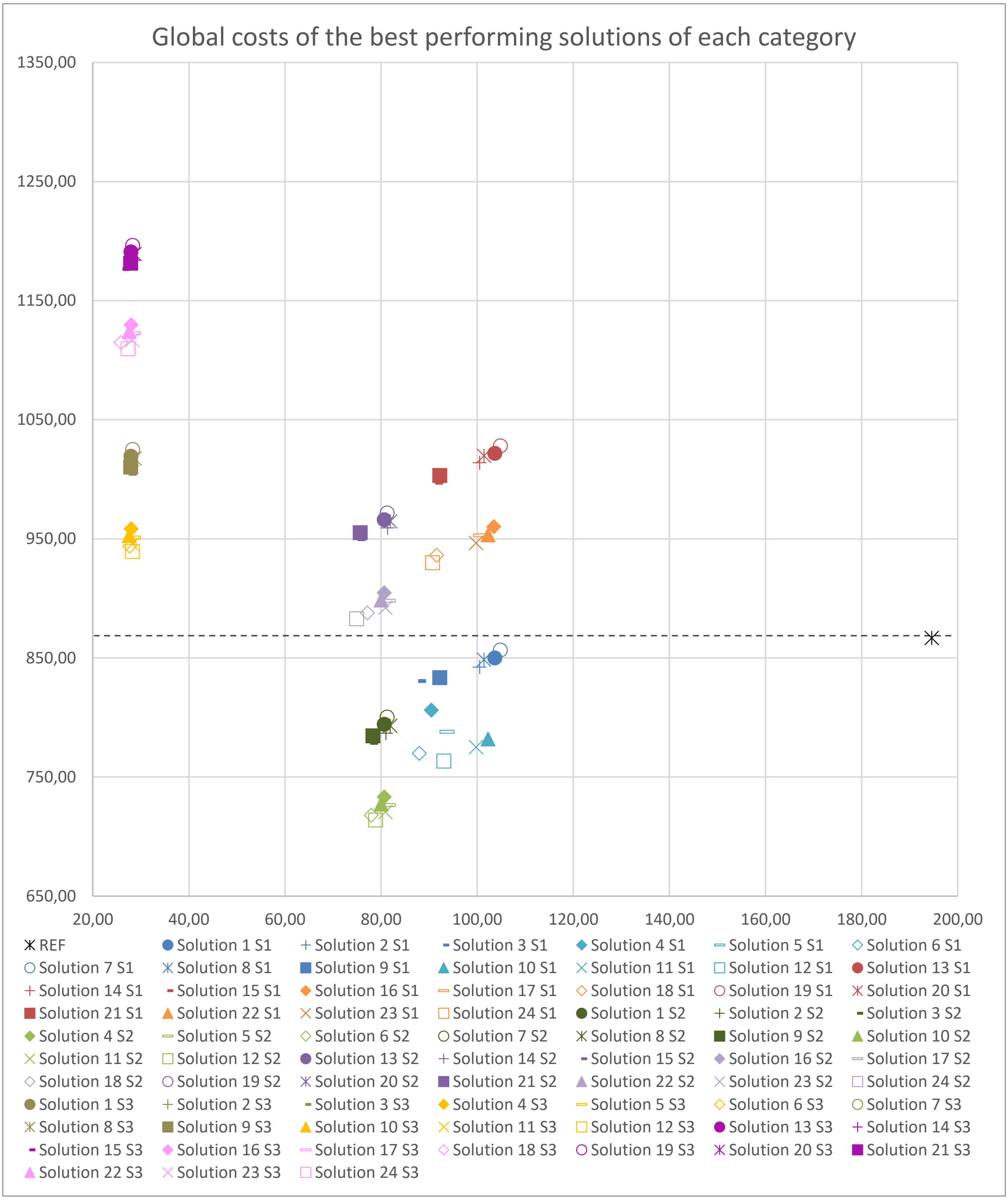


Figure 25 - Cost Optimal Graph 3 – Best performing solutions

The separated results of the analysis can provide a clearer understanding of the results. Figure 26 shows a bar graph comparing the best performing solutions, as shown in figure 25. This graph displays the amount of primary energy consumed in the designed building. The results show clearly the disparity between the reference building energy consumption and the other solutions. The consumption of the solutions that only changed the external envelope is on average 47,8% of the reference building. The solutions that considered system 2 represent only 38,7% of the reference building energy demand. The systems results display the advantages of considering a simple water-to-air heating system associated with an electric boiler for DHW. The results of system 3 represent 12.8% of the reference energy consumption. Moreover, the results display the advantages of acquiring a high-efficiency HVAC system on the energy demand.

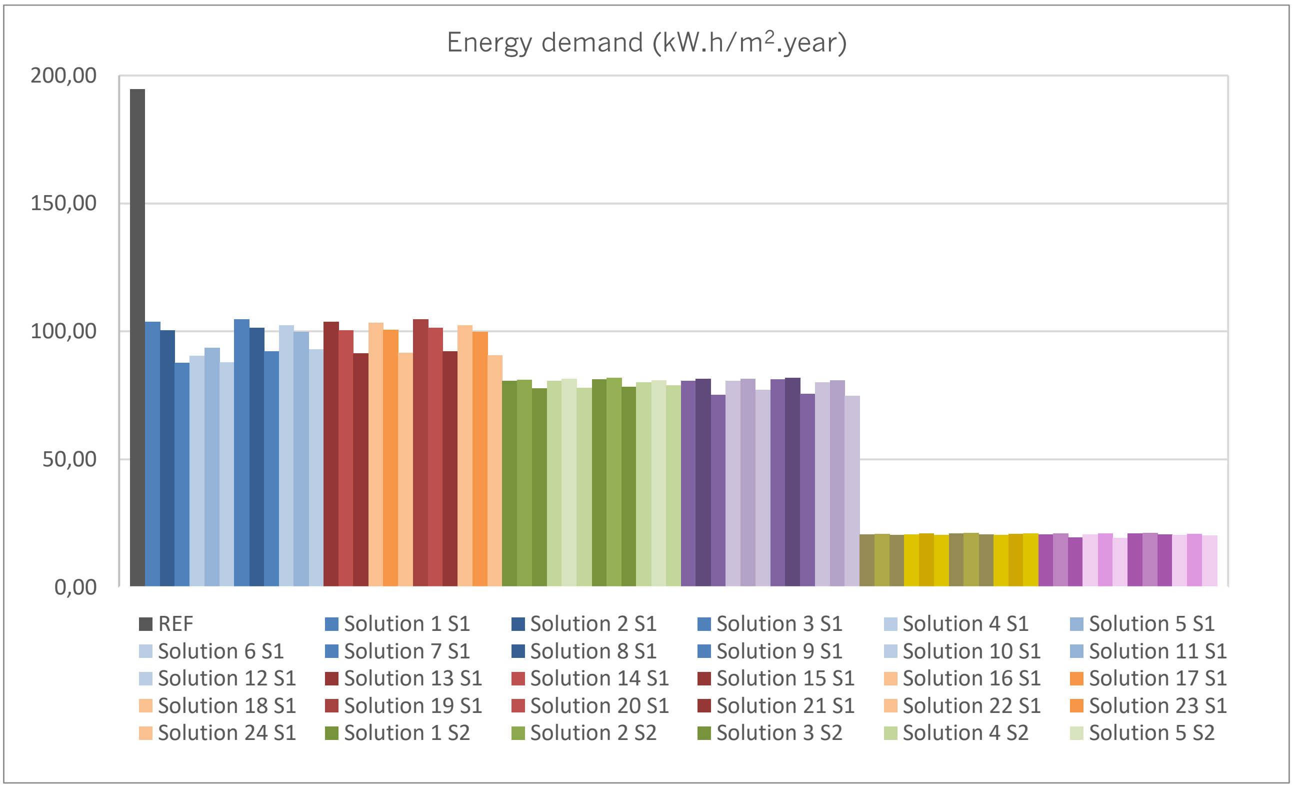


Figure 26 - Primary energy demand of the building solutions

In contrast with figure 26, figure 27 displays the results only from the perspective of the private global cost. This graph results display the 26.1% higher global cost of the most energy-efficient solutions. Furthermore, this result displays the solutions without considering the benefit of adding renewable energy sources; it can be assumed that the RES in the analysis would perform better.

