# ENHANCING BUILDING ENVELOPE PERFORMANCE AND RESISTANCE IN THE HIGH MOUNTAINS OF LEBANON

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## Abstract

In the high mountains of Lebanon, internal comfort heavily relies on fuel consumption for indoor space heating. Being a country that lacks natural resources such as fuel and gas, the energy sector in Lebanon had been unable to meet the market demand for a long time. The simple solution that was adopted to compensate for the electricity shortage over the past years was to rely on private generators for power supply. This solution urged additional energy costs for heating and cooling demands through the inefficient use of air cooling and heating, and since cooling and heating depend primarily on fuel. Studies around the world have shown that 40% of the global energy used in the residential sector is mainly consumed by heating and cooling systems (Aznabaev, A. et al., 2016). As for Lebanon, several studies had been conducted by local and international experts to investigate this issue. These studies recommended specific thermal property for each building envelope in each climate zone in Lebanon to reduce energy demand for heating and cooling. Thus, these recommendations had not been taken into consideration, where we can notice the same building materials used everywhere regardless of the difference of climate characteristics from region to the other. Moreover, the Lebanese building code does not take into consideration the specification of building materials according to climate nor imposes any material restrictions except intermittently the definition of the required percentage of exterior finishing of stone cladding and roof tiles in certain land zones. Therefore, we see the essential need to define the types of construction materials according to each climatic zone.

The built environment in Lebanon is mainly composed of masonry systems and concrete products as primary construction materials. This critical observation, where the frequent use of the same construction materials in all types of climates, raises the question on how to use high thermal construction materials in an extreme environment of Lebanon to decrease energy demand for heating and cooling. To reach this goal, the study investigates the thermal performance of residential buildings of various construction types. It takes as a case study the town of Bcharre, located in the high mountains of North Lebanon.

The method used in this study compare different types of envelope materials such as concrete masonry unit, reinforced concrete, natural stone, and wood. Besides, an economic analysis is done. In order to find the construction material with the highest thermal properties that reduce energy demand and consumption, this thesis analyzes the energy report of each material and compare it through Insight 360 software. Besides, this comparison will help to understand the behavior of building envelope materials in the high mountain of Lebanon climatic region, by providing a detailed assessment by simulation software showing expectations of each studied material. Finally, the results show that wooden construction materials have the least energy consumption, while single masonry wall construction the highest. This study proved that an insulated wooden wall can provide the least energy consumption spent on space heating when compared to different walls in the cold climate of Lebanon.

# 1. Introduction

The available Construction materials in Lebanon, such as concrete masonry units, stone, and wood, defines the external wall components of the built-up fabric. These materials affect the energy demand and consumption in buildings in general, especially in the high mountain areas with cold climate. Moreover, a visual inspection shows that in Lebanon, the use of construction materials is almost the same in the different climatic regions. Materials such as reinforced concrete, stone, concrete masonry units, and their combination shape the built environment in the residential and commercial sectors of Lebanon. According to Saleh, P. (2019, p.19), these construction materials absorb, store, and release heat. For this reason, such materials are recommended for a hot climate where summers are long with minimal to no precipitations, and winters are short and mild, with a maintained internal temperature (Saleh, P. 2019, p. 18).

Lebanon suffers from a daily power shortage (table 1.1). The reason behind this shortage is the high demand for electricity, where there are no enough power plants. Accordingly, there is a lack of electricity to meet the actual demands (Fardoun et al. 2012, p.317). Moreover, recently, it is noticed that there is a growing shortage gap, where demand is increasing while the supply is decreasing due to the Syrian crisis which has created additional strain on the electricity system (BLOMINVEST BANK, 2013). In order to compensate for the lack of required energy, people tend to depend on diesel generators provided by the private sector. In order to protect the consumers, the Lebanese Council of Ministers assigned measures in order to control the private electricity generators fees through installing electricity meters for the generators subscribers and charging as per consumption (Ministry of Economy and Trade, 2020). Therefore, users end up paying two monthly bills, one for the governmental power provided by Electricité du Liban (EDL) and another one for a neighborhood generator (Rabah M., 2018, p.5). The energy consumption analysis of the residential sector shows that the highest levels are reached in winter due to heating demand (MoEW/GEF/UNDP, 2015, p. 19).

As table 1.1 shows, since 2011, the deficiency between the demand of Megawatt (MW) in Lebanon is increasing in comparison to the yearly generated power in MW.

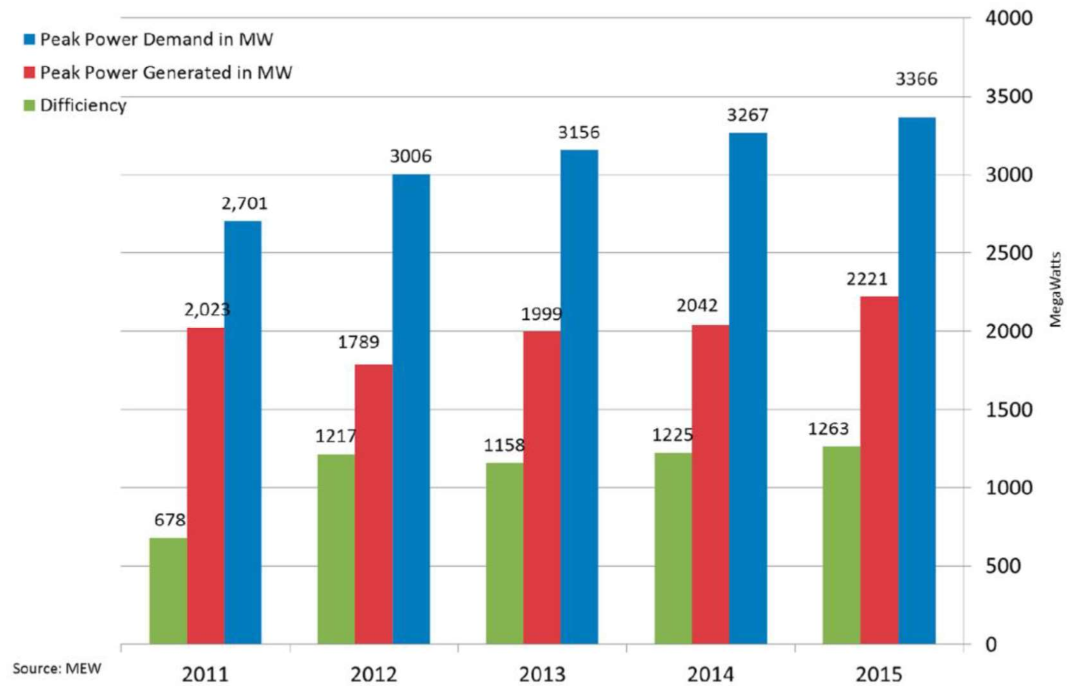



*Table 1.1 Electricity sector overview. Source: CDR 2016, accessed 24 January 2020.*

Given that there is a continuous need for cooling and heating coupled with an energy shortage, several strategies and recommendations had been conducted to tackle buildings' envelopes. These studies have been issued since the mid-2000s with regular updates, by local and international bodies (ASHRAE 2004, UNDP 2005). Moreover, (Building Energy Codes Program, 2015) recommends thermal properties for each envelope within the four climatic zones of Lebanon that can reduce energy consumption and demand caused by heating and cooling. Regardless of these available guidelines, construction throughout the four climatic zones has more similarities than differences in construction materials and methods. These differences are beyond the variation over external finishing imposed by the local authorities (percentage of stone cladding and roof tile covers). The built-up fabric of Lebanon, in all climatic zones, consists mainly of the same materials as reinforced concrete, and their derivatives and combinations. Several studies questioned the topic of energy reduction for winter heating demands in a cold climate (Jradi, Veje & Jørgensen, 2018, pp. 62-76), (Pisello et al. 2012, pp. 5257-5278). Yet, there are seldom studies found on energy reduction for concrete masonry units and stone construction materials within such context.

Bcharre, Lebanon 33°N, 35°E is located in the northern part of the country with an altitude that starts from 1400m (fig. 1.1). This area falls within the high mountains zone, which is the focus of this study. The climate of this area is based on the Koppen-Geiger world climate classification under the general of cold temperature climates (Kottek et al., 2006, pp. 259-263). According to the UNDP study (2005.

*Figure 1.1 Town of Bcharre showing Kannoubin Valley inbetween the mountains. Source: instagram live love Bcharre accessed 03-05-2019*

P.23), the monthly temperatures and relative humidity fall outside the comfort zone for all the months (table 1.2). Similarly, (Djamila, 2017, p. 570) confirms the same results by stating that the high mountains of Lebanon region, present considerable variations of temperature and relative humidity between seasons.

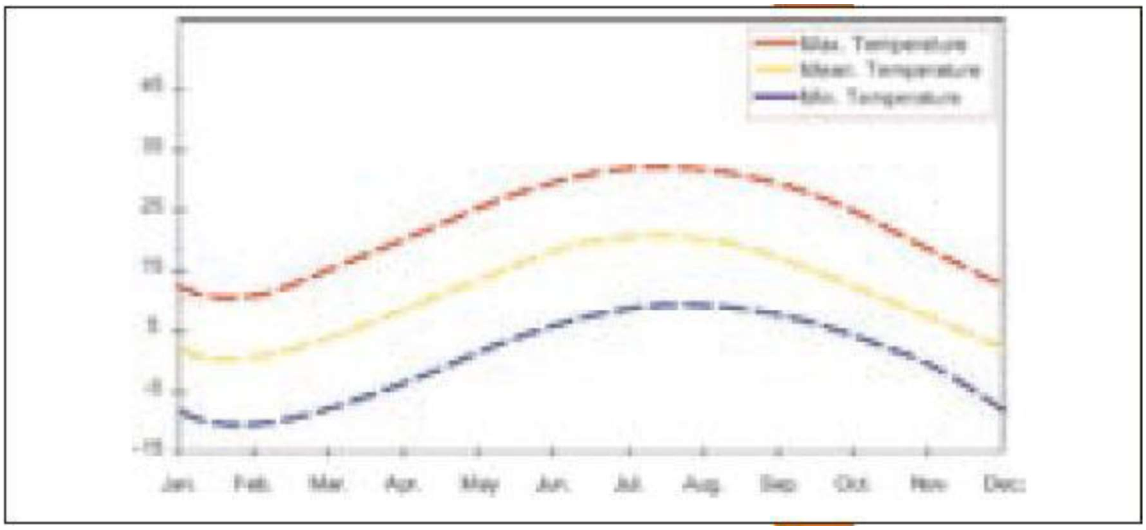



*Table 1.2 High mountain's region temperature. Source: UNDP 2005 Accessed: 08-06-2020*

### 1.1- Statement of the Problem:

Up to 36% of the Lebanese population is considered poor, a significant part of their income is spent on space heating, especially where heating constitutes 40 % of the energy

| Construction Permits by Use | | | | | |
|---|---|---|---|---|---|
| (in ,000 sqm) | 2008 | 2009 | 2010 | 2011 | 2012 |
| Residential Buildings | 10,264 | 6,441 | 8,203 | 7,401 | 6,714 |
| *% Change* | | *-37%* | *27%* | *-10%* | *-9%* |
| Commercial Buildings | 1,066 | 338 | 598 | 616 | 845 |
| *% Change* | | *-68%* | *77%* | *3%* | *37%* |
| Public Buildings | 547 | 486 | 381 | 236 | 425 |
| *% Change* | | *-11%* | *-22%* | *-38%* | *80%* |
| Economic Sector Buildings | 252 | 284 | 520 | 425 | 397 |
| *% Change* | | *13%* | *83%* | *-18%* | *-6%* |
| Hotel & Tourism Services Buildings | 296 | 122 | 156 | 232 | 104 |
| *% Change* | | *-59%* | *28%* | *49%* | *-55%* |

*Table 1.3 Construction permits in Lebanon. Source: Bank MED 2019 accessed 12-04-2019*

consumed (Serrano S., 2015, pp.85-98). Since the highest portion of construction permits goes for the residential sector (table 1.3), we can denote the amount of energy consumption and cost that could be reduced if the energy demand could be decreased, especially that this cost affects the households directly. "In Lebanon, 27% of the Lebanese population are considered relatively poor" (UNDP in Lebanon, 2019, p.14). This number sinks to 16 percent in urban areas like the capital city Beirut and climbs to 36 percent in some rural areas (UNDP in Lebanon, 2019, p.14). It was also found that 28.6% of Lebanese households are poor, whereas 8% among them are considered extremely poor or below the lower poverty line. The discrepancy between this rate (28.6%) and the income-related component of the Living Conditions Index (LCI) (51.6%) is noteworthy and indicative of the significance of the methodology used to measure poverty. The analysis of the construction permits over the past three decades shows that residential buildings represent the highest portion by (79%) of total construction permits followed by commercial buildings (10%), public buildings (5%), and the economic sector buildings (5%) (BANK MED, 2019, p. 10) (Table 1.3).

Lebanon's topography differs across the four climatic regions according to the 1996 National Physical Master Plan of the Lebanese Territory (NPMPLT). This topography played a vital role in the history of the country and the settlement of Lebanon's population (fig. 1.2). The NPMPLT (1996) stated that during winter, one hundred residences in the high mountains of Lebanon are inhabited with an average of 4.8 residents (p.18). However, Nowadays, the rural population is decreasing. We can see the difference when we compare the percentage of the rural population in 2019, which constitutes 11.41 % of the total Lebanese population, where in the 1960s this portion represented 57.66 % according to population and urbanization statistic of the world bank (2020).

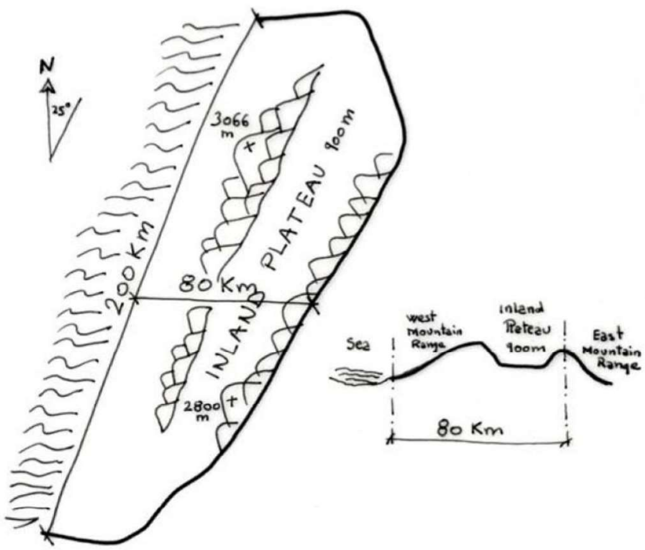



*Figure 1.2 Schematic diagram showing the topography of Lebanon. Source: Saleh, P. 2019, p.26*

In comparison, this average differs from one country to another, for example, it constitutes 6.8 persons in Pakistan, 5 in the Philippines, 4.7 in Tunisia, 2.4 in France and 2.3 in Quebec […]. This reduction is caused by many reasons: changes in habits and traditions, higher standards of living, as well as the aging of populations (NPMPLT, 1996). At the time being, this region that includes villages, agricultural areas, and natural spaces is only adequate for rugged and rural housing. For the people living in these houses in all seasons, the accommodation is affecting them, since it causes them high fuel costs for heating during winter.

According to Lundgren & Kjellstrom (2013), high energy consumption for space heating has a significant impact on climate change, while it relies on non-renewable resources, has its impact on resource depletion, human health, water resources, biodiversity, regenerative materials, and natural resources (pp. 3116, 3128).

In Lebanon, vernacular constructions, mainly constructed with materials found in the same region, were performing reasonably over all seasons (Fishfish, A. 2004) (fig. 1.3). At this time, even though there is an advanced knowledge of technology, houses are still built with the same approach of materials in all microclimatic regions. This situation is leading to improper use of materials that are almost the same in all climatic zones of Lebanon. At the same time, each zone has its proper climatic properties that should be known to preserve energy saving and the environment. According to Hwaish (2015): “the building envelope plays a significant role in optimizing interior temperatures, the amount of energy required to maintain thermal comfort, and defines the heating and cooling needs of the building” (p.1). Besides, Moore (1993) asserts that each component of the envelope has its specific thermal properties that directly affect the building (p. 210). And when it comes to the selection of building materials, Akadiri (2015) claims that:

"The selection of sustainable building materials has been identified as an

*Figure 1.2 This picture showing an old Lebanese house Located in Bcharre built with stone. Source: instagram live love Bcharre accessed 03-05-2019*

important strategy in the design of a building. Although the sustainability imperative is gaining in importance, there are still major barriers preventing this new architectural style practice becoming the norm" (p. 89).

If we try to analyze vernacular constructions, several exciting techniques can be found (Creangă E. et al., 2010). Kimura (1994) considers that vernacular architecture devised uniquely to regions where people adapt to the severe climate through many passive ways without resorting to fossil fuels such as building orientation, integration, the shape of sun shades, ventilation, heat gain, and cooling effects.

Since heating records the highest energy usage in high mountains of Lebanon, and this cold climatic zone is proved to have high impact on energy consumption, this thesis will limit the focus on external envelope (construction materials) in residential buildings in the high mountains of Lebanon focusing on space heating consumption and demand. Thus analyzing external envelope's construction materials to show the lowest heat exchange to minimize energy consumption and demand in the residential sector of the high mountains of Lebanon would decrease also running cost and greenhouse gas emissions and improve the environmental conditions. Bcharre Town will serve as a sample to the high mountains area of Lebanon. A 45 % reduction on energy consumption for space heating can be obtained if the use of timber wood and limestone construction materials for external buildings envelope were conducted.

**1.2- Aims and Objectives:**

As previously mentioned, each construction material has different thermal properties and configurations in terms of forms, type, and dimensions. The aim of this study is to specify the suitable construction materials of exterior walls with the optimum performance in the high mountains of Lebanon. In order to do this, several aspects should be examined, such as material conditions and properties, climatic response, impact on indoor space heating and demand, availability in the market, and energy reports. Moore (1993) also assures that:

"The exterior envelope of the building behaves differently in extreme temperature because heat and cool enters one side of the material and must conduct through the entire thickness of that material before it finally exits from the other side into the interior" (p. 210).

This statement asserts that the usually used material in normal conditions should be replaced with the proper ones, or different construction materials should be combined to decrease indoor energy consumption for heating. Therefore, this study aims to analyze the scenarios of the various existing, available, and used construction materials in the high mountains of Lebanon, in Bcharre region specifically, to establish the ultimate construction material or combination of materials that would decrease the energy spent on space heating.

The combination of all these factors leads to the fundamental research question:

What are the proper thermally performing wall components, in terms of materiality, economically, and construction, producing minimal heat exchange in the residential sector in the High Mountains of Lebanon?

To answer this question, the research will further expand on the following related objectives:

1- Improve the understanding of thermal performance of reinforced concrete construction materials in local construction in the high mountains of Lebanon.
2- Overview and analyze the performance and thermal properties of various construction materials for external building's envelope.
3- Show the expectations and limitations of concrete products compared to other construction materials, specifically in a cold climate in terms of thermal performance.
4- Identify scenarios of thermal properties in the study area.

5- Show the proper construction material that decrease energy consumption and demand for space heating by minimizing heat loss which will lead to achieve 45 % less energy consumption for space heating.
6- Estimate impact of each construction material on indoor heating energy consumption.
7- Construction recommendation for future construction in the high mountains of Lebanon.

The fundamental hypothesis based on literature review is: Insulated wooden external walls will provide the least internal heat loss when compared to outer, middle, and non-insulated similar walls with inner side thermal mass.

This research will introduce a systematic building performance evaluation approach to access pre and post energy and thermal environmental performance of dwellings from technical and analytical perspectives. These objectives will be addressed through a literature review on concrete products, wood, and stone construction materials to know how to achieve better thermal properties and less energy demand in the high mountain of Lebanon context. Besides, I will analyze the currently used materials to enhance their performance. I will be doing these steps through literature review to research studies and similar cases, data collection for 3D modeling and simulation, testing, and analysis of results in the contemporary building envelopes.

Each objective will be addressed through different methods; whether based on secondary data in the literature review or based on experimental and primary data. Observation will be implemented in order to identify the different construction materials types found in the context chosen. Building modeling and energy simulation will be used in order to estimate the energy consumed on space heating by designing a model using several architectural software; Revit, Insight 360, and Green Building Studio.

### 1.3- Thesis Structure:

This study is composed of ten complementary chapters that answer the previously mentioned objectives. The first chapter (introduction) gives an overview of the subject and defines the main research question and objectives. The second chapter includes the literature review and explains the context of the research by highlighting the main essential problems. This chapter sets a coherent theoretical background for the topic by reviewing and analyzing similar case studies yet expanding the performance and quality of each material. The study will inspect previous studies for each material to investigate their thermal performance. Following (chapter three) the geographic and climatic overview of the high mountains of Lebanon, the study is addressing the issue of energy, lack of resources, and the built environment in this local context. With the combination of these factors, the purpose of the research is to find the best suitable thermal properties construction used in Lebanon for reducing heat loss and demand. Chapter four sets the methodology that should be followed to achieve the desired results and to answer the research question. The study suggests the simulation of different scenarios to document and analyze construction materials' performance through two software, Revit Autodesk and Insight 360. Revit will be used to create physical models of each scenario and to obtain their u-value, resistance, and thickness. Insight 360 will be used to generate each scenario's model for extracting energy reports. The extracted energy reports assess energy consumption and demand performed by each material to obtain the best suitable construction material for such a climate. Chapter five describes each scenario to show the impact of each material on indoor heating demand to define the suitable construction material or combination of materials while also comparing the u-value of each wall. It will also evaluate for every chosen material, life cycle analysis, environmental effect, and cost spent in terms of construction and heating consumption. The primary objective of this chapter is to assess the methodology and to highlight the outcomes of the comparison. It also reviews the wall materials' thermal properties in different wall assemblies during the winter season period. In effect, chapter five presents the outcome and results based on the simulation tool. Chapter six analyzes the results per seasons for comparison. Chapter seven analyzes the life-cycle cost analysis showing each materials lcca, while chapter eight analyzes and discuss the thesis content to show the results. Finally, the conclusion will identify the suitable construction material’s combination in the high mountains of Lebanon to answer the fundamental question of the thesis, without forgetting to mention the current limitations of this study and research recommendations for future studies.

# 2. LITERATURE REVIEW

## 2.1 Introduction

In the high mountains of Lebanon, people rely excessively on diesel fuel for heating and to reach the suitable warm indoor temperature (Salem, 2009, p. 2). This chapter sets the theoretical framework to be followed by acknowledging previous studies and similar case studies on similar topic of this thesis. Thus, this review proceeds to investigate energy consumption through different wall components such as concrete and their derivatives, stone, and wood in a cold climate. Each section will define the effect of each studied material and its thermal performance in cold climate. Several factors affecting the performance of materials will be explored. This chapter ends by discussing the lowest heat transfer material upon all the studied materials through comparison between the studied construction materials to decrease energy consumption and demand. The literature will help frame the implemented methodologies and shed light on gaps in previous similar work.

## 2.2-Concrete and Derivatives

Concrete Masonry Unit (CMU) is the core of the wall component used in residential buildings. “Residential buildings are inhabited day and night, and most often, are built with concrete and masonry” (UNDP,2005, p.44). People tend to use concrete masonry widely because it has several advantages. Isler (2012) conducted a study to

Figure 2.1 Picture showing concrete masonry unit used in Lebanon. Source: http://abourachid.com/home/products/ accessed on 03-05-2019

understand why concrete masonry is extensively used in building construction industry. The study showed that it is an appealing material because of its durability, fire resistance, availability, versatility, and capabilities. Moreover, it can be manufactured at high speed, with a low cost and different sizes of units. (p.12) (fig. 2.1).

In Lebanon, different types of concrete masonry units are available. There are no statistics that show the usage of this construction material. Lightweight hollow blocks are available for interior partitioning and building envelope. According to Sibline technical data sheets (2016), lightweight hollow blocks stands out for its low thermal transmittance compared to other construction materials that decrease energy consumption and heat transfer (p.3).

In contrast, Kalkatchi (2016), in his study on environmental performance, highlighted the disadvantages of concrete masonry units. First, he mentioned the issue of an inefficient thermal performance, the high-embodied energy, and water permeability, in addition to airtightness, acoustic problems, cracks, moisture infiltration, and thermal bridging. It also has a heavyweight, high carbon footprint, and it needs maintenance (p.12). “Despite the advancements in structural and thermal efficiency, masonry construction is a slow, labor-intensive process that is limited by both the number of units a masonry crew can lay and the time that mortar needs to cure” (Hines 1992, p.21).

Javier, M. & Andino, M. (2018) studied heat loss in buildings in cold climates. They investigated concrete masonry unit wall components with different dimensions and with varying rows of gaps to know which one has higher thermal conductivity and higher thermal resistance. The study aimed to examine the behavior of masonry walls through experimental tests and numerical models. Besides, the study examined the thermal performance of masonry through thermos-dynamic models. The analysis of the types of concrete masonry units showed a distribution of temperature within each group. The results revealed the importance of having more gap rows in each unit in order to increase thermal performance, minimize heat transfer, and have low thermal conductivity.