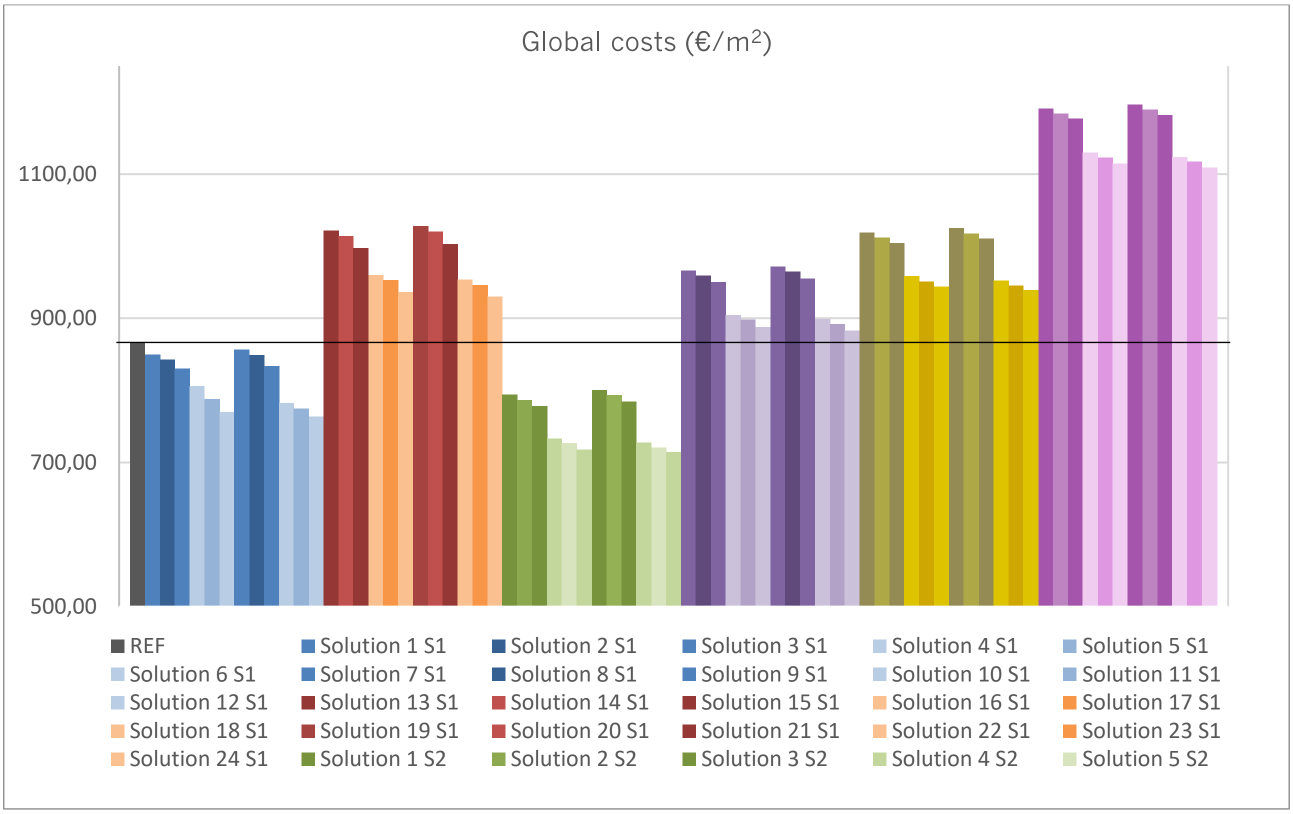


Figure 27 - Global cost of the building solutions

The solutions that considered systems 1 and 2 with LSF structure have the best results in the cost-optimal analysis. Moreover, although system 3 have much better performance, its global costs were not better than the other systems. They are concluding that the system's efficiency alone is not capable of making the solutions cost-optimal. The initial cost in solutions considering system 2 is higher than the reference building; however, solution 2 had the best results considering the global cost.

When comparing the external panel structure performance, the LSF structure has shown a better global cost. In addition, the wood-frame structure provided slightly better insulation than the LSF structure; however, it was not enough to compensate for the higher cost. In the façade materials, the MDF façade had a better performance compared to the aluminium façade. Moreover, the MDF better overall performance is due to the lower cost and higher thermal insulation than the aluminium façade. Thus, proving that the MDF panel is a better material for the façade element. The insulation materials had close results, as expected, due to their carefully selected thickness. The mineral wool has proven to be the best overall insulation. The best thermal insulation material was the black cork; however, its higher initial cost has negatively affected the cost-optimal performance. Although a small sample of materials was considered in this optimisation, the results showed that the balance between cost, quantity and thermal performance is crucial for choosing a thermal insulation material for a building. The internal panel material element has an expected result where the performance of the OSB III panel is better in every category compared to the gypsum panel. In addition, the OSB III panel had a better initial cost, maintenance cost and thermal performance than the gypsum plasterboard.

Despite the HVAC systems tested were limited and could use more variants and types for further development. The cost-optimal analysis results have shown that sometimes the most efficient solution is not cost-optimal, and the overall energy demand cost does not compensate for the high initial investment. These results ask for a more significant sample demonstration in order to achieve an optimised solution. It is essential to remember that the results could vary if renewable energy sources were considered in this dissertation. Possible future development of this methodology could be developed by including renewable energy sources.

The designed roof solutions had a high impact on the building thermal performance compared to the reference solution. The green roof used for systems 2 and 3 had a much higher initial and maintenance cost than the reference roof. Even so, the designed roof solution with high thermal insulation lowered their global costs.

Chapter 5: Discussion

This chapter will discuss the results obtained and their applicability and relationship to the reviewed literature. The main objective of this chapter is to understand if the results obtained are up to the expectations and their relevance concerning what has been reviewed in the literature.

5.1 Catalogue

The cataloguing was an essential part of the development of this dissertation. The library of techniques, results and methodologies accumulated provided a foundation to develop the other steps. In its development, the literature [24]–[26], [47], [126], [127] provided knowledge for developing the dissertation project in Portugal. The fundamental analysis of the catalogue options while designing its solutions provided an estimative about how the building will behave in terms of cost and energy efficiency. Furthermore, the analysis comparing the cost of a solution and comparing it with a wall solution with the same or higher thermal insulation provides an overview of the building thermal behaviour.

The project designed solutions for this dissertation have lower thermal performance than others in the literature [16], [22], [24], [27], [28], [34], [43], [47]. Although its cost is low compared to the reference solution, the prefabrication of the building elements could also decrease the overall building costs, thus enhancing the building solutions cost-optimal performance [24]. Considering the results obtained from the cost-optimal analysis, having the best performing solution could enhance the model and design. Some features, such as the connections of the panels, could be further developed. Designing a simple attachment method as used in the renovation panel by Silva et al. [28] could improve the building assembly, adaptability, and maintenance.

In addition, it is recognized here that catalogue options could be broader and include, for example, new technologies such as PCM or vacuum panels. This development can serve as a base for further enrichment of a building construction catalogue for this type of research development.

5.2 Project

The project design integrated with the simulation software provided the confidence for developing a building aiming to be sustainable and efficient. Furthermore, it was possible to notice energy efficiency improvements during the building development due to the alignment with the simulation software and passive solutions such as shading elements.

The solutions considered in the development of this dissertation approximate what was studied by Yu et al.[40] in the Solar Decathlon Madrid. Although the design could be more developed, its housing function is comparable with some of the projects reviewed in the literature [27], [47], [90], [91], [94]. The shading element tests also demonstrated that up to 33% of the energy demand decrease by adopting the solution. The passive results brought by the shading were expected as some of the literature reviewed discussed the topic [30], [40], [44], [128].

The methodology could be improved by analysing the efficacy of building material usage and shape in parametric software to obtain optimal material usage. Although much improvement can be made in the methodology, its usage in the development stage improved the design quality and ensured high energy efficiency.

5.3 Simulations and optimisations

The simulation and optimisation process of the selected building options have shown us results that this methodology is an effective way of decision making regarding the built environment. Furthermore, the selection and testing of the building elements on an optimisation process can reduce the building's initial and life cycle costs while being more energy-efficient.

The methodology adopted for developing the dissertation simulation is similar to the ones used in the literature [19], [24], [43], [64]. The quasi-steady-state used for the Design Builder[111]optimisation software made the simulations fast and adaptable. Although the simulation used was not dynamic, some resources from the literature had an impact on the simulation, such as the data from the green roof by Capozzoli et al.[122] and the optimisation by Ascione et al.[95] .In addition, a dynamic approach to the simulation could be considered for future analysis [102], [116].

Moreover, the methodology used in this dissertation fits the Portuguese climate and objectives [64], [102]. Of course, this simulation method could be more detailed and more specific for more accurate results. However, the simulation method used for the development of this study suffice the needs of the main objective.

5.4 Cost-optimal analysis

The results analysed in their materials categories show us the direct impact on the cost analysis of the building structure, façade, insulation, internal panel, HVAC systems used and roof solutions. Those results are the product of the methodology developed in this dissertation for investigating the optimisation process of a building to achieve energy-efficient solutions.

The cost-optimal analysis results, in some specific categories, are similar to the analysed in the literature. The design by Silva et al.[28] referenced the LSF structure as an optimised structure for the specific case. The study by Pihelo et al.[34] also considered mineral wool as an optimal cost material. The MDF wood façade was proven to be a good solution for sustainability, cost, and thermal resistance, as the study by Freitas [27] has proved. However, some worst performance solutions have better results in other studies [24], [26]–[28], [34]. These results show that the optimal cost analysis and design optimisation are specific for each case, design, and climate. As stated by the EPBD [6], the practice of this analysis must be done to every new construction or renovation. In addition, the analysis results on energy efficiency demonstrate that there is much improvement that can be done. With the addition of RES and its optimisation, it is possible for the building to be nZEB.