To counter the negative impact of excessive energy, use in residential buildings and to consider indoor thermal comfort as a preliminary achievement, research studies focused on improving the performance of building envelope systems. To improve CMU construction, Diaz et al. (2010) focused on the reduction of the weight of the block; they kept the same structural characteristics and made some thermal improvements. Also, they introduced lightweight concrete to optimize thermal performance and increase energy savings (p.146). The authors stated that the concrete masonry units cannot achieve an efficient thermal resistance in cold climates without an effective insulation property. The insulation has its impact on airflow within the unit's modeled interior space (cell), Where it increases the thermal performance of the CMU. Also, the authors took the airflow into account in the study of the thermal behavior of CMUs. This research showed an increase of 42% of thermal efficiency through insulation. They showed the difference between insulated and non-insulated CMU walls. Generally, the concrete masonry units had a higher thermal resistance than the wall without insulation. They stated that rigid insulation, such as EPS (expandable polystyrene) makes the wall less conductive by 40 % in comparison to conventional CMU wall. To decrease energy consumption caused by heating in residential buildings, the author addressed the problem by studying the thermal properties of a concrete masonry unit wall with and without insulation through numerical analysis for a better understanding. In this paper, the insulation had a high impact on the thermal performance of the wall. The authors stated that the conventional CMU wall without insulation had a lower resistance of 42%.

According to Sibline (2016), which is one of the major cement producers in the Republic of Lebanon and the only company in Lebanon that publishes consumption reports each year, the annual production of cement exceeds 1.35 Million tons. A lightweight Double-Hollow Block is a non-load-bearing lightweight CMU used in external and internal walls and made from lightweight aggregates. Light yet still substantial, this material is produced with a proprietary mix design containing sand, cement, and lightweight materials, including non-toxic flame retardant EPS. One of the advantages of this lightweight block stands in its low U-value compared to other construction materials that decrease energy consumption in the lifetime of the building (table 2.1). Its low water absorption / low water permeability makes it an ideal block for external walls. Besides, its lightweight makes it easier to be carried on site, reduces the risk of injuries, and decreases the cost of workmanship. The lightweight concrete masonry unit is lower than the regular block by 1.49 W/m2k. Its thermal conductance is 0.42 W/m2k compared to the benchmark set by the local and international bodies that which is 0.5 W/m2k. As shown in table 2.1, the lightweight CMU is lower than the regular block by 0.67 W/M²K. This difference increases to reach 1.49 W/M²K when adding EPS.

In their research, Buratti, C. & Moretti, E. (2005) presented a methodology to measure masonry walls' thermal resistance. They measured the external walls of the Acoustics Laboratory of the Department of Industrial Engineering, University of Perugia. Four tests were done on a period of 1500 hours of heating and cooling during day and night, and three data analysis were proposed. The first one without external heat transfer. The second one convergence of a fixed thermal resistance. And finally, a filtering of the measured data. The study concluded that masonry wall having a u-value of 0.5952 W/m2k had the proper thermal resistance.

### 2.2.1-CMU Workmanship

Among different construction materials, CMU is an essential material used to build the external envelope. It is divided into two major types, the hollow concrete block, and the solid concrete block. A hollow concrete block has a rectangular shape, and voids constitute part of its unit, contrary to the solid concrete blocks that have fewer hollows. These two types differ in weight, thermal and acoustic properties. The concrete masonry units are a standard size rectangular block made of

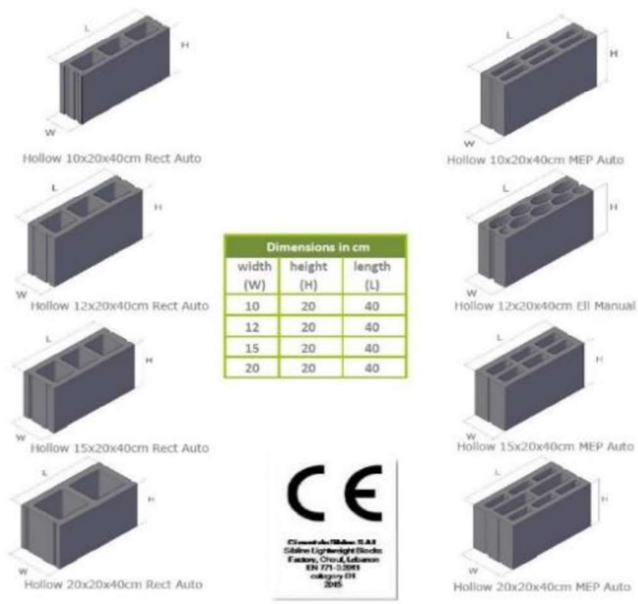



*Figure 2.2 Picture showing different types of CMU used in Lebanon Source: Sibline technical data sheet 2016 accessed on 03-05-2019*

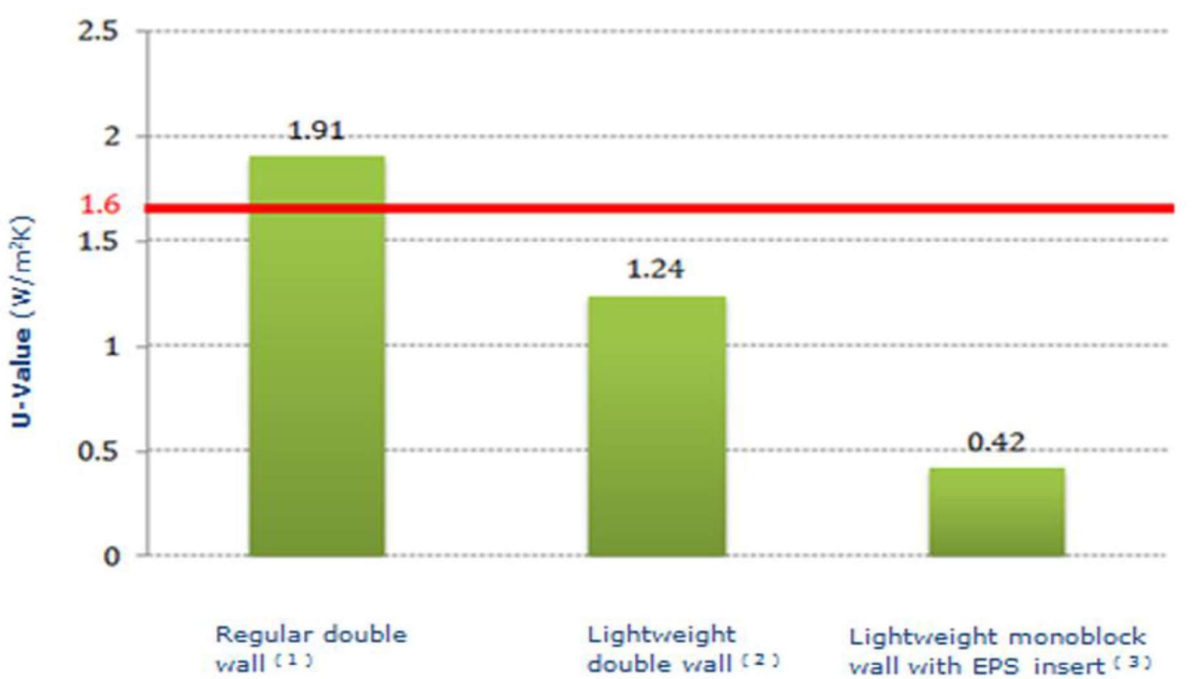



Table 2.1 table showing cmu vs. lightweight cmu Source: Sibline technical data sheet 2016 accessed on 03-05-2019

Portland cement, aggregate, and sand. The use of such materials allows masons to stack above each other to form a staggered wall. The structure and the composition of the concrete masonry units varies according to the needs of different types of structures. Sibiline's technical data sheet (2016, p.3), shows that CMU dimensions are made according to the Lebanese market consumption. They all have the same length and height (40 cm, 20cm) with a different range of widths that starts from 10 cm, 12 cm, 15 cm to 20 cm (fig. 2.2).

Concrete masonry units are an addition to the types of masonry units available to construction materials, and its use is continuously increasing in Lebanon due to the advantages mentioned before.

Since there is a lack of awareness regarding the workmanship of the studied materials, this section will study the method of concrete masonry unit construction to minimize after construction problems. Rafiq et al. (2013) define the materials used in this type of construction, which are CMU, cement, sand, and mortar (p.15).

According to CMA (2007, pp. 85-92), several steps should be followed to build with concrete masonry units.

- Step one is setting out the block modules. Masons have to start then by putting the start-end point, which he will be following (fig. 2.3).
- Step two is putting mortar for buttering the first layer of mortar on the ground (fig. 2.3).
- Step three is the positioning of the first corner block, which will be the base of the wall (fig. 2.3).

- Step four is tapping the block into position, to make sure that each unit will absorb mortar (fig. 2.3).


*Figure 2.3 Concrete Masonry Units Steps. Source: CMA (2007)*

- Step five is removing mortar excess (fig. 2.4).
- Step six is the buttering end of the block to stack blocks with each other (fig. 2.4).

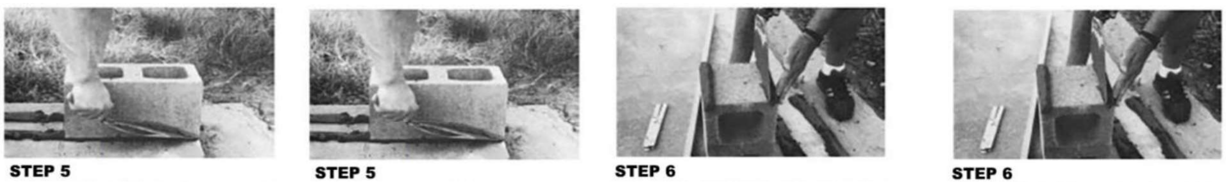



*Figure 2.4 Concrete Masonry Units Steps. Source: CMA (2007)*

- Step seven is placing block against the previous unit, and then step number eight is tapping into position (fig. 2.5).
- Step nine requires checking block alignments with a straightedge to check the level and 90 degrees' angles (fig. 2.5).

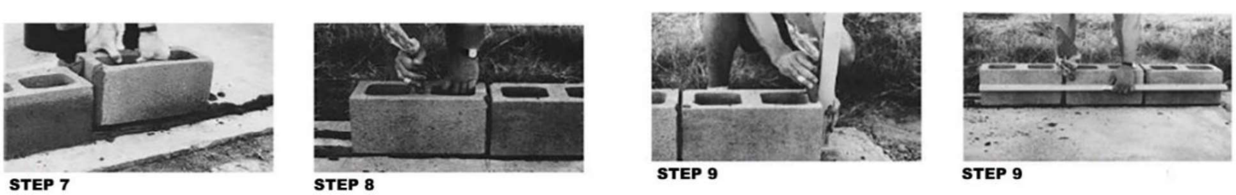



*Figure 2.5 Concrete Masonry Units Steps. Source: CMA (2007)*

- Step number ten faces shall mortar bedding on the first layer of the wall (fig. 2.6).

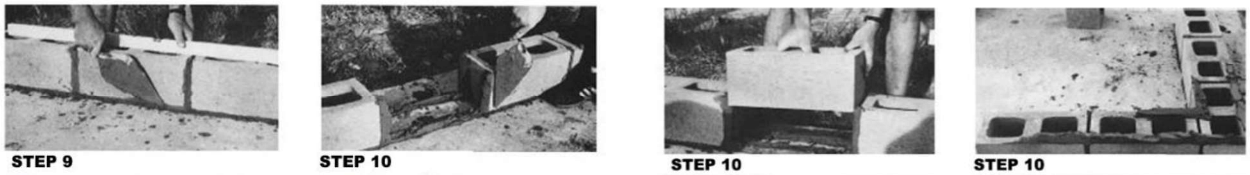



*Figure 2.6 Concrete Masonry Units Steps. Source: CMA (2007)*

- In Step eleven, there is a checking of course height, level, corner alignment (fig. 2.7).
- Step twelve consists of refilling mortar joints and checking vertical joints to make

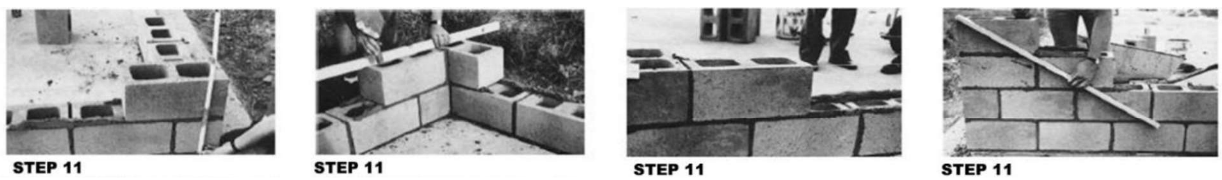



*Figure 2.7 Concrete Masonry Units Steps. Source: CMA (2007)*

sure that all block connections are stacked with mortar. And finally, step thirteen consists of removing the excess of mortar burrs (fig. 2.8).