Moreover, when comparing the results obtained in the cost-optimal calculation process, it can be observed points for further improvement where there can be a future development on this methodology. A life cycle analysis of the materials can also be included in the final graphs to study the relationship between the cost-optimal solutions and their sustainability. The inclusion of more opaque envelope composition options, HVAC systems and openings can be improved.

Chapter 6: Conclusion

6.1 Conclusions

The global goal to reduce the built environment energy consumption is only achievable by adopting more efficient materials and methods. In this dissertation, a conceptual building architectural design and its wall combinations were developed and analysed to investigate the effects of modular and prefabricated construction on cost-optimality and energy efficiency of single-family housing. The study was developed in four stages: cataloguing, project designing, simulation and optimisation, and cost-optimal analysis.

The catalogue stage analysed and catalogued solutions from the literature review that was thought relevant to the study at the time of the dissertation development. The selected references served as a base for the development of the wall solutions used for this dissertation. In the project designing stage, the designed building was optimised in the Software Design-Builder[111], having a 27% window to wall ratio, with the most openings oriented south. The building shadings were also optimised and tested. The best result in performance was a one-meter South oriented overhang shading with a vertical Southwest shading. The addition of shadings to the building decreased the buildings energy demand by 26%. According to the designed solutions, the simulation and optimisation step simulated the designed building with 197 possible external wall compositions. In addition, those simulations considered the heating-load and cooling-load of the building. Lastly, in the cost-optimal step, the simulations results were compared to their life-cycle costs.

The final result of this methodology was the analysis of the solutions combinations and possibilities. The LSF structure demonstrated a better global cost than the wood structure, even though the wood structure had a better thermal performance. The MDF wood panel had a better overall performance than the aluminium façade. The best performing insulation was the mineral wool, and the best internal panel solution was the OSBIII panel. From the HVAC and DHW systems tested, the air-to-air heat pump, as the most efficient solution, had on average 12,8% of the energy consumption of the base reference solution. Although this system is responsible for low energy consumption, its initial and maintenance costs made it not cost-optimal. The analysis concludes that the cost-optimal system was system S2, a split wall mounter air-conditioning with an external condenser and an electric boiler for DHW and space heating through a radiator system. The best cost-optimal solution combination was the external envelope 12B with system S2: light steel frame panel with an MDF wood façade panel of 22mm, an internal OSBIII panel of 15mm and 90mm Mineral wool insulation material.

Through prefabrication and modularity, it is possible to diminish the overall energy demand while having a lower initial and global cost. Those improvements could be observed in this study even without accounting for the labour costs. However, if the pre-fabrication cost were calculated, the difference gap between the reference building and the building solutions would be even more significant. In addition, the optimisation process had the most significant impact on the decision making for the building design. Therefore, its usage in early-stage development is vital for achieving the balance between sustainability and cost-efficiency. The chosen materials recyclability and embodied energy could also be of positive influence on the building's sustainability.

The objective of developing and optimising a modular prefabricated house and its wall solutions to investigate the energy demand, sustainability, and global cost relation compared to the traditional construction method was successful. The analysis of the optimisation methodology and energy-efficient design for a southern European climate was the main contribution of this dissertation to the scientific environment. The conclusion that an efficient prefabricated design can significantly impact the global cost suggests that such a building could be cost-optimal and achieve the nZEB level. Moreover, it can be concluded that a prefabricated and modular building environment can increase cost-optimality and reduce the energy demand; thus, those construction techniques have the potential to help achieve the 2050 carbon zero EU goal. Although this research can be further developed and refined, it is possible to use the knowledge produced in this dissertation as a stepping stone to achieving more tangible results.

6.2 Future development

The future developments include investigating and further improving the energy efficiency, sustainability, and modularity of a prefabricated building and its solutions. This development could be achieved by including the renewable energy sources in the cost-optimal analysis to investigate the impacts of the RES on the achieved results. In addition, the modularity and prefabrication aspects can be further tested on how those processes impact building costs, sustainability, and energy demand. Another approach for further development could be an extensive analysis of more systems and material solutions to obtain results that could be applied in more building designs.

References

[1] United Nations: Department of Economic and Social Affairs, "World Urbanization Prospects - Population Division," *United Nations*. 2019. Accessed: Sep. 06, 2020. [Online]. Available: https://population.un.org/wup/

[2] IEA, "Cities energy transition," 2016. https://www.iea.org/news/cities-are-at-the-frontline-of-the-energy-transition (accessed Sep. 06, 2020).

[3] IEA, "Data & Statistics," 2017. https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy consumption&indicator=Electricity consumption (accessed Sep. 01, 2020).

[4] D. Satterthwaite, "Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions," vol. 20, no. 2, pp. 539–549, 2008, doi: 10.1177/0956247808096127.

[5] European Comitee, *EPBD*, vol. 2018, no. April. 2018, pp. 75–91.

[6] EPBD, "DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)." Official Journal of the European Union, Brussels, Belgium, 2010.

[7] "SDGs – United Nations Sustainable Development," 2020. https://www.un.org/sustainabledevelopment/why-the-sdgs-matter/ (accessed Aug. 30, 2020).

[8] IEA and UNEP, *2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and constructi on sector*, vol. 224. 2019. [Online]. Available: https://www.iea.org/reports/global-status-report-for-buildings-and-construction-2019

[9] K. E. Thomsen *et al.*, *Implementing Cost Optimality by the Buildings Performance Institute Europe (BPIE)*. 2013. [Online]. Available: www.buildingsdata.eu

[10] EU, "Going climate-neutral by 2050, a strategic long-term vision foor a porperous, modern, competitive and climate-neutral EU economy," Jul. 2018.

[11] EU, "Submission by Croatia and the European Commission on behalf of the European Union and its Member States," 2020.

[12] D. Kolokotsa, D. Rovas, E. Kosmatopoulos, and K. Kalaitzakis, "A roadmap towards intelligent net zero- and positive-energy buildings," *Solar Energy*, vol. 85, no. 12, pp. 3067–3084, 2011, doi: 10.1016/j.solener.2010.09.001.

[13] M. Hamdy, A. Hasan, and K. Siren, "A multi-stage optimization method for cost-optimal and nearly-zero-energy building solutions in line with the EPBD-recast 2010," *Energy and Buildings*, vol. 56, pp. 189–203, 2013, doi: 10.1016/j.enbuild.2012.08.023.

[14] J. Kurnitski, "How to calculate cost-optimal nZEB energy performance?," Mar. 2011.

[15] EC 2012/C 115/01, *EU Delegated Regulation No. 244*. 2012, p. 28. doi: 10.3000/1977091X.C_2012.115.eng.

[16] V. M. Barthelmes, C. Becchio, S. P. Corgnati, and C. Guala, "Design and construction of an nZEB in Piedmont Region, North Italy," *Energy Procedia*, vol. 78, pp. 1925–1930, 2015, doi: 10.1016/j.egypro.2015.11.373.

[17] F. Barbolini, P. Cappellacci, and L. Guardigli, "A Design Strategy to Reach nZEB Standards Integrating Energy Efficiency Measures and Passive Energy Use," *Energy Procedia*, vol. 111, no. September 2016, pp. 205–214, 2017, doi: 10.1016/j.egypro.2017.03.022.

[18] P. M. Congedo, C. Baglivo, D. D'Agostino, and I. Zacà, "Cost-optimal design for nearly zero energy office buildings located in warm climates," *Energy*, vol. 91, no. 244, pp. 967–982, 2015, doi: 10.1016/j.energy.2015.08.078.

[19] M. Ferrara, V. Monetti, and E. Fabrizio, "Cost-optimal analysis for nearly zero energy buildings design and optimization: A critical review," *Energies*, vol. 11, no. 6, 2018, doi: 10.3390/en11061478.

[20] J. Kurnitski, A. Saari, T. Kalamees, M. Vuolle, J. Niemelä, and T. Tark, "Cost optimal and nearly zero (nZEB) energy performance calculations for residential buildings with REHVA definition for nZEB national implementation," *Energy and Buildings*, vol. 43, no. 11, pp. 3279–3288, 2011, doi: 10.1016/j.enbuild.2011.08.033.

[21] E. Pikas, J. Kurnitski, M. Thalfeldt, and L. Koskela, "Cost-benefit analysis of nZEB energy efficiency strategies with on-site photovoltaic generation," *Energy*, vol. 128, pp. 291–301, 2017, doi: 10.1016/j.energy.2017.03.158.

[22] S. Schiavoni, S. Sambuco, A. Rotili, F. D'Alessandro, and F. Fantauzzi, "A nZEB housing structure derived from end of life containers: Energy, lighting and life cycle assessment," *Building Simulation*, vol. 10, no. 2, pp. 165–181, 2017, doi: 10.1007/s12273-016-0329-9.

[23] A. Mohamed, A. Hasan, and K. Sirén, "Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives," *Applied Energy*, vol. 114, pp. 385–399, 2014, doi: 10.1016/j.apenergy.2013.09.065.

[24] M. Almeida, R. Barbosa, and R. Malheiro, "Effect of embodied energy on cost-effectiveness of a prefabricated modular solution on renovation scenarios in social housing in Porto, Portugal," *Sustainability (Switzerland)*, vol. 12, no. 4, 2020, doi: 10.3390/su12041631.

[25] L. Aelenei, H. Gonçalves, and C. Rodrigues, "The Road Towards 'Zero Energy' in Buildings: Lessons Learned from Solar XXI Building in Portugal," pp. 1–8, 2016, doi: 10.18086/eurosun.2010.06.01.

[26] M. J. Mendes, "Dissertação: Análise Energética de Construção Modular com Contentores Marítimos," Covilhã, 2010. [Online]. Available: http://hdl.handle.net/10400.6/3582

[27] M. Freitas, "Dissertation: Construção modular sustentável: propostas de um projeto tipo," Viana do Castelo, 2014.

[28] P. C. P. Silva, M. Almeida, L. Bragança, and V. Mesquita, "Development of prefabricated retrofit module towards nearly zero energy buildings," *Energy and Buildings*, vol. 56, pp. 115–125, 2013, doi: 10.1016/j.enbuild.2012.09.034.

[29] R. U. Ayres, H. Turton, and T. Casten, "Energy efficiency, sustainability and economic growth," *Energy*, vol. 32, no. 5, pp. 634–648, 2007, doi: 10.1016/j.energy.2006.06.005.

[30] J. Fernandes and R. Mateus, "Energy efficiency principles in Portuguese vernacular architecture," *BSA 2012: 1st International Conference on Building Sustainability Assessment*, pp. 561–572, 2012, [Online]. Available: http://repositorium.sdum.uminho.pt/handle/1822/19845%5Cnhttp://hdl.handle.net/1822/19845

[31] C. de la Cruz-Lovera, A. J. Perea-Moreno, J. L. de la Cruz-Fernández, J. A. Alvarez-Bermejo, and F. Manzano-Agugliaro, "Worldwide research on energy efficiency and sustainability in public buildings," *Sustainability (Switzerland)*, vol. 9, no. 8, 2017, doi: 10.3390/su9081294.

[32] S. Navaratnam, T. Ngo, T. Gunawardena, and D. Henderson, "Performance review of prefabricated building systems and future research in Australia," *Buildings*, vol. 9, no. 2. MDPI AG, Feb. 03, 2019. doi: 10.3390/buildings9020038.

[33] V. W. Y. Tam, C. M. Tam, S. X. Zeng, and W. C. Y. Ng, "Towards adoption of prefabrication in construction," *Building and Environment*, vol. 42, no. 10, pp. 3642–3654, 2007, doi: 10.1016/j.buildenv.2006.10.003.

[34] P. Pihelo, T. Kalamees, and K. Kuusk, "NZEB Renovation with Prefabricated Modular Panels," *Energy Procedia*, vol. 132, pp. 1006–1011, 2017, doi: 10.1016/j.egypro.2017.09.708.

[35] S. Colclough, O. Kinnane, N. Hewitt, and P. Griffiths, "Investigation of nZEB social housing built to the Passive House standard," *Energy and Buildings*, vol. 179, no. 2018, pp. 344–359, 2018, doi: 10.1016/j.enbuild.2018.06.069.

[36] R. A. Leal, "Dissertation: Construção modular em LSF – Estudo do comportamento térmico passivo," Coimbra, 2015. [Online]. Available: http://hdl.handle.net/1822/30309

[37] A. I. Machado, "Dissertation: Simulação numérica do comportamento térmico ee energético de uma construção modular leve," Porto, 2017. Accessed: Jul. 31, 2021. [Online]. Available: https://hdl.handle.net/10216/107675

[38] J. Aranda, I. Zabalza, A. Conserva, and G. Millán, "Analysis of Energy Efficiency Measures and Retrofitting Solutions for Social Housing Buildings in Spain as a Way to Mitigate Energy Poverty," *Sustainability*, no. 9, 2017, doi: 10.3390/su9101869.

[39] I. Kovacic, J. Reisinger, and M. Honic, "Life Cycle Assessment of embodied and operational energy for a passive housing block in Austria," *Renewable and Sustainable Energy Reviews*, vol. 82, no. July 2017, pp. 1774–1786, 2018, doi: 10.1016/j.rser.2017.07.058.

[40] Z. Yu, Z. Gou, F. Qian, J. Fu, and Y. Tao, "Towards an optimized zero energy solar house: A critical analysis of passive and active design strategies used in Solar Decathlon Europe in Madrid," *Journal of Cleaner Production*, vol. 236, p. 117646, 2019, doi: 10.1016/j.jclepro.2019.117646.

[41] R. Li, M. Wang, and J. Zhu, "Indoor thermal environment monitoring and evaluation of double-deck prefabricated house in central China-taking Zhengzhou area as an example," *Energy Procedia*, vol. 158, pp. 2812–2819, 2019, doi: 10.1016/j.egypro.2019.02.043.

[42] D. Kim, "Preliminary life cycle analysis of modular and conventioinal housing in benton harbor, michigan," *University of Michigan*, p. 53, 2008.

[43] C. Becchio, P. Dabbene, E. Fabrizio, V. Monetti, and M. Filippi, "Cost optimality assessment of a single family house: Building and technical systems solutions for the nZEB target," *Energy and Buildings*, vol. 90, pp. 173–187, 2015, doi: 10.1016/j.enbuild.2014.12.050.

[44] Z. Ma, H. Ren, and W. Lin, "A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses," *Journal of Cleaner Production*, vol. 240, p. 118158, 2019, doi: 10.1016/j.jclepro.2019.118158.

[45] E. P. Judson and C. Maller, "Building Research & Information Housing renovations and energy efficiency: insights from homeowners' practices Housing renovations and energy e⁄ciency: insights from homeowners' practices," 2014, doi: 10.1080/09613218.2014.894808.

[46] R. Jiang, C. Wu, C. Mao, and A. Shrestha, "Ecosystem Visualization and Analysis of Chinese Prefabricated Housing Industry," *Procedia Engineering*, vol. 145, pp. 436–443, 2016, doi: 10.1016/j.proeng.2016.04.011.

[47] V. Tavares, N. Lacerda, and F. Freire, "Embodied energy and greenhouse gas emissions analysis of a prefabricated modular house: The 'Moby' case study," *Journal of Cleaner Production*, vol. 212, pp. 1044–1053, 2019, doi: 10.1016/j.jclepro.2018.12.028.

[48] A. Chegut, P. Eichholtz, and R. Holtermans, "Energy efficiency and economic value in affordable housing," *Energy Policy*, no. 97, pp. 39–49, 2016, doi: 10.1016/j.enpol.2016.06.043.

[49] S. Copiello, "Achieving affordable housing through energy efficiency strategy," *Energy Policy*, vol. 85, pp. 288–298, Oct. 2015, doi: 10.1016/j.enpol.2015.06.017.

[50] N. Simões, D. Teles, and C. Serra, "Portuguese Passive House case study : a comparison between monthly and seasonal energy performance methods," *WIT Conferences*, vol. 205, no. Eq, 2016, doi: 10.2495/EQ160161.

[51] V. P. S. N. Nanyam, A. Sawhney, and P. A. Gupta, “Evaluating Offsite Technologies for Affordable Housing,” *Procedia Engineering*, vol. 196, no. June, pp. 135–143, 2017, doi: 10.1016/j.proeng.2017.07.183.

[52] N. Wang, T. Esram, L. A. Martinez, and M. T. McCulley, “A marketable all-electric solar house: A report of a Solar Decathlon project,” *Renewable Energy*, vol. 34, no. 12, pp. 2860–2871, 2009, doi: 10.1016/j.renene.2009.05.003.

[53] M. A. Ahmed, Y. C. Kang, and Y. C. Kim, “Communication network architectures for smart-house with renewable energy resources,” *Energies*, vol. 8, no. 8, pp. 8716–8735, 2015, doi: 10.3390/en8088716.

[54] R. H. Crawford and A. Stephan, “Ii. Calculating the Life Cycle Energy Demand of a Passive House,” *World Academy of Science, Engineerign and Technology*, no. 78, pp. 473–479, 2013.

[55] A. Figueiredo, J. Kämpf, and R. Vicente, “Passive house optimization for Portugal: Overheating evaluation and energy performance,” *Energy and Buildings*, vol. 118. Elsevier Ltd, pp. 181–196, Apr. 15, 2016. doi: 10.1016/j.enbuild.2016.02.034.

[56] J. Cronemberger, M. A. Corpas, I. Cerón, E. Caamaño-Martín, and S. V. Sánchez, “BIPV technology application: Highlighting advances, tendencies and solutions through Solar Decathlon Europe houses,” *Energy and Buildings*, vol. 83, pp. 44–56, 2014, doi: 10.1016/j.enbuild.2014.03.079.