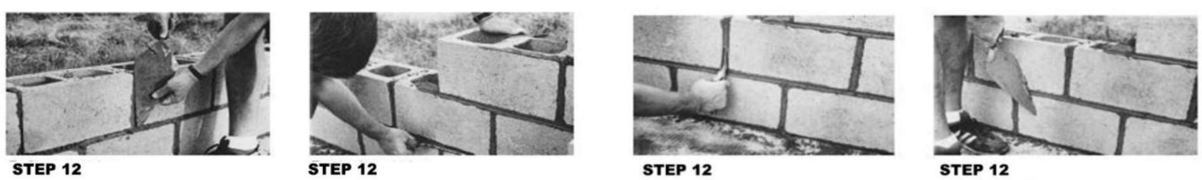



*Figure 2.8 Concrete Masonry Units Steps. Source: CMA (2007)*

## 2.3-Timber Wood construction material

Taking into consideration the growing importance of energy-efficient building methods, wood construction has presented a high capacity that decreases energy. Several studies reviewed the use of wood construction materials in cold climate.

This section of the literature review starts with Arumägi & Kalamees (2014), who studied wooden apartments. Twenty-nine buildings and forty-one apartments were examined under the same characteristic, function, and size. The author used an energy simulation program to calculate the energy consumption of each building. The study shows that the wood wall can achieve a maximum of sixty-three percent reduction compared to concrete masonry units (p.331) (fig. 2.9).

Arumägi & Kalamees (2014) studied wooden apartments. The study aimed to demonstrate the energy-saving potential in timber wood apartment buildings based on field measurements, computer simulations, and calculations. Twenty-nine buildings were analyzed under the same function, and size while concentrating on the envelope. The external walls were made of 120 to 160 mm thick logs (fig. 2.9). Field measurements included indoor and outdoor temperature studies for the same period and building surveys and measurements of each envelope. Also, data for energy consumed on space heating was collected for comparison. The energy consumption of the buildings was analyzed based on the collected data to give a view on the real energy use in timber wood buildings in cold climates. The research showed that the energy performance of timber wood construction is lower than the limit set for existing buildings constructed with other materials, where the energy consumption was below the benchmark level. This is due to the reduction of heat loss through the timber wood construction material. This study

*Figure 2.9 Picture showing wooden house construction. Source: https://pl.pinterest.com/pin/390547217455746167/ accessed on 01-02-2020*

showed that the timber wood could achieve a maximum of 45 % reduction if the wall was constructed of wood compared to concrete masonry units.

Pierquet, Bowyer & Huelman (1998, pp. 53-60) studied this topic in the United States in a cold climate. The study examines different types of wall systems, such as wood and concrete, and compares them to calculate the embodied energy of each wall component. The Eleven different wall systems were compared to the timber wood insulated construction. The wall systems varieties are steel construction, concrete construction, and stone construction, and the thermal performance was analyzed on HOT-2000 software. Timber wood construction showed the best long-term energy performance compared to other construction materials. The study showed that walls made from non-renewable construction materials such as steel and concrete have higher energy consumption compared to timber wood, which has a high and long-term thermal performance.

Hermawan et al. (2019) analyzed the thermal performance of timber wood compared to exposed stone-walled buildings in mountainous areas with a variety of building envelopes. They examined one wood and one stone wall buildings in a cold climate zone. The research used building prototypes of 0.60 x 0.60 x 0.60 meter-sized in a sloped mountain area. The research results indicate that the appropriate building's envelope is timber wood construction, since it preserves indoor temperature more than stone, especially while having a substantial difference in temperature between inside and outside.

Zhen, M. & Zhang, B. (2018) studied the energy performance of a timber structured in a 196 m² house in Harbin, which located in a cold region in China. The average winter temperature in the study area is equal to 3.6 °C. The authors monitored the house for three months from the $15^{th}$ of January till the $15^{th}$ of April 2008. The goal was to study winter heating consumption, the building heat storage capacity, and the heat transfer coefficient of the external walls. The authors concluded that timber wood construction materials created a comfortable and livable thermal environment for residents in severe cold areas and reduced energy consumption.

### 2.3.1-Wood Workmanship

This section addresses wood workmanship construction materials in residential construction. The process of construction of residential houses requires attention and care to provide comfort and to ensure less maintenance. Wood construction is fast and easy to build and renovate, durable, built from a renewable resource. It is also considered a natural insulator that minimizes heat loss, durable, light, and adaptable to cold climatic weather. Besides, in wooden constructions, different elements work together as a whole system in the structure of the house. These structural systems are floors, walls, and roofs. In this research, the focus of the study is the wall component. The goal is to reach a better thermal insulator in the high mountains that have a cold climate.

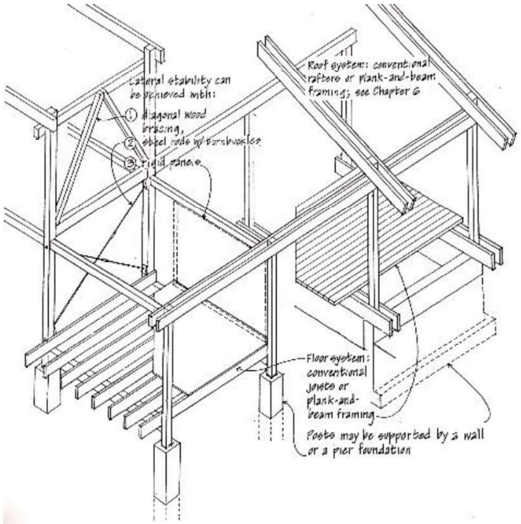



*Figure 2.10 Wooden structure. Source: Building construction illustrated (1991)*

According to the American Forest and Wooden Association, the wooden wall supports the load from the roof and floors above.

"The Wall studs are vertical, repetitive framing members spaced at regular intervals to support the wall sheathing […] however, the Cripple studs are placed above or below a wall opening and are not full-height" (p.32).

Wooden construction requires several steps:

- The first step in wooden construction is the platform frame. It consists of forming a platform to erect exterior walls and interior partitioning (fig. 2.10).
- The second step is the balloon frame, where the exterior walls stud through the upper floors.
- The third step is fastening, which consists of nailing with metal framing to provide the best performance in load distribution.
- Step number four is plank and beam construction. Equal beam size supports floor and roof loads. In exterior walls, wood framing and sheathing is used and installed.

## 2.4- Stone construction material

Traditional Lebanese houses are made from limestone materials that provide structural and thermal performance building elements. This section focuses on thermal performance. The studies were chosen from a similar context to the Lebanese high mountain area and using the same materials used in traditional Lebanese houses. The comparison focuses on stone, the core of a traditional solid stonewall (fig. 2.11).

*Figure 2.11 Picture showing a stone house in the High Mountains context. Source: Lebanese Traditional Architecture (2011)*

Özkahraman, Selver & Işık (2004) studied the energy efficiency of buildings using stone as an external wall construction material in cold climates to reduce energy consumed on space heating. The author studied the thermal conductivity and factors that have an impact on heat transfer. The results showed that stone construction materials are good insulators of heat, where they store heat and release it due to thermal mass. These factors depend on stone minerals that affect the thermal properties of the external envelope. The thermal conductivity test was conducted on a 50 x 50 x 50 cm sample stone, and the results showed that thermal conductivity is directly connected to the bulk of the stone unit and strength.

Also, limestone had warmest energy conservation compared to other types of stone that reduce energy demand and reduce fossil fuel combustion.

In the research about the natural stone contribution in energy efficiency, Lopez-Buendia A. et al. (2010) studied and analyzed energy consumption and thermal conductivity contribution in buildings. They stated that energy consumption in stone walls depends on its mineral composition, porosity, and cementation. The authors studied six types of stones of 60 x 60 x 60 cm each to measure the energy consumption and thermal conductivity. Data were obtained by using an automated system (NEOTIM, ECOSTONE). According to this study, the evaluated natural stone behaved as a material with high energy efficiency, where it can delay heat transfer between inside and outside (fig. 2.12).

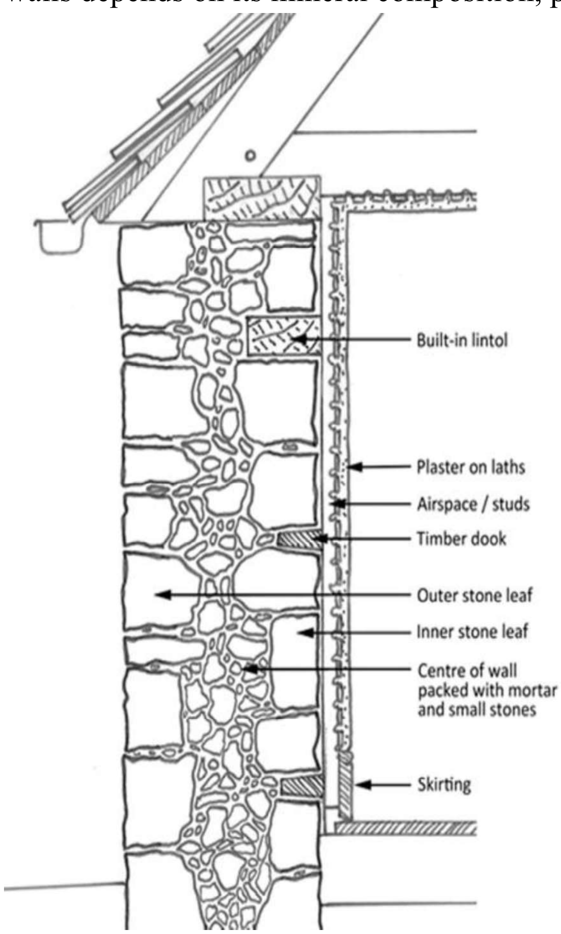



*Figure 2.12 Stone wall section. Source: Baker P. (2011).*

Baker P. (2011), in his study Historic Scotland Technical Paper 10, studied u-values and historic buildings in Scotland and provided the results of the thermal performance of elements of traditional construction. The study focused on U-values as an indicator of thermal performance, and a comparison with U-values calculated with software programs.

In this study, 67 historic buildings in Scotland were studied to compare their u-values. The external walls that are made of thick solid stone are not uniform constructions. Traditional building envelopes have thick solid walls. These walls are made from larger stones with their inside faces left rough, and the center of the wall is packed with smaller stones and mortar (fig. 2.12). The scope of the comparison was the impact of limestone. The authors found that traditional buildings composed of stone and especially limestone perform better thermally. Moreover, wall thickness improves the thermal resistance and results in a lower U-value. The walls with internal finishes that incorporate an air-filled cavity, such as plaster on laths, dry lining, or timber lining, have lower U-values than the walls of the same thickness finished with plaster. This demonstrates the insulating effect of such an air cavity, especially where the air is stagnant or moving slowly. In conclusion, the walling material significantly impacts the thermal performance, and the insulation of solid stonewalls can highly improve the thermal performance of the wall.

### 2.4.1-Stone Workmanship

According to Daoyand M. (1998), using mortar when making a stone wall gives it more strength and stability. There are two types of stone masonry: the random masonry (fig. 2.13) and the coursed masonry (fig. 2.14). The random masonry is the simple type that does not require laying the stone in courses. Yet, it requires horizontal bonding of stones that expand all over the wall to tie the units and maintain stability. The two primary materials used in this type of construction are stone and mortar. The coursed stone masonry requires roughly squared stones having horizontal continuous layout beds in joints (p.229). Daoyand M. (1998) asserts that the best suitable stones to use are limestone, sandstone, granite, and slate.

*Figure 2.13 Sketch showing a random stone wall. Source: author*

*Figure 2.14 Sketch showing coursed stone wall.*

To lay the stone wall, laborers have to build it by the side of a horizontal line to have it plumbed and straight to the edge. Then, they use a perpendicular wood corner to construct a perpendicular wall and start laying stone to the line. Laborers must also put each stone on the largest face to have it horizontal. The wall has to be larger at the bottom of the wall to the smaller on the top.