[57] A. Stephan, R. H. Crawford, and K. de Myttenaere, “A comprehensive assessment of the life cycle energy demand of passive houses,” *Applied Energy*, vol. 112, pp. 23–34, 2013, doi: 10.1016/j.apenergy.2013.05.076.

[58] S. Patinha, “Dissertação: Construção Modular – Desenvolvimento Da Ideia: Casa Numa Caixa,” Aveiro, 2011. Accessed: Jul. 31, 2021. [Online]. Available: http://hdl.handle.net/10773/6096

[59] European Commission, “COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating,” *Official Journal of the European Union*, 2012.

[60] M. Almeida and M. Ferreira, “Ten questions concerning cost-effective energy and carbon emissions optimization in building renovation,” *Building and Environment*, vol. 143, no. April, pp. 15–23, 2018, doi: 10.1016/j.buildenv.2018.06.036.

[61] E. E. A. SOCIAL and COMMITTEE, *Energy Efficiency Plan*, no. 1. 2011, pp. 6–8. doi: 10.16309/j.cnki.issn.1007-1776.2003.03.004.

[62] ODYSSEE, “Sectoral Profile-Households Energy consumption Household energy consumption by energy in the EU Household energy consumption in the EU,” 2017. Accessed: Sep. 02, 2020. [Online].

Available: http://www.odyssee-mure.eu/publications/efficiency-by-sector/households/household-eu.pdf

[63] "Declining share of space heating in the EU | Space Heating | ODYSSEE-MURE." https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/declining-share-space-heating-eu.html (accessed Jul. 27, 2021).

[64] Diário da Républica, *Decreto-Lei n.º 118/2013, de 20 de agosto*, vol. 159. 2013, pp. 4988–5005.

[65] Diário da Républica, *Decreto-Lei n.o 78/2006*. 2006, pp. 1–4.

[66] Ministérios, *Portaria n.º 349-B/2013 - Portaria n.º 319/2016*, vol. 1.ª série, no. N.º 239. Portugal, 2016, pp. 4723–4725.

[67] Ministério do Ambiente Ordenamento do Território e Energia, *Portaria nº 14*. Portugal, 2015, pp. 524–532.

[68] P. Europeu, *Portaria n.º 379-A*, no. 2. Portugal, 2014, pp. 1840–1844.

[69] Diário da Républica, *Portaria n.º 98/2019 de 2 de abril*. 2019, pp. 1816–1818.

[70] D. da República, *Portaria n.º 349-B/2013 de 29 de Novembro*, no. 232. Portugal, 2013, pp. 18–29.

[71] Diário da Républica, *Diário da República, 1.ª série — N.º 159 — 20 de agosto de 2018 Artigo 6º*. Portugal, 2018, pp. 5688–5724.

[72] M. Silva, "Dissertação: Edifícios com necessidades quase nulas de energia (nZEB) em paises no sul da Europa.," Porto, 2020. [Online]. Available: https://repositorio-aberto.up.pt/bitstream/10216/127975/2/410028.pdf

[73] A. Boccalatte, M. Fossa, and C. Ménézo, "Best arrangement of BIPV surfaces for future NZEB districts while considering urban heat island effects and the reduction of reflected radiation from solar façades," *Renewable Energy*, vol. 160, pp. 686–697, 2020, doi: 10.1016/j.renene.2020.07.057.

[74] R. Azari and N. Abbasabadi, "Embodied energy of buildings: A review of data, methods, challenges, and research trends," *Energy and Buildings*, vol. 168. Elsevier Ltd, pp. 225–235, Jun. 01, 2018. doi: 10.1016/j.enbuild.2018.03.003.

[75] T. Ramesh, R. Prakash, and K. K. Shukla, "Life cycle energy analysis of buildings: An overview," *Energy and Buildings*, vol. 42, no. 10, pp. 1592–1600, 2010, doi: 10.1016/j.enbuild.2010.05.007.

[76] H. J. Wu, Z. W. Yuan, L. Zhang, and J. Bi, "Life cycle energy consumption and CO2 emission of an office building in China," *International Journal of Life Cycle Assessment*, vol. 17, no. 2. pp. 105–118, 2012. doi: 10.1007/s11367-011-0342-2.

[77] Z. Toth *et al.*, "WHOLE-LIFE CARBON: CHALLENGES AND SOLUTIONS FOR HIGHLY EFFICIENT AND CLIMATE-NEUTRAL BUILDINGS," *Buildings Performance Institute europe (BPIE)*, 2021, Accessed: Jul. 20, 2021. [Online]. Available: https://www.bpie.eu/

[78] R. H. Crawford, E. L. Bartak, A. Stephan, and C. A. Jensen, “Evaluating the life cycle energy benefits of energy efficiency regulations for buildings,” *Renewable and Sustainable Energy Reviews*, vol. 63. Elsevier Ltd, pp. 435–451, Sep. 01, 2016. doi: 10.1016/j.rser.2016.05.061.

[79] L. Yang, J. Lam, and C. L. Tsang, “Energy and associated emission analysis in office buildings,” *Applied Energy*, vol. 85, no. 1, pp. 800–817, 2008, doi: 10.1016/j.apenergy.2007.11.002.

[80] M. Kamali and K. Hewage, “Life cycle performance of modular buildings: A critical review,” *Renewable and Sustainable Energy Reviews*, vol. 62. Elsevier Ltd, pp. 1171–1183, Sep. 01, 2016. doi: 10.1016/j.rser.2016.05.031.

[81] Y. Teng, K. Li, W. Pan, and T. Ng, “Reducing building life cycle carbon emissions through prefabrication: Evidence from and gaps in empirical studies,” *Building and Environment*, vol. 132, pp. 125–136, Mar. 2018, doi: 10.1016/j.buildenv.2018.01.026.

[82] T. C. Haupt, L. Bikitsha, and P. T. C. Haupt, “Impact of prefabrication on construction site health and safety: Perceptions of designers and contractors,” 2011. [Online]. Available: https://www.researchgate.net/publication/327727819

[83] D. Lopez and T. M. Froese, “Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes,” *Procedia Engineering*, vol. 145, pp. 1291–1297, 2016, doi: 10.1016/j.proeng.2016.04.166.

[84] J. Quale, M. J. Eckelman, K. W. Williams, G. Sloditskie, and J. B. Zimmerman, “Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States,” *Journal of Industrial Ecology*, vol. 16, no. 2, pp. 243–253, 2012, doi: 10.1111/j.1530-9290.2011.00424.x.

[85] P. Y. Hsu, P. Angeloudis, and M. Aurisicchio, “Optimal logistics planning for modular construction using two-stage stochastic programming,” *Automation in Construction*, vol. 94, no. May, pp. 47–61, 2018, doi: 10.1016/j.autcon.2018.05.029.

[86] I. K. Hui, A. H. S. Chan, and K. F. Pun, “Study of the Environmental Management System implementation practices,” *Journal of Cleaner Production*, vol. 9, no. 3, pp. 269–276, 2001, doi: 10.1016/S0959-6526(00)00061-5.

[87] R. A. Begum, S. K. Satari, and J. J. Pereira, “Waste generation and recycling: Comparison of conventional and industrialized building systems,” *American Journal of Environmental Sciences*, vol. 6, no. 4, pp. 383–388, 2010, doi: 10.3844/ajessp.2010.383.388.

[88] M. F. Musa, M. R. Yusof, M. F. Mohammad, and N. S. Samsudin, “Towards the adoption of modular construction and prefabrication in the construction environment: A case study in Malaysia,” *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 13, pp. 8122–8131, 2016.

[89] G. Tumminia, F. Guarino, S. Longo, M. Ferraro, M. Cellura, and V. Antonucci, "Life cycle energy performances and environmental impacts of a prefabricated building module," *Renewable and Sustainable Energy Reviews*, vol. 92, no. September 2017, pp. 272–283, 2018, doi: 10.1016/j.rser.2018.04.059.

[90] G. Tumminia *et al.*, "Life cycle energy performances of a Net Zero Energy prefabricated building in Sicily," *Energy Procedia*, vol. 140, pp. 486–494, 2017, doi: 10.1016/j.egypro.2017.11.160.

[91] E. Antonini, D. Longo, and V. Gianfrate, "Towards nZEB: modular pre-assembled steel systems for residential buildings," *WIT Transactions on Ecology on The Built Environment*, vol. 142, pp. 1743–3509, 2014, doi: 10.2495/ARC140301.

[92] A. Pinto, R. Mateus, J. Silva, and M. Lopes, "NZEB Modular Prefabricated Building System," in *Sustainability and Automation in Smart Constructions*, 2021, pp. 169–179.

[93] S. Pulakka, S. Vares, E. Nykänen, M. Saari, and T. Häkkinen, "Lean Production of Cost Optimal Wooden nZEB," in *Energy Procedia*, 2016, vol. 96, pp. 202–211. doi: 10.1016/j.egypro.2016.09.122.