Below are the main steps to be followed to construct a masonry wall:

- Step 1 begins with moistening. Porous stones should be moistened before placing them in the mortar to prevent water absorption and weakening the bond" (Daoyand, M. p.229).

- Step two is packing and filling. It consists of piling up adjoining stones tightly and filling the spaces between them with smaller stones and mortar" (Daoyand, M. p.229).
- Step three is removing a stone after placing it on the mortar bed, lift it clear, and reset it" (Daoyand, M. p.229).

Always use the most massive stones in the wall footing to give it high strength and to ensure equitable settlement. According to Daoyand M. (p.229), stones used for wall footing have to be laid in mortar about 5 cm deep and spaced between them should be filled with small stones and mortar. The use of a bonding stone for every 0.5 to 1 sqm of the wall is necessary, and the bonding should pass through the entire wall (fig. 2.15).


*Figure 2.15 Sketch showing Stone wall. Source: Author*

**2.5-Comparison between the three Construction Materials**

This section outlines a comparison between five different types of construction materials, solid wood, wood frame, and concrete. Each type of construction was evaluated separately according to specific criteria such as the quality of living, construction costs, construction time, depreciation costs, design (Kuzman & Grošelj, 2012, pp. 591-602). The embodied energy of construction was assessed separately for each criterion (fig. 2.16). However, Depreciation costs were assessed based on the relation between the service life of the material and the construction costs. Moreover, the quality of living was evaluated based on comfort, health, and psychological factors. The weighting coefficients for the construction design criterion were estimated based on several indicators such as functionality, span possibility, multistory construction, system solutions, and surface efficiency. They were selected based on the survey. Embodied energy in building materials represents the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction – it represents the relationship between building materials, construction processes, and their environmental impacts. It was defined as the commercial energy used in the process of making a product, bridging it to the market, and disposing of it (cradle to cradle) (p. 598). Factors such as prefabrication level, drying, transport, and experience affected the estimate of the construction time criterion.

The analysis of the listed construction materials above in residential buildings

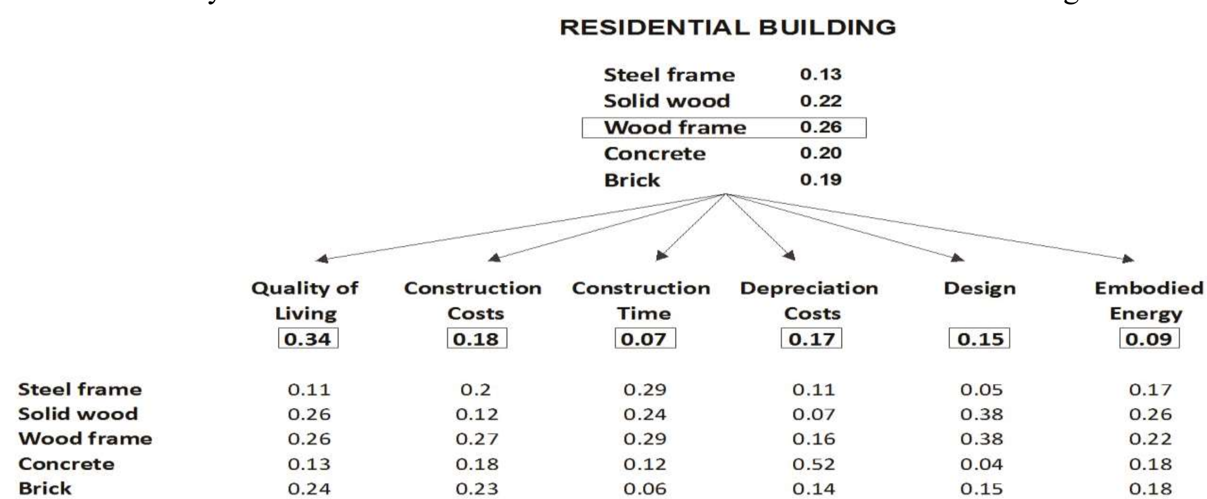



*Figure 2.16 Diagram showing study results. Source: Kuzman & Grošelj, (2012, p.598)*

showed that timber is the best choice in terms of energy efficiency in construction since it serves as a high thermal insulator and ensures a comfortable indoor living climate.

## 2.6- Construction Material's Environmental Impact

This section outlines the impact of materials and energy consumption for space heating on the environment. This analysis is used as a tool to evaluate the effect of the studied cases on the environment. The energy consumption of each scenario will be analyzed to assess its impact on reducing energy demand, which is linked to the thermal properties of each material. The purpose of this section is to generate a comparative assessment of three materials (concrete and products, wood, and stone) to show which material has the lowest environmental impact in terms of greenhouse gas emissions, energy generation processes, and consumption.

Human activities, such as construction and operation of buildings, consume a high amount of natural resources (Bicknell, K.B. et al., 1998, pp. 60-149). According to Crawford, R. (2011, p.5). Combined with the increase of the global population and living standards, the demand for energy is increasing enormously and leading to more greenhouse gas emissions. Crawford, R. (2011, p.6) adds that using natural resources for energy generation and construction materials such as cement has a significant impact on human health, natural environment, and local ecosystems. Moreover, it is estimated that the operation of buildings worldwide is responsible for up to 40 % of the total global energy demand, resource consumption, and greenhouse gas emissions (OCED 2003).

In general, the life cycle of a building passes through different stages from the extraction of raw materials for construction until the demolition of buildings (Langston et al. 2008, p.18). The extraction of raw materials is causing the depletion of natural resources, the upsurge of energy and water consumption, and the surge of emissions and pollutants (Crawford, R., 2011, p.16). Thus, after extracting and manufacturing of raw materials, comes the transportation phase to construction sites, which also requires energy for the delivery process. During the construction phase, a huge amount of waste is always produced (Crawford, R., 2011, p.18). In the operation and maintenance phase, energy is required for all the systems of the house to operate, such as space heating, space cooling, lighting, and others (Crawford, R., 2011, p.19).

Globally, the industrial sector emissions such as cement, which is non-metallic, include chemical and mineral production and are responsible for 44 % of the total CO2 from this sector and 52% of the greenhouse gas emissions (Fischedick M. et al., 2014). Notably, it is essential to realize that, in Lebanon, CO2 emissions were reduced by 8% due to the sustainable development strategy launched in 2016 (Holcim Sustainable Report, 2018, p.10).

According to Kittipongvises, S., (2017, pp. 67-83), limestone passes through different phases before being ready for construction. It starts by extracting the stones from the ground, transporting raw materials, cutting and crushing them, and finally sending the final product to construction sites. All these phases require fuel and electricity that produces harmful emissions (Kittipongvises S., 2017, pp. 67-83). It is estimated that the power consumed to produce one ton of limestone is responsible for 51 % of the CO2 emissions and has the highest impact on climate change. While in the case of diesel fuel, 36 % of the total greenhouse gas emissions are caused by limestone production and also has the highest environmental impact (Kittipongvises, S., 2017, pp. 67-83).

Pillai et al. (2019, pp. 111-119), in their study, wanted to assess the impact of concrete and limestone on the environment. They took the same quantity of the two materials, and the results were the following: limestone extraction and production produced 0.5179 kgCO2eq./kg, while the concrete generated 0.82 kgCO2eq./kg. The primary factor that had a major effect on the results was transportation. the shipping of limestone produced 0.092 kgCO2eq./kg, while the concrete's transportation, produced 0.0924 kgCO2eq./kg for 100 km. Nonetheless, wood produces 0.328 kgCO2eq./kg, which is the lowest among all studied construction materials (Sathre & González-García, 2014, pp. 311-337).

This section focused on a comparison between the three studied construction materials (concrete and products, wood, and stone). The goal is to decide which one is the proper external envelope that decreases energy demand and consumption and, at the same time, has a less harmful impact on the environment in terms of $CO_2$ and greenhouse gas emissions. In general, a non-renewable material source like concrete should be used very scarcely due to its damage to the environment and its impact on humans. Nevertheless, in Lebanon, concrete is the most commonly used material for construction. While wood, which is a recyclable material, is way less used.

### 2.7- Energy Consumption

According to the Ministry of Transport & Japan International Cooperation Agency (2008, p.5), construction prices are divided into two components: the material's cost and the labor cost. In recent years, the country witnessed a remarkable increase in materials prices due to the intensive investments and activity in the real estate sector (Bank MED, 2016, pp. 1-24). Also, (Bank Audi, 2018, pp. 1-9) stated that material prices increased by 15% in 2018, and it is expected to rise from 10 to 30% in the coming years.

In Lebanon, there is no price book or a unified resource that specifies the prices of construction materials. Therefore, none of the materials nor the labor cost could be referenced. For this reason, the study referred to people who have knowledge and experience in the field and to data gathered from construction projects during the period of study.

Since the 2000s, people started to raise awareness about energy conservation in the Lebanese context. During this period, the government launched the Lebanese Center for Energy Conservation (LCEC). At the same time, the Association Libanaise pour Maitrise de L'Energie et de L'Environment (ALMEE) was founded as a non-governmental organization. These institutes, with the Lebanon Green Building Council (LGBC), published several energy studies that encourage less dependency on fuel energy, and they also specified general and specific guidelines that work with the local context. Within the work on climate and comfort, passive strategies for Lebanon, the UNDP (2005) published the thermal standards for buildings in Lebanon. In 2010, an updated edition was issued with grouped a larger number of contributors: The order of Engineers and Architects, ALMEE, LGBC, and others (Singh *et al.*, 2011).

According to Saleh, P. (2019, p.44), The thermal standard for building in Lebanon published in 2005, was the first publication by the government (UNDP and the ministry of public work and transport) that tackles the envelope's thermal properties, u values, and window to wall ratio for buildings in Lebanon through the four climatic regions.

The LCEC (2014, pp. 1-172), under the name of national energy efficiency and renewable energy action (NEERA), published new guidelines targeting free interest loans for buildings that can be applied during the design phase. According to LCEC (2014, pp. 1-172), the estimated overall building's energy can be reduced by 20% to 40%.

Within this context, u-values in this climatic zone, according to (UNDP, 2005) and (LCEC, 2014), should be equal to 0.55 w/m²k. As for heating, LCEC (2014, p. 89) stated that the energy consumed for heating in the High Mountains of Lebanon is 194 KWH/m²/year, which is considered a high consumption. This value can be reduced up to 40% by improving external wall resistance through the thermal properties and heat transfer coefficient of the construction materials.

According to Uygunoğlu, T., & Keçebaş, A. (2011, pp. 2077-2085), extensive research has been conducted to minimize the energy consumption in domestic buildings in cold climates where space heating requires large quantities of heat energy. Therefore, energy savings can be accomplished using construction materials with low thermal conductivity (Uygunoğlu, T., & Keçebaş, A., 2011, pp. 2077-2085). The energy consumption was extracted from the simulation tool software (Insight 360) for each scenario according to the building construction envelope materials, location, orientation, and degree hour (DH) values. As for the energy consumption types, as mentioned in the high mountains of Lebanon, heating is based on fuel (diesel) and electricity. The energy consumed was calculated according to a full year calculation taking into consideration the hight seasons of fuel consumption (fall and winter) and the lowest seasons (spring and summer). The target is to obtain the best construction wall materials with a maximum reduction of heating load, demand, and cost.

In general, insulation is not always applied in developing countries due to its high cost that increases the cost of the construction (Uygunoğlu, T., & Keçebaş, A., 2011, pp.

2077-2085). Therefore, cost analysis is essential to estimate savings and the pay-back period to minimize the total cost (construction and energy cost). This thesis studies only heat loss due to external wall envelope for comparison.

**2.8-Chapter Conclusion**

In this chapter, several studies were acknowledged regarding the thermal performance of construction materials. Thermal properties of external envelopes affect the performance of the building. In the high mountains zone of Lebanon, concrete masonry unit is commonly used since it is not recommended due to the high thermal transmittance, and thus high heating demand. Moreover, insulated construction materials from the outer side and thermal mass from the inner side of the external envelope should be considered in the construction. Therefore, construction material type and placement should be considered in early stages to help decrease space heating demand in cold climate.

In conclusion, several measures have to be considered in order to decrease indoor space heating and decrease energy consumed. The literature framed further the methodology and scope of scenarios of important factors that affect external envelope to be applied in the specified focus area; Bcharre high mountains of Lebanon.