[94] Macieirinha Maria Lopes Marlene and D. Carlos Nuno Lacerda Lopes, "A Habitação Modular Pré-Fabricada Uma perspetiva dos últimos 20 anos em Portugal," Porto. Accessed: Jul. 26, 2021. [Online]. Available: https://hdl.handle.net/10216/131507

[95] F. Ascione, N. Bianco, R. F. de Masi, G. M. Mauro, and G. P. Vanoli, "Design of the building envelope: A novel multi-objective approach for the optimization of energy performance and thermal comfort," *Sustainability (Switzerland)*, vol. 7, no. 8, pp. 10809–10836, 2015, doi: 10.3390/su70810809.

[96] W. Ott *et al.*, *Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56). Energy in Buildings and Communities Programme.*, no. March. 2017. [Online]. Available: https://www.iea-ebc.org/Data/publications/EBC_Annex_56_Methodology_Cost-Effective_Energy_Carbon_Emissions_Optimization_Building_Renovation.pdf

[97] A. Caseiro, "O Sistema Construtivo Modular em Madeira como Contributo à Arquitetura Sustentável," Covilhã, 2013. [Online]. Available: https://ubibliorum.ubi.pt/bitstream/10400.6/2379/1/Modelo de dissertaçao1.pdf

[98] A. Rauf and R. H. Crawford, "Building service life and its effect on the life cycle embodied energy of buildings," *Energy*, vol. 79, no. C, pp. 140–148, 2015, doi: 10.1016/j.energy.2014.10.093.

[99] Y. Wang and H. Fukuda, "Timber chips as the insulation material for energy saving in prefabricated offices," *Sustainability (Switzerland)*, vol. 8, no. 6, Jun. 2016, doi: 10.3390/su8060587.

[100] W. Wu, H. M. Skye, and P. A. Domanski, "Selecting HVAC systems to achieve comfortable and cost-effective residential net-zero energy buildings," *Applied Energy*, vol. 212, no. October 2017, pp. 577–591, 2018, doi: 10.1016/j.apenergy.2017.12.046.

[101] “EnergyPlus,” 2020. https://energyplus.net/ (accessed Sep. 08, 2020).

[102] P. Silva, S. Silva, M. Almeida, and L. Bragança, “Accuracy of the portuguese EPBD implemented thermal performance calculation procedures - RCCTE,” *IBPSA 2009 - International Building Performance Simulation Association 2009*, no. D, pp. 2106–2113, 2009.

[103] USDE, “About Building Energy Modeling | Department of Energy,” *United States Departament of Energy*, 2021. https://www.energy.gov/eere/buildings/about-building-energy-modeling (accessed Jul. 06, 2021).

[104] M. Ferreira, M. Almeida, A. Rodrigues, and S. M. Silva, “Comparing cost-optimal and net-zero energy targets in building retrofit,” *Building Research & Information*, vol. 44, no. 2, Feb. 2016, doi: 10.1080/09613218.2014.975412.

[105] L. Aye, T. Ngo, R. H. Crawford, R. Gammampila, and P. Mendis, “Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules,” *Energy and Buildings*, vol. 47, pp. 159–168, 2012, doi: 10.1016/j.enbuild.2011.11.049.

[106] O. Pons and G. Wadel, “Environmental impacts of prefabricated school buildings in Catalonia,” *Habitat International*, vol. 35, no. 4, pp. 553–563, 2011, doi: 10.1016/j.habitatint.2011.03.005.

[107] P. dos Santos and L. Matias, *ITE50*. ICT Informação Técnica, 2006.

[108] CYPE, “Gerador de preços para construção civil. Portugal. CYPE Ingenieros, S.A.,” 2020. http://www.geradordeprecos.info/ (accessed Jul. 27, 2020).

[109] Graphisoft, “Archicad 24.” https://graphisoft.com/solutions/archicad, 2021. Accessed: Jul. 07, 2021. [Online]. Available: https://graphisoft.com/solutions/archicad

[110] A. A. Latiffi, J. Brahim, S. Mohd, and M. S. Fathi, “Building Information Modeling (BIM): Exploring Level of Development (LOD) in Construction Projects,” *Applied Mechanics and Materials*, vol. 773–774, pp. 933–937, Jul. 2015, doi: 10.4028/www.scientific.net/amm.773-774.933.

[111] “DesignBuilder.” https://designbuilder.co.uk//, 2021. Accessed: Jul. 07, 2021. [Online]. Available: https://designbuilder.co.uk//

[112] “Weather Data | EnergyPlus.” https://energyplus.net/weather (accessed Jul. 22, 2021).

[113] REH, *Diário da República, 2.ª série-N.º 234-3 de dezembro de 2013 35088-(27), Despacho (extrato) n.º 15793-F/2013*.

[114] PORDATA, “PORDATA - Average household size, according to the Census,” *2011*. https://www.pordata.pt/en/Portugal/Average+household+size++according+to+the+Census-908 (accessed Dec. 01, 2020).

[115] OECD, “OECD Family Database,” 2016. [Online]. Available: www.oecd.org/els/family/database.htm

[116] G. Pernigotto and A. Gasparella, "Quasi-steady state and dynamic simulation approaches for the calculation of building energy needs: Part 1 thermal losses," *International High Performance Buildings Conference*, 2012, Accessed: Jul. 26, 2021. [Online]. Available: http://docs.lib.purdue.edu/ihpbc/88/

[117] C. Loss and B. Davison, "Innovative composite steel-timber floors with prefabricated modular components," *Engineering Structures*, vol. 132, pp. 695–713, 2017, doi: 10.1016/j.engstruct.2016.11.062.

[118] S. Lehmann, "Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions," *Sustainable Cities and Society*, vol. 6, no. 1, pp. 57–67, 2013, doi: 10.1016/j.scs.2012.08.004.

[119] M. Medineckiene, Z. Turskis, and E. K. Zavadskas, "Sustainable construction taking into account the building impact on the environment," *Journal of Environmental Engineering and Landscape Management*, vol. 18, no. 2, pp. 118–127, 2010, doi: 10.3846/jeelm.2010.14.

[120] F. A. R. Esteves, "Dissertation: Modern materials useful in rehabilitation of buildings," 2015. Accessed: Jul. 31, 2021. [Online]. Available: http://www.fe.up.pt

[121] S. Guzmán-Sánchez, D. Jato-Espino, I. Lombillo, and J. Manuel Diaz-Sarachaga, "Assessment of the contributions of different flat roof types to achieving sustainable development," 2018, doi: 10.1016/j.buildenv.2018.05.063.

[122] A. Capozzoli, A. Gorrino, and V. Corrado, "THERMAL CHARACTERIZATION OF GREEN ROOFS THROUGH DYNAMIC SIMULATION," 2013.

[123] K. Perini and P. Rosasco, "Cost-benefit analysis for green façades and living wall systems," *Building and Environment*, vol. 70, pp. 110–121, Dec. 2013, doi: 10.1016/j.buildenv.2013.08.012.

[124] Z. Gorišek, Miha. Humar, Milan. Šernek, and University. Faculty of Forestry (Zagreb)., *Implementation of wood science in woodworking sector : proceedings*. University, Faculty of Forestry, 2016.

[125] M. S. Al-Homoud, "Performance characteristics and practical applications of common building thermal insulation materials," *Building and Environment*, vol. 40, no. 3, pp. 353–366, 2005, doi: 10.1016/j.buildenv.2004.05.013.

[126] F. Rodrigues, R. Matos, A. Alves, P. Ribeirinho, and H. Rodrigues, "Building life cycle applied to refurbishment of a traditional building from Oporto, Portugal," *Journal of Building Engineering*, vol. 17, no. January, pp. 84–95, 2018, doi: 10.1016/j.jobe.2018.01.010.

[127] P. Vaquero, "Buildings Energy Certification System in Portugal: Ten years later," *Energy Reports*, vol. 6, pp. 541–547, 2019, doi: 10.1016/j.egyr.2019.09.023.

[128] J. Fernandes and R. Mateus, "Portuguese vernacular architecture : The contribution of vernacular materials Portuguese vernacular architecture : the contribution of vernacular materials and design

approaches for sustainable construction," no. April 2016, 2015, doi: 10.1080/00038628.2014.974019.