## 3. The High Mountain Region: Bcharre in North Lebanon

### 3.1- Introduction

The following chapter will introduce the selected area to be studied: Bcharre town. Having the area used as a sample to the high mountains zone in the country, the climate of this climatic region will be presented. Where it directly affects the energy consumed in buildings by the materials used in the building's external envelope. Therefore, the building envelope's existing conditions and construction materials used in the selected area will be reviews to further build the model upon its thermal characteristics. Exploring the selected area and its buildings will help build an accurate model and obtain factual estimations. The use of this material will minimize internal heat loss and thus reduce energy demand for heating and cooling. This chapter will introduce the selected studied area to define the high mountains area, especially Bcharre town exploring its geographic, economic, population and focusing on the climate. The high mountains of Lebanon areas are characterized by a cold winter and mild other seasons (UNDP, 2005, p.10). Therefore, the climate of the high mountains region directly affects the energy consumption in buildings by the external envelope construction materials used.

### 3.2- Geographic Description

Lebanon is a Middle Eastern country located on the eastern side of the Mediterranean Sea (fig. 3.1). It is composed of two parallel mountains facing the sea and embracing the inland area elevated from the sea level, and a coastline of two hundred m length (Ministry of Foreign Affairs, 2018, p.4). The western mountain range reaches three thousand and sixty-six meters above the sea level in its northern part, whereas its eastern part reaches only two thousand and eight hundred meters in the highest mountain peak (fig. 3.2) (Farjalla et al. 2014, p. 9). Even though the maximum width of the country is eight kilometers, and its area is ten thousand four hundred fifty-two square kilometers; it includes four climatic zones (NPMPLT, 2005, pp. 2-27).


*Figure 3.1 Location of Lebanon on the eastern side of the Mediterranean Sea. Source: Google earth Pro accessed 06-01-2020*

The western mountain range reaches 3066 m above the sea in its northern part, whereas its eastern part reaches a maximum of 2800 m (fig. 3.2) (Farjalla, et al. 2014, p. 9). The width of the country is 70 km, yet this 10452 km² has four climatic zones (NPMPLT, 2005, pp. 2-27).

### 3.3- Climatic Classification

Lebanon is divided into four climatic zones (UNDP, 2005, p.10). These climatic zones are classified according to their altitude and their heating and cooling degree day threshold brackets (Saleh, P., 2019, p.27). Three local publications provided a detailed description of the climate which are: The Climatic Zoning for Buildings in Lebanon (Republic of Lebanon, 2005), Passive Design Strategies in Lebanon (Republic of Lebanon, 2005), and Thermal Standard for Building in Lebanon (Order of Engineers, 2010). The classified four zones are: First, the coastal zone that starts from the sea level reaching 499 m of altitude. Second, the mid-mountain zone located on the western mountain slopes, starting from a height of five hundred meters and reaching 999 m of altitude. Third, the high mountains zone beginning from one thousand meters' altitude and above. And fourth, the inland zone, which is located between the eastern and western mountains (fig. 3.3). Figure 3.3 shows the four climatic zones of Lebanon.

The winter in the coastal region is warm and short, while Summer is hot and humid. The daily temperature gap between day and night is small all year round. However, this moderate climate

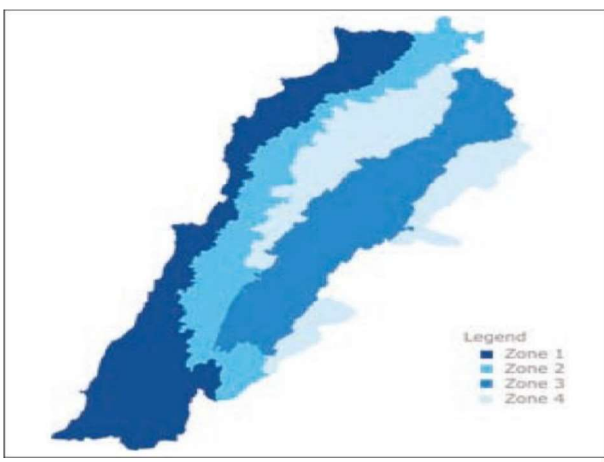



*Figure 3.3 Map of Lebanon showing different climatic zones. Source: Climate and Comfort 2005 p.10*

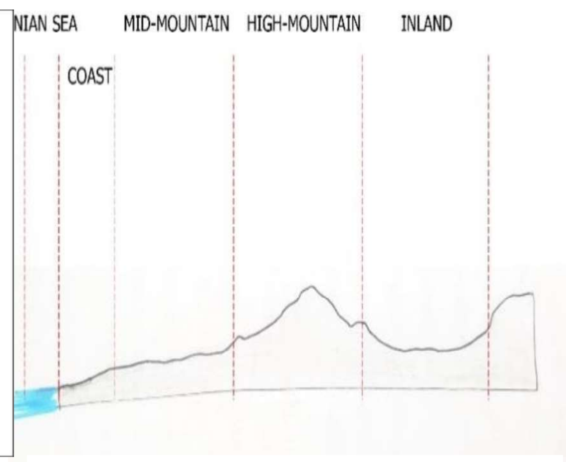



*Figure 3.2 Section showing Lebanese topography and climatic regions*

differs with altitude, where the atmosphere becomes colder and with more precipitations. Moreover, it is noticed that snow covers the high mountain peaks for almost all the time of the year. In summer, temperatures in the high mountains might reach similar levels as those seen in coastal areas during the daytime, but at night temperatures are markedly lower. (Hassan Z., 2011, p.62). According to UNDP (2005), the high mountain area's hourly temperature is below the comfort zone (table 3.1). These numbers outline the need for heating more than cooling. Table 3.1 shows the average hourly temperature degree by hour in the High Mountains of Lebanon. It can be observed that the majority of hours are below comfort outdoor temperature.

| | Hourly Temperature (deg C) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
| 0 | -3.5 | -3.6 | -3.1 | 3.6 | 7.6 | 9.7 | 13.2 | 15.8 | 12 | 8.2 | 5.8 | 0.4 | 5.6 |
| 1 | -3.3 | -3.4 | -2.9 | 3.7 | 7.8 | 9.8 | 13.4 | 15.8 | 12.2 | 8.3 | 5.9 | 0.4 | 5.7 |
| 2 | -3 | -3 | -2.6 | 4.1 | 8.3 | 10.5 | 14.1 | 16.4 | 12.8 | 8.9 | 6.3 | 0.8 | 6.2 |
| 3 | -2.5 | -2.3 | -1.9 | 4.8 | 9 | 11.4 | 15 | 17.4 | 13.7 | 9.9 | 7.1 | 1.5 | 6.9 |
| 4 | -1.8 | -1.5 | -1.1 | 5.7 | 10.1 | 12.7 | 16.3 | 18.7 | 15 | 11.1 | 8.1 | 2.2 | 8 |
| 5 | -0.9 | -0.5 | -0.2 | 6.7 | 11.3 | 14 | 17.8 | 20.1 | 16.4 | 12.5 | 9.2 | 3.2 | 9.2 |
| 6 | -0.1 | 0.6 | 0.8 | 7.8 | 12.7 | 15.6 | 19.3 | 21.7 | 17.9 | 14 | 10.3 | 4.2 | 10.4 |
| 7 | 0.8 | 1.7 | 1.9 | 8.8 | 14.1 | 17.1 | 21 | 23.2 | 19.5 | 15.5 | 11.5 | 5.1 | 11.7 |
| 8 | 1.7 | 2.7 | 2.8 | 9.9 | 15.3 | 18.5 | 22.4 | 24.6 | 20.9 | 16.9 | 12.7 | 6 | 12.9 |
| 9 | 2.3 | 3.6 | 3.7 | 10.7 | 16.3 | 19.7 | 23.7 | 25.9 | 22.1 | 18.1 | 13.6 | 6.8 | 13.9 |
| 10 | 2.8 | 4.2 | 4.3 | 11.4 | 17.1 | 20.6 | 24.6 | 26.8 | 23.1 | 19 | 14.3 | 7.4 | 14.7 |
| 11 | 3.2 | 4.5 | 4.7 | 11.8 | 17.7 | 21.2 | 25.3 | 27.4 | 23.7 | 19.6 | 14.8 | 7.8 | 15.2 |
| 12 | 3.3 | 4.8 | 4.9 | 12 | 17.8 | 21.4 | 25.6 | 27.6 | 23.8 | 19.9 | 14.9 | 7.9 | 15.4 |
| 13 | 3.2 | 4.5 | 4.7 | 11.8 | 17.7 | 21.2 | 25.3 | 27.4 | 23.7 | 19.6 | 14.8 | 7.8 | 15.2 |
| 14 | 2.8 | 4.2 | 4.3 | 11.4 | 17.1 | 20.6 | 24.6 | 26.8 | 23.1 | 19 | 14.3 | 7.4 | 14.7 |
| 15 | 2.3 | 3.6 | 3.7 | 10.7 | 16.3 | 19.7 | 23.7 | 25.9 | 22.1 | 18.1 | 13.6 | 6.8 | 13.9 |
| 16 | 1.7 | 2.7 | 2.8 | 9.9 | 15.3 | 18.5 | 22.4 | 24.6 | 20.9 | 16.9 | 12.7 | 6 | 12.9 |
| 17 | 0.8 | 1.7 | 1.9 | 8.8 | 14.1 | 17.1 | 21 | 23.2 | 19.5 | 15.5 | 11.5 | 5.1 | 11.7 |
| 18 | -0.1 | 0.6 | 0.8 | 7.8 | 12.7 | 15.6 | 19.3 | 21.7 | 17.9 | 14 | 10.3 | 4.2 | 10.4 |
| 19 | -0.9 | -0.5 | -0.2 | 6.7 | 11.3 | 14 | 17.8 | 20.1 | 16.4 | 12.5 | 9.2 | 3.2 | 9.2 |
| 20 | -1.8 | -1.5 | -1.1 | 5.7 | 10.1 | 12.7 | 16.3 | 18.7 | 15 | 11.1 | 8.1 | 2.2 | 8 |
| 21 | -2.5 | -2.3 | -1.9 | 4.8 | 9 | 11.4 | 15 | 17.4 | 13.7 | 9.9 | 7.1 | 1.5 | 6.9 |
| 22 | -3 | -3 | -2.6 | 4.1 | 8.3 | 10.5 | 14.1 | 16.4 | 12.8 | 8.9 | 6.3 | 0.8 | 6.2 |
| 23 | -3.3 | -3.4 | -2.9 | 3.7 | 7.8 | 9.8 | 13.4 | 15.8 | 12.2 | 8.3 | 5.9 | 0.4 | 5.7 |

*Table 3.1 Showing hourly temperature profile by month in the High Mountains of Lebanon (Cedars). Source: UNDP, 2005*

The Inland region receives less precipitation and humidity than coastal regions. This is mainly because of its location between the high mountains of Lebanon. According to the Koppen-Geiger world climate classification and the specific coordinates, Lebanon is classified as Csa & Csb (Kottek et al., 2006). It means that a warm temperature characterizes the country all year round, dry summer in terms of precipitation, and a changing temperature that differs from region to other.

### 3.4- Bcharre's Weather

Each site has its characteristics and configurations of topography, orientation towards the sun, relative humidity, and wind direction. Table 3.2 shows the simulated hourly temperature profile per month in the high mountains of Lebanon (UNDP 2005). This Data reveals that heating is needed for almost all year round. Besides, recordings show that in January, February, March, April, November, and December, heating is necessary all day long. While, from May till October, only a few hours per day have a mild and comfortable temperature. Thus, the temperature rates in July and August exceed the

| | Hourly Temperature (deg C) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
| 0 | -3.5 | -3.6 | -3.1 | 3.6 | 7.6 | 9.7 | 13.2 | 15.8 | 12 | 8.2 | 5.8 | 0.4 | 5.6 |
| 1 | -3.3 | -3.4 | -2.9 | 3.7 | 7.8 | 9.8 | 13.4 | 15.8 | 12.2 | 8.3 | 5.9 | 0.4 | 5.7 |
| 2 | -3 | -3 | -2.6 | 4.1 | 8.3 | 10.5 | 14.1 | 16.4 | 12.8 | 8.9 | 6.3 | 0.8 | 6.2 |
| 3 | -2.5 | -2.3 | -1.9 | 4.8 | 9 | 11.4 | 15 | 17.4 | 13.7 | 9.9 | 7.1 | 1.5 | 6.9 |
| 4 | -1.8 | -1.5 | -1.1 | 5.7 | 10.1 | 12.7 | 16.3 | 18.7 | 15 | 11.1 | 8.1 | 2.2 | 8 |
| 5 | -0.9 | -0.5 | -0.2 | 6.7 | 11.3 | 14 | 17.8 | 20.1 | 16.4 | 12.5 | 9.2 | 3.2 | 9.2 |
| 6 | -0.1 | 0.6 | 0.8 | 7.8 | 12.7 | 15.6 | 19.3 | 21.7 | 17.9 | 14 | 10.3 | 4.2 | 10.4 |
| 7 | 0.8 | 1.7 | 1.9 | 8.8 | 14.1 | 17.1 | 21 | 23.2 | 19.5 | 15.5 | 11.5 | 5.1 | 11.7 |
| 8 | 1.7 | 2.7 | 2.8 | 9.9 | 15.3 | 18.5 | 22.4 | 24.6 | 20.9 | 16.9 | 12.7 | 6 | 12.9 |
| 9 | 2.3 | 3.6 | 3.7 | 10.7 | 16.3 | 19.7 | 23.7 | 25.9 | 22.1 | 18.1 | 13.6 | 6.8 | 13.9 |
| 10 | 2.8 | 4.2 | 4.3 | 11.4 | 17.1 | 20.6 | 24.6 | 26.8 | 23.1 | 19 | 14.3 | 7.4 | 14.7 |
| 11 | 3.2 | 4.5 | 4.7 | 11.8 | 17.7 | 21.2 | 25.3 | 27.4 | 23.7 | 19.6 | 14.8 | 7.8 | 15.2 |
| 12 | 3.3 | 4.8 | 4.9 | 12 | 17.8 | 21.4 | 25.6 | 27.6 | 23.8 | 19.9 | 14.9 | 7.9 | 15.4 |
| 13 | 3.2 | 4.5 | 4.7 | 11.8 | 17.7 | 21.2 | 25.3 | 27.4 | 23.7 | 19.6 | 14.8 | 7.8 | 15.2 |
| 14 | 2.8 | 4.2 | 4.3 | 11.4 | 17.1 | 20.6 | 24.6 | 26.8 | 23.1 | 19 | 14.3 | 7.4 | 14.7 |
| 15 | 2.3 | 3.6 | 3.7 | 10.7 | 16.3 | 19.7 | 23.7 | 25.9 | 22.1 | 18.1 | 13.6 | 6.8 | 13.9 |
| 16 | 1.7 | 2.7 | 2.8 | 9.9 | 15.3 | 18.5 | 22.4 | 24.6 | 20.9 | 16.9 | 12.7 | 6 | 12.9 |
| 17 | 0.8 | 1.7 | 1.9 | 8.8 | 14.1 | 17.1 | 21 | 23.2 | 19.5 | 15.5 | 11.5 | 5.1 | 11.7 |
| 18 | -0.1 | 0.6 | 0.8 | 7.8 | 12.7 | 15.6 | 19.3 | 21.7 | 17.9 | 14 | 10.3 | 4.2 | 10.4 |
| 19 | -0.9 | -0.5 | -0.2 | 6.7 | 11.3 | 14 | 17.8 | 20.1 | 16.4 | 12.5 | 9.2 | 3.2 | 9.2 |
| 20 | -1.8 | -1.5 | -1.1 | 5.7 | 10.1 | 12.7 | 16.3 | 18.7 | 15 | 11.1 | 8.1 | 2.2 | 8 |
| 21 | -2.5 | -2.3 | -1.9 | 4.8 | 9 | 11.4 | 15 | 17.4 | 13.7 | 9.9 | 7.1 | 1.5 | 6.9 |
| 22 | -3 | -3 | -2.6 | 4.1 | 8.3 | 10.5 | 14.1 | 16.4 | 12.8 | 8.9 | 6.3 | 0.8 | 6.2 |
| 23 | -3.3 | -3.4 | -2.9 | 3.7 | 7.8 | 9.8 | 13.4 | 15.8 | 12.2 | 8.3 | 5.9 | 0.4 | 5.7 |

*Table 3.2 Hourly temperature profile by month. Source UNDP 2005*

comfort degree, where the need here is to have a cooling system. All temperatures are for the dry bulb temperature of the external ambient air.

### 3.5- Types of Heaters in Bcharre

Residential buildings in the high mountains of Lebanon usually have heating, but they rarely have cooling (Table 3.2). In old and new constructions, people tend to use diesel fuel boilers (fig. 3.4); However, recently, heat pomp air conditioning units (in the form of split AC units) are being incorporated. Moreover, there are other heating options, such as diesel and wood stoves and fireplaces according to the author's observation (fig. 3.5).

*Figure 3.4 Diesel stove used in High Mountains of Lebanon. Taken by author on 28-01-2020*

*Figure 3.5 Wood stove used in High Mountains of Lebanon. Taken by author on 28-01-2020*

Currently, the electricity sector in Lebanon is operating through seven thermal power plants, six hydroelectric plants, and two power ships. In addition to diesel generators that are being used to compensate for the deficit in supply (Berjawi et al., 2017 p. 10). Based on available statistics (ALMEE, 2010), the government produces 65% of the overall electric power needed. A small portion is being imported: 4% from Syria and 3% from Egypt (ALMEE, 2010). the rest, which constitutes 28%, is provided by the private sector through neighborhood generators. Lebanon depends on fossil fuel importation to generate power, and supply has always been insufficient to meet the country's demand. Jouni & Mortada (2011) expected that in 2030, the energy consumption of buildings in Lebanon would reach five times the energy consumed in 2010. Yathreb (2016) declares that the main contributor to this increasing energy demand is the inadequate performance of the existing buildings (p. 359-370). And the residential sector consumes 47% of the produced energy (Tibi et al. 2012, pp. 177–193).

"In Lebanon, 27% of the Lebanese population is considered poor. This number dwindles to 16 % in urban areas like the capital Beirut and rises to 36 percent in some rural areas" (UNDP, 2008, p. 14). Whereas 28.6% of Lebanese households were considered poor, 8% of them are extremely poor and under the lower poverty line. Besides, we notice a noteworthy discrepancy between this rate (28.6%) and the income-related component of the Living Conditions Index (LCI) which constitutes (51.6%). This

| Country/area | Total forest area (1 000 ha) | Primary designated function (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Production | Protection of soil and water | Conservation of biodiversity | Social services | Multiple use | Other | None or unknown |
| Lebanon | 137 | 6 | 25 | 3 | 0 | 66 | 0 | 0 |
| Occupied Palestinian Territory | 9 | – | – | – | – | – | – | – |
| Oman | 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| Qatar | 0 | – | – | – | – | – | – | – |
| Saudi Arabia | 977 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Syrian Arab Republic | 491 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Tajikistan | 410 | 5 | 11 | 84 | 0 | 0 | 0 | 0 |
| Turkey | 11 334 | 70 | 17 | 8 | n.s. | 6 | 0 | 0 |
| Turkmenistan | 4 127 | 0 | 97 | 3 | 0 | 0 | 0 | 0 |
| United Arab Emirates | 317 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Uzbekistan | 3 276 | n.s. | 93 | 6 | 0 | 0 | 0 | 0 |
| Yemen | 549 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |

*Table 3.3 Total forest area. Source: Global Forest Resources Assessment, 2010, p. 242*

difference assures the significance of the methodology used to measure poverty" (UNDP, 2008, p. 14).

Based on the Forest Resources Assessment FRA (2010), green areas cover 23% of the country's territories. Those green areas consist of forests around 13% (137,000 ha) and Other Wooded Land (OWL), around 10 % (106 000 ha) (Table 3.3).

The recent changes in the population habitats are causing fundamental transformations in the Lebanese territory. Among them the uncontrolled urban expansion (urbanization, population growth), the destruction and alteration of the land zone, the reduction of agricultural areas, and finally, the spread of quarries, sand removal, and forest fires (MOE/UNDP, FNR-CBD, 2009, p.150).

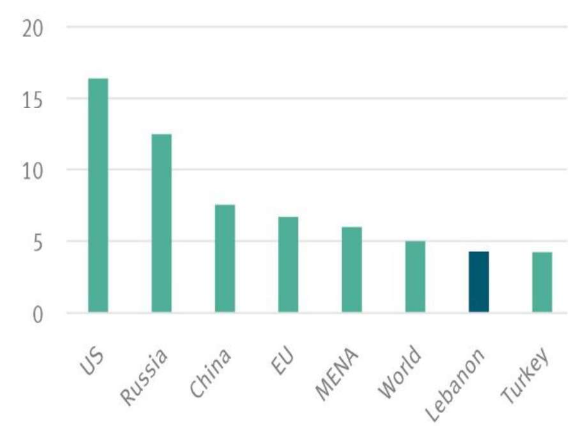



*Table 3.4 CO2 emissions (tCO2/Capita). Source: Barjawi et al. (2007), p. 7*

According to the study of Berjawi (2017), Lebanon generates around 22.5 Mt of CO2. This number is ranked 78th globally. The research also shows that the country has lower levels of CO2 emissions per capita than the MENA and the world averages (table 3.4). At the same time, Lebanon scores a higher level of CO2 emissions per GDP USD than the World average (Barjawi et al., 2017). The power sector is responsible for fifty-one percent of the total GHG emissions, which thirty-two percent is caused by the EDL, sixteen percent comes from private diesel generators, and the rest comes from the consumption of fuels used for cooking and heating (p.7).

According to MoE/UNDP/GEF (2015), GHG emissions caused by the energy sector produced an equivalent of 1,000 tons of carbon dioxide in 2011. Energy is the main responsible for carbon dioxide emissions, where it also contributes to methane and

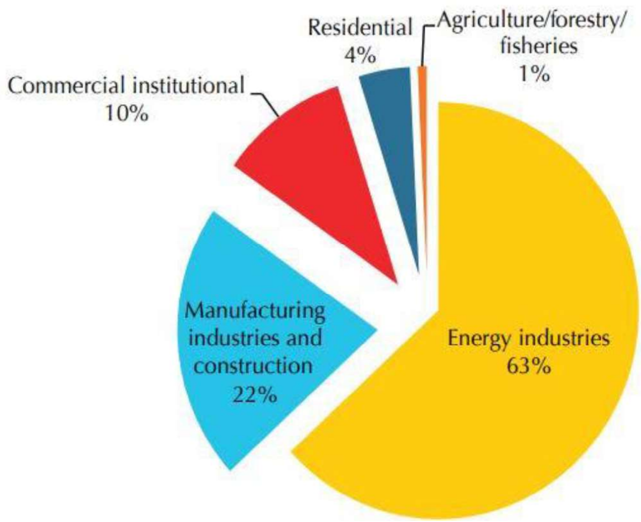



*Table 3.5 Contribution of energy emission sources to the sector's total for 201. Source: Barjawi et al. (2007), p.6*

nitrous oxide emissions and other air pollutants (CO, NOx, and SO2). The distribution of each source to the electric sector is shown in the figure below (table 3.5).

In conclusion, the lack of wood resources, the toxic CO2 emissions, and the high price of fuel caused by the monopoly Lebanese fuel cartels urges the essential need to reduce energy consumption in high mountains of Lebanon.

### 3.6- Building's Typologies in Bcharre

When it comes to the Lebanese urban fabric, no accurate statistical data can be found (Saleh P., 2019, p.38). The same answer was provided by order of Engineers and Architects and Bcharre municipality after several attempts to find information about the built-up context. Therefore, I

*Figure 3.6 A selection of different of types of residential houses in Bcharre. Source: Author, taken on 03-05-2020* relied on field observation to analyze the studied area. It was found that the built-up fabric mainly consists of reinforced concrete for the building's structure and an alternate of concrete or stone related materials for envelopes. Several studies have already mentioned this issue among them Fishfish (2011, p.10) that since the civil war, wood and stone materials are progressively being replaced by concrete and their derivatives. Also, Jayyusi et al. (2008) noticed that buildings typologies are being transformed after the spread of concrete buildings materials from stone buildings to concrete and CMU buildings (fig. 3.6).

The dominant residential building typology found in Bcharre consists of a reinforced concrete core and slabs. There are only a few houses that kept the stone structure and followed the dominant residential typology. A current observation of the houses built after 2004, where the building law was modified, shows that residential buildings comprise double cavity walls. This wall is constructed mainly from concrete masonry units (CMU), plastered from both sides, and painted from inside but sometimes left on plaster from outside. The local building code does not set any requirements for the exterior finishing of the building nor obliges the adoption of a treating or cladding material. (Appendix A).

As stated before, there are no studies that provide statistics on the number and percentages of individual housing in Bcharre or Lebanon. A study from the Atlas du Liban (2004), reveals that seventy-three percent of the residential buildings in Lebanon consists of apartment buildings in 1997 (p.80). Since then, there was no recent updated statistics available. According to Saleh, P. (2019), individual or independent houses in Lebanon differs in size and name (p.39). He classified them into three categories: a small house, villa, and palace. These buildings vary in terms of the number of floors according to each local code. The current zoning, according to the municipality of Bcharre, allows a maximum of four stories and a roof that could be counted as a fifth floor (fig. 3.7).