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 01	LSF Steel Structure	1,4	7701,00	3,22 €	0,00 €	0,00 €	Kg	50,000	5,71E-01	8,66E+00
	Plasterboard	30	875	23,76 €	1,39 €	1,13 €	m^2	0,250	3,50E-01	5,74E+00
	Polyurethane Rigid	20	50	2,57 €	0,12 €	0,02 €	m^2	0,040	4,26E+00	1,00E+02
	Polyvinyl chloride (PVC)	5	1200	6,88 €	0,00 €	0,00 €	m^2	0,140	1,97E+00	4,69E+01
	Rockwool	140	50	13,64 €	0,28 €	0,56 €	m^2	0,035	1,46E+00	2,16E+01
	Cement	10	2300	5,33 €	0,51 €	0,60 €	m^2	1,825	1..95E-01	1,31E+00
	Expanded Polyestyrene	15	15,5	2,63 €	0,71 €	0,16 €	m^2	0,040	4,14E+00	1,05E+00
	Fiberglass	5	160	1,55 €	0,87 €	0,12 €	m^2	0,046	-	-
	Plaster + Paint	10	1150	5,50 €	9,90 €	0,04 €	m^2	0,650	2,46E+00	4,78E+01
Wall 02	Wood-frame structure	140	7701,00	38,83 €	4,18 €	1,21 €	Kg	50,00	8,46E-02	1,92E+00
	OSB Pannel 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,13	4,72E-01	9,22E+00
	Injected cellulose insulation foam	30	610	6,01 €	0,12 €	0,02 €	m^2	-	1,36E+01	5,87E+01
	Smart Vapour Retarder	1,5	15	5,08 €	0,00 €	9,04 €	m^2	0,04	-	-
	Wood Structure 30x30mm	30	2300	1,41 €	0,00 €	0,09 €	m^2	1,83	-	-
	OSB Pannel 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,13	4,72E-01	9,22E+00
	Air	50	1,23	0,00 €	0,00 €	0,00 €	Kg	0,03	0	0
	MDF + Cork Insulation	20	115	7,19 €	0,24 €	0,00 €	m^2	0,05	1,59E+00	2,16E+01
Wall 03	LSF Rigid C140-42-1.4	1,4	7701,00	3,22 €	0,00 €	0,00 €	Kg	50,00	5,71E-01	8,66E+00
	OSB Pannel 11mm	22	650	7,15 €	0,00 €	0,00 €	m^2	0,25	4,72E-01	9,22E+00
	Agglomerated expanded cork	40	-	2,57 €	0,00 €	0,00 €	m^2	0,04	-	-
	Rockwool	140	50	13,64 €	0,28 €	0,56 €	m^2	0,035	1,46E+00	2,16E+01
	Air gap	114	1,23	0,00 €	0,00 €	0,00 €	m^2	1,83	-	-
	Gypsum Plasterboard	30	875	23,76 €	1,39 €	1,13 €	m^2	0,250	3,50E-01	5,74E+00
Wall 04	Reinforced concrete structure	60	2350,00	0,00 €	0,00 €	0,00 €	m^2	2	1,48E-01	5,87E+01
	Wood chip insulation	70	138	0,00 €	0,00 €	0,00 €	m^2	0,071	-	-
	Phenolic Foam Insulation Layer	50	1300	0,00 €	0,00 €	0,00 €	m^2	0,3	-	-
	Reinforced concrete structure	70	2350	0,00 €	0,00 €	0,00 €	m^2	2	1,48E-01	5,87E+01
	Light elastic Mineral Wool	50	27,5	5,57 €	0,16 €	0,21 €	m^2	0,045	1,46E+00	2,16E+01
	Smart Vapour retarder	15	-	7,65 €	0,00 €	9,05 €	m^2	0,5	-	-
	Timberframe pannels	100	525	24,55 €	0,00 €	2,44 €	m^2	0,21	8,46E-02	1,92E+00
	Rockwool	70	100	6,82 €	0,14 €	0,28 €	m^2	0,035	1,46E+00	2,16E+01
	Rockwool	195	100	17,94 €	0,36 €	0,76 €	m^2	0,035	1,46E+00	2,16E+01
	Semi-rigid mineral wool slab with special wind barrier facing	30	180	5,03 €	0,10 €	0,16 €	m^2	0,031	-	-
Wall 05	Original building wall	-	-	-	-	-	m^2	0,96	-	-
	Rockwool	140	50	13,64 €	0,28 €	0,56 €	m^2	0,035	1,46E+00	2,16E+01
	Coretech® Sheets	10	-	0,00 €	0,00 €	0,00 €	m^2		-	-
	Polyurethane Foam	100	35	6,01 €	0,01 €	0,02 €	m^2	0,7	4,26E+00	1,00E+02
	Coretech® Sheets	10	-	0,00 €	0,00 €	0,00 €	m^2		-	-
Wall 06	Aluminium finishing	6	2700,00		-	-	m^2	230	4,28E+00	6,82E+01
	Agglomerated black cork	20	200		-	-	m^2	0,055	1,59E+00	2,88E+01
	Smart vapour retarder	1.5	-		-	-	m^2	-	-	-
	XPS	120	32,5	46,90 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Steel U Profile	1.5	7800		-	-	m^2	50	5,71E-01	8,66E+00
	Agglomerated black cork	30	200		-	-	m^2	0,055	1,59E+00	2,88E+01
	Aluminium façade	6	2700		-	-	m^2	230	4,28E+00	6,82E+01
Floor 01	Structural building concrete	100	2350	87,23 €	0,55 €	-	Kg	2,3	1,48E-01	1,24E+00
	Insulation (XPS)	50	32,5	3,87 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Damp-proof membrane	-	-	-	-	-	m^2	-	-	-
	Reinforced concrete slab	150	2350	20,94 €	0,38 €	-	m^2	2,3	1,48E-01	1,24E+00
	Cement mortar	50	2300	10,22 €	0,05 €	-	m^2	1,825	1,95E-01	1,31E+00

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m^2K)	GWP	NRPE
Floor 02	Ventilated air gap	150	-	-	-	-	-	-	-	-
Floor 02	Lightened concrete slab with prefabricated beams	150	2350	40,60 €	0,28 €	-	m^2	-	-	-
Floor 02	Insulation layer - RockWool	140	50	13,64 €	0,28 €	0,56 €	m^2	0,035	1,46E+00	2,16E+01
Floor 02	Floating vinylic floor	30	610	26,44 €	0,10 €	-	m^2	-	-	-
Floor 03	Concrete Foundation	500	1500	1 323,88 €	3,98 €	-	m	2,3	1,48E-01	1,24E+00
Floor 03	Steel Fram Strucutre	1,5	2700	3,22 €	-	-	Kg	50,00	5,71E-01	8,66E+00
Floor 03	Screen delta facade plus	1,5	-	0,00 €	-	-	m^2	-	-	-
Floor 03	OSB 15mm	15	650	9,77 €	-	2,37 €	m^2	0,13	4,72E-01	9,22E+00
Floor 03	Wood frame structure	150	7701,00	38,83 €	4,18 €	1,21 €	Kg	50,00	8,46E-02	1,92E+00
Floor 03	Rockwool insulation	150	50	13,64 €	0,28 €	0,56 €	m^2	0,035	1,46E+00	2,16E+01
Floor 03	OSB 15mm	15	650	9,77 €	-	2,37 €	m^2	0,13	0,472	9,22
Floor 03	Finishing layer	10	-	-	-	-	m^2	-	-	-
Floor 04	Reinforced concrete slab	200	2350	20,94 €	0,38 €	-	m^2	2,3	1,48E-01	1,24E+00
Floor 04	Steel re-used shipping container flooring	135	-	-	-	-	m^2	-	-	-
Floor 04	XPS	30	32,50	3,87 €	-	-	m^2	0,04	3,86E+00	9,69E+01
Floor 04	Aglomerated hidro phobic layer	80	-	-	-	-	m^2	-	-	-
Floor 04	Geotextil protection layer	150	-	-	-	-	m^2	-	-	-
Floor 04	Cement mortar	5,5	650	-	-	-	m^2	-	1,95E-01	1,31E+00
Floor 04	Floating vinylic floor	10	610	-	-	-	m^2	-	-	-
Floor 05	Light Steel Frame Strucutre	0,000252	2700	2,19 €	0,00 €	0,00 €	Kg	-	-	-
Floor 05	OSB 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,13	4,72E-01	9,22E+00
Floor 05	Rockwool insulation	140	50,00	13,64 €	0,28 €	0,56 €	m^2	0,04	1,46E+00	2,16E+01
Floor 05	OSB 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,13	4,72E-01	9,22E+00
Floor 05	Smart Vapour Retarder	1,5	15	5,08 €	0,00 €	9,04 €	m^2	0,038	-	-
Floor 05	Wooden Floor	15	650	9,77 €	0,00 €	2,37 €	m^2	0,13	4,72E-01	9,22E+00

	System	Cost	Maint. (€.year)	Demo.	Cost Unit	Efficiency
DHW 1	Natural Gas Boiler 42kW	€ 1 688,23	€ 160,38	-	u	0,71
DHW 2	Eletric Boiler 120l	€ 352,82	€ 26,81	-	u	2,00
DHW 3	Reversible Heatpump integrated DHW	€ 12 264,04	€ 784,99	-	u	3,44
HVAC 1	Reversible Heatpump integrated Heating	€ 12 264,04	€ 784,99	-	u	3,44
HVAC 1	Reversible Heatpump integrated Cooling	-	-	-	u	3,62
HVAC 2	Eletric Thermo accumulator Heater Radiator	€ 263,23	€ 44,75	-	u	2
HVAC 2	Multi-split wall monted air-conditioning 1700W	€ 1 118,42	€ 31,32	-	u	3
HVAC 3	Eletric Thermo accumulator Heater Radiator	€ 263,23	€ 44,75	-	u	2
HVAC 3	Multi-split wall monted air-conditioning 1700W	€ 1 118,42	€ 31,32	-	u	3

Annex 1

Building wall solutions

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 1a	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	7,15 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	60	200,00	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	80	200,00	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	100	200,00	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	120	200,00	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	140	200,00	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	160	200,00	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	200	200,00	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 1h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	240	200,00	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,83 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1										
	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 2g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 2h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	3,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3b	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3c	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3d	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3e	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3f	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3g	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 3h	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 4a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	3,92 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	60	200,00	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	4,29 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	80	200,00	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	4,65 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	100	200,00	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	5,01 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	120	200,00	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	5,37 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	140	200,00	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 4f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	5,73 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	160	200,00	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	6,46 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	200	200,00	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 4h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	7,18 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	240	200,00	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Steel Frame	1,5	7800	3,92 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 5h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	3,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 6e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 6g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 6h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 7a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	7,15 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 7h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,83 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 8d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 8h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	3,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 9h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 10a	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	7,15 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 10c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 10h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,83 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 11h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	3,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 12b	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,10 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12c	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	4,64 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12d	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,00 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12e	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,36 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12f	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	5,72 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12g	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,45 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 12h	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	LSF Structure	1,5	7800	6,81 €	-	-	Kg	50	5,71E-01	8,66E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 13a	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 13h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 14a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 14h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15b	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15c	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15d	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15e	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15f	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 15g	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 15h	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 16a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 16h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

Wall	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 17g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 17h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 18g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 18h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 19a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 19f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 19h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 20h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21a	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21b	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21c	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21d	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 21e	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21f	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21g	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 21h	Plaster board	15	650	15,29 €	1,74 €	-	m^2	0,25	3,50E-01	5,74E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Aluminium Façade	1,5	2700	33,27 €	63,10 €	-	m^2	230	4,28E+00	6,82E+01
Wall 22a	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	60	200	19,61 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	80	200	27,51 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	100	200	30,98 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	120	200	39,22 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	140	200	45,52 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	160	200	55,02 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	200	200	61,96 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 22h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Black cork	240	200	78,44 €	-	-	m^2	0,55	1,59E+00	2,88E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	50	32,5	11,24 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23b	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	70	32,5	15,73 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23c	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	100	32,5	22,47 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Wall 23d	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	120	32,5	26,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23e	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	140	32,5	31,26 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23f	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	160	32,5	35,96 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23g	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	200	32,5	44,94 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 23h	OSB III 15mm	15	650	3,22 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	XPS	220	32,5	49,44 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24a	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	65	32,5	4,37 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24b	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	90	32,5	6,56 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24c	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	120	32,5	8,98 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24d	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	140	32,5	10,07 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24e	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	160	32,5	11,16 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24f	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	220	32,5	13,12 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24g	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	17,40 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00
Wall 24h	OSB III 15mm	15	650	9,77 €	-	-	m^2	0,19	4,72E-01	9,22E+00
	Wood Frame	40	7800	28,68 €	4,18 €	-	m^2	0,15	8,46E-02	1,92E+00
	Mineral Wool	240	32,5	18,49 €	-	-	m^2	0,037	3,86E+00	9,69E+01
	Wood Façade	22	2700	38,09 €	5,13 €	-	m^2	0,15	8,46E-02	1,92E+00

Annex 1

	Material	Thickness (mm)	Density (kg/m3)	Cost	Maint. (€.year)	Demo.	Cost Unit	U-Value (W/m²K)	GWP	NRPE
Floor 01	Steel Frame Strucutre	1,5	2700	2,19 €	0,00 €	0,00 €	Kg	0,15	8,46E-02	1,92E+00
	OSB III 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,19	4,72E-01	9,22E+00
	Mineral Wool	140	50	13,64 €	0,28 €	0,56 €	m^2	0,037	3,86E+00	9,69E+01
	OSB III 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,19	4,72E-01	9,22E+00
	Smart Vapour Retarder	1,5	15	5,08 €	0,00 €	9,04 €	m^2	-	-	-
	Wooden Floor	15	650	9,77 €	0,00 €	2,37 €	m^2	0,15	8,46E-02	1,92E+00
Floor 02	Wood Frame Strucutre	1,5	2700	28,68 €	4,18 €	0,00 €	Kg	0,15	8,46E-02	1,92E+00
	OSB III 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,19	4,72E-01	9,22E+00
	Rockwool insulation	140	50	13,64 €	0,28 €	0,56 €	m^2	0,037	3,86E+00	9,69E+01
	OSB III 15mm	15	650	9,77 €	0,00 €	2,37 €	m^2	0,19	4,72E-01	9,22E+00
	Smart Vapour Retarder	1,5	15	5,08 €	0,00 €	9,04 €	m^2	-	-	-
	Wooden Floor	15	650	9,77 €	0,00 €	2,37 €	m^2	0,15	8,46E-02	1,92E+00

	Material	Thickness (mm)	Dim. (mm)	Density (kg/m^3)	Mass (kg/m^2)	Cost	Cost Unit	Maint. (€.year)	GWP	NRPE
Roof Ref	LSF Slab	150	150	-	-	65,73 €	m^2	0,04	8,46E-02	1,92E+00
	Mortar + Primer Roof	100	100	-	-	54,80 €	m^2	1,53	-	-
	Mineral Wool	200	300	875	78,75	22,32 €	m^2	-	3,86E+00	9,69E+01
Roof 1	Cobertura Verde Extensiva	100	100	4700	470	106,21 €	m^2	3,34	-	-
	LSF Structure	300	1,2	7800	4,68	15,07 €	m^2	0	8,46E-02	1,92E+00
	Mineral Wool	300	300	875	78,75	22,32 €	m^2	0	3,86E+00	9,69E+01
Roof 2	Cobertura Verde Extensiva	100	100	4700	470	106,21 €	m^2	3,34	-	-
	Wood Frame Structure	200	100*200	550	11	42,03 €	m^2	0,63	8,46E-02	1,92E+00
	Mineral Wool	300	300	875	78,75	22,32 €	m^2	0	3,86E+00	9,69E+01
Roof 3	LSF Structure	300	1,2	7800	4,68	15,07 €	m^2	0	8,46E-02	1,92E+00
	Cobertura	100	100	6700	670	67,50 €	m^2	1,89	-	-
	Mineral Wool	300	300	875	78,75	22,32 €	m^2	0	3,86E+00	9,69E+01
Roof 4	Wood Frame Structure	200	100*200	550	11	42,03 €	m^2	0,63	8,46E-02	1,92E+00
	Cobertura	100	100	6700	670	67,50 €	m^2	1,89	-	-
	Mineral Wool	300	300	875	78,75	22,32 €	m^2	0	3,86E+00	9,69E+01

	Elemento	Altura (mm)	Espessura (mm)	Densidade	kg/m2	Preço (euros/m3)	Cost Unit	Maint. (€.year)	Man (€/m^2)	Total (€/m²)
Found.	Plane concrete foundation with natural air ventilation	500	500	2730	682,5	105,91 €	m^2	0,55	3,98E+00	2,00E+01

	Model	Solar Factor (Sw)	Light Transmit.	Acoustics (dB)	U-Value (W/m²K)	Cost Unit	Cost	Maint.	Max. Dim. (LxH)
Window 01	Sapa Perf. 70 OC+	0,43	0,54	40	1,3	m^2	-	-	1900 1475
Window 02	Technal EASY ECO	0,43	0,54	40	1,3	m^2	-	-	1900 1475

Annex 1										
	Model	Window Type	Solar F. (Sw)	Light Transmit.	Acoustics (dB)	U-Value (W/m²K)	Cost Unit	Cost	Maint.	Max. Dim. (LxH)
Window 03	Technal ECOTHERMIC 65			0,51	39	0,6	m^2	-	-	1300 1420
										
Window 04	Tigal Double-glazed window CIRCAL Hydro			0,63	45	0,85	m^2	-	-	2300 2180
										
Window 05	Sapa Performance OC+			0,54	41	0,9	m^2	-	-	1250 1480
										
Window 06	Double-glazed sliding window (Cype, 2020)			0,63	45	2,8	m^2	-	-	2300 2180
										
Door 01	Simple PVC Door w/ external painting					-	m^2	861,26 €	7,75 €	900 2100
										
Door 02	Aglomerated Wood Door					-	m^2	247,54 €	2,74 €	900 2100
										
Door 03	Natural Wood Door					-	m^2	303,94 €	3,34 €	900 2100
										
Door 04	External MDF Door					-	m^2	282,40 €	3,11 €	900 2100
										
Door 05	External Aluminium Door					-	m^2	467,23 €	5,14 €	900 2100