*Figure 3.7 A photo showing houses in Bcharre. Source: LiveloveBcharre Instagram Page. Accessed on: 06-08-2020*

### 3.7- Chapter Conclusion

This chapter gives data on the case study tackled through this thesis; Bcharre. The construction material collected in the area will be inserted in the model to be built with the climate and location. These data have the impact on the simulation and analysis to get accurate and applicable results in order to assess the energy consumption and demand through external envelope's construction materials in the selected area.

# 4. Methodology

## 4.1- Introduction

The aim of this thesis is to assess and estimate the impact of external envelope's construction materials on the energy consumed on space heating in the high mountains of Lebanon. This chapter acknowledges the previous methodologies used in order to frame further methodology and build upon it. The following sections will explore several methods used by researchers implemented in this thesis.

The following sections will help explore and indicate the strengths and weaknesses of each method used for the identifying of the methodology as energy modeling and simulation for decreasing energy demand.

## 4.2- Building Modeling and Energy Simulation

Each tool or method could be used to estimate the energy consumption in buildings. Each of which has its limitation. Measuring energy consumption could be obtained by using manual recording or simulation software, while, predicting the energy consumption could be done only through simulation software.

Energy simulation software allow to design, analyze, predict, and evaluate energy consumed in models in a specific location, orientation, climatic conditions (Fasi & Budaiwi, 2015). Insight 360 (Autodesk) and Green Building Studio are software used to quantify all types of energy needed or consumed in buildings ("Green Building Studio Validation | Search | Autodesk Knowledge Network", 2020).

In order to simulate the models and analyze them, several steps must be followed. The first step determines the characteristics and thermal properties of the studied materials. The second step identifies the scenarios of existing and non-existing wall type assemblies through various conditions of usage. The third one consists of taking a benchmark and compare it to all scenarios through simulation-based software. This step requires a comparison of the baseline with the different scenarios using Insight 360 software. Moreover, this study continues to analyze the life cycle assessment of each material in order to compare the initial cost with the running cost and maintenance over the year to conclude the highest thermal characteristics. The final step consists of turning these software models and results in tables and figures to analyze them and be able to reach a conclusion and pick a suitable outcome.

The experimental setup deals with different wall components and thermal configurations. Hence, this study aims to discover the suitable wall configuration with minimal heating and energy demand, when compared to other walls. The main reason behind this study is the increasing energy demand for heating in this context. The study also takes into account the construction materials and their life over two phases. The first phase consists of studying each element separately. Then, after analyzing the obtained results by the simulation software, the best suitable material is identified for this context. The second phase consists of testing the chosen material over a certain period to calculate the return on investment and demonstrate the choice.

A different tool will be used in each stage to assess the climatic needs of the chosen area. The first tool is observation, where the scenarios will be identified. The study will adopt an analysis of the statistical data in addition to revising the literature review.

Twelve scenarios consisting of different external construction material for building envelope with different U-values and thermal resistance are simulated to compare energy demand and consumption:

- Scenario number one is a house having reinforced fair-faced concrete and concrete masonry units as construction materials for the external envelope.
- Scenario number two is a house that has its external envelope made of cavity wall concrete masonry units.
- Scenario number three is a house with an external envelope composed of cavity wall concrete masonry units having an insulation layer to show its impact on energy demand for space heating.
- Scenario number four is a house having its external envelope composed of cavity wall concrete masonry units with an insulation layer and a wet cladding from outside to test the impact of thermal mass on energy demand.
- Scenario number five has the same envelope of scenario number four but with a mechanical cladding instead of wet cladding to identify the impact of having two cavities in the external envelope and its effect on the energy demand for space heating.
- Scenario number six is a house having its external envelope composed of a reinforced concrete wall. This scenario will show the impact of thermal mass on energy demand for space heating.
- Scenario number seven is a house having its external envelope composed of insulated timber wood and concrete masonry unit from inside to show the impact of outer insulation on energy consumption for space heating.

- Scenario number eight is the same as scenario number seven while replacing the concrete masonry units by reinforced concrete.
- Scenario number nine is a house having its external envelope made of cavity timber wooden construction material with insulation. This scenario will show the impact of outer and inner insulation on energy demand for space heating.
- Scenario number ten is a house having its external envelope composed of concrete masonry units to show the impact of having a high U-value and low resistance on energy demand for space heating.
- Scenario number eleven is a house having its external envelope composed of a thick limestone construction material. The purpose of this scenario is to show the effect of local materials and thermal mass on energy spent for space heating.
- The last scenario is number twelve, which is a house having its external envelope composed of insulated timber wood and stone from inside to show the effect of insulation from outside and the impact of thermal mass from the inside.

The studied scenarios will be defined and tested with ASHRAE 140 as reference. For this purpose, the energy simulation tools utilized are Revit Autodesk and Insight 360.

Revit software provides advanced building information modeling (BIM) to create accurate and detailed models (EL Emira, Robert, Haas & Zreik, 2015). Each model will be considered a separate scenario that will assess each material's thermal properties according to the climatic area, weather data, orientation, location, window to wall ratio, and energy consumption.

After finishing with Revit, an analytical simulation of energy demand and consumption for indoor heating will be tested through Insight 360. And by using this simulation tool, each scenario will be tested and verified according to ASHRAE 140. This tool is usually practiced in design projects in the pre-design phase to examine the end-results of the project. It also helps in generating energy reports, graphical representations, comparison, and weather data.

### 4.3- Chapter Conclusion

The acknowledged methodologies inspired further thesis work and data collection, and framed the methodology to be implemented. By following this methodology, the proper construction materials that decrease energy consumption can be obtained. In addition, using the energy simulation software compatible with Revit will allow the energy estimation, and thus the objectives of the thesis can be answered and analyzed.

# 5. Analysis of Building's External Envelopes

## 5.1-Introduction

The following chapter present the implemented methodologies to analyze and obtain the results. This chapter describes each scenario chosen. The first section describes the location and context in order to identify the external building envelope typologies studied in this thesis. The second section describes the degree day of analysis as a method and tool to estimate the energy demand. Then, the third section describes the building envelope studied. The simulation found in this chapter is representative and repetitive to all scenarios. The detailed procedure done on each scenario will be referred to the appendix.

The previous chapter put forward the problem and analyzed the methods used in similar studies. It also suggested that outer-insulated walls provide a better option for lower interior heating or, subsequently, less heating loads. The first section of this analytical part of the research uses a similar method used in similar experiments based on simulation tools and software to analyze heating consumption in different buildings located in the high mountainous area of Lebanon. This thesis specifically takes Becharre as a case study, and the analysis period extends over a year. The intention of this chapter is to assess the applied methodology and to highlight its learning outcomes. Twelve scenarios located in a North Lebanon village, Bcharre, are analyzed. Each scenario varies according to the construction materials used as a wall envelope. After an in-depth analysis and research, the materials found were wood, stone, concrete, and concrete masonry units. This analysis will take each material and test their fuel consumption behavior in the previously defined context of this study.

The observation of the internal temperature behavior of the concrete masonry unit construction in wintertime shows a high response to external temperature. This behavior is due to low thermal properties in the building mass. Furthermore, cold nights where the temperature falls outside the comfort zone are compared to the warmer cooler outdoors night temperature. High wind velocity flushes away the internal excess of stored heat form the mass of the envelope. The annual external temperature will show the relationship between internal and external surfaces, and the factors influencing the time difference between both. With the same usage in each house, this chapter shows the best logical outcome and will explain how the choice of construction materials plays a significant role in each scenario.

The method used to compare the effect in each wall component is not straightforward since various variables can interfere. For example, the mechanical heating schedules vary from house to the other, in addition to the living patterns of users or even window to wall ratio and shutter closure and opening schedules. However, the analysis method or scenarios allows choosing the same properties and comparing it within all situations such as the window to wall ratio, type of roof, and type of glazing.

## 5.2- Scenarios Type Selection

After a thorough literature review on construction material and their thermal performance and effect on the energy consumed, a gap in the literature was found. The combination of material and the comparison between all of these construction materials was not studied in accordance to thermal performance and energy consumption, therefore the thermal performance of each building in the specific location can't be indicated and thus has to be simulated. In order to identify the construction materials used in the context of study, Bcharre, site observation methodology is held. There are mainly three types of construction materials used. The site observation method will help locate and identify which construction materials are being used in the focus area. Therefore, a site observation took place in Bcharre area to specify the construction materials found for further simulations. The twelve scenarios are:

- Scenario number 1: Reinforced Concrete and CMU.
- Scenario number 2: CMU Cavity Wall.
- Scenario number 3: Insulated CMU Cavity Wall.
- Scenario number 4: CMU Cavity wall with Wet Stone Cladding.
- Scenario number 5: CMU Cavity wall with Mechanical Stone Cladding.
- Scenario number 6: Reinforced Concrete.
- Scenario number 7: Timber Wood and CMU.
- Scenario number 8: Timber Wood with Reinforced Concrete.
- Scenario number 9: Timber Wood Cavity Wall.
- Scenario number 10: Single CMU Wall.
- Scenario number 11: Limestone.
- Scenario number 12: Timber Wood and Limestone.

The site observation occurred on Tuesday, January 28, 2020 at 10:00pm, for approximately 6 hours, by car and foot. Several stops and pictures were taken when construction materials were observed. The different construction materials were all found and observed. The figures below were taking during the observation, each figure indicates the detection of a balcony typology and glazed balcony in the observed area. The model simulation designed models representing the three construction materials types found in the area.

*Figure 5.4 Picture showing building having the external envelope made of single CMU wall. Taken on: January 28th 2020 . Source: Author*

*Figure 5.1 Picture showing building having the external envelope made of cavity wall. Taken on: January 28th 2020 . Source: Author*

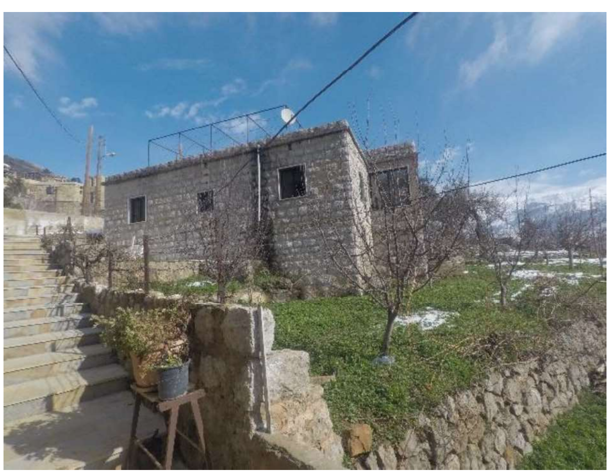


*Figure 5.3 Picture showing Stone House. Taken on: January 28th 2020 . Source: Author*

*Figure 5.2 Picture showing Stone and wood House. Taken on: January 28th 2020 . Source: Author*

Figure 5.6 Picture showing Wooden House. Taken on: January 28th 2020 . Source: Author

Figure 5.5 Picture showing building having the external envelope made of cavity wall with natural stone cladding. Taken on: January 28th 2020 . Source: Author

Figure 5.1 shows building having the external envelope made of CMU cavity wall. Figure 5.2 shows building made of stone and wood. Figure 5.3 shows stone house. Figure 5.4 shows building having the external envelope made of single CMU. Figure 5.5 building having the external envelope made of cavity wall with natural stone cladding. Figure 5.6 shows timber wood house.

**5.3- Scenarios Simulation**

In the following section, twelve different envelope construction materials (scenarios) are analyzed in terms of internal heat loss and dry bulb temperature over the same period (all year long) in order to assess energy consumption on space heating. As mentioned before, the houses are in the high mountain area, specifically in Bcharre (fig. 5.7). The weather data file used for the analysis period is taken from the nearest weather station adjacent to the village through Revit Autodesk (fig. 5.8; 5.9). The construction materials chosen for each scenario is according to the data collected from the observation done on the building external envelopes construction materials found in Bcharre. The modeling and energy simulation allows the extraction of the energy consumption on space heating. All scenarios are similar in term of shape, orientation, location, area, and window to wall ratio. Each scenario will have its construction materials combination for external envelope. The detailed and repetitive simulation description for each scenario will be found in the appendix. Results of each simulation will be presented in a table form in order to further analyze and discuss the simulated energy consumption in the next chapter.

Revit 2020 (Autodesk) was used to design each scenario, since it is an architectural tool. As for the energy analysis, Insight 360 (Autodesk) is a plug-in to Revit that creates energy model for each scenario. Green Building Studio is an online tool that export energy reports and show energy consumption in different units to estimate energy demand and consumption for space heating.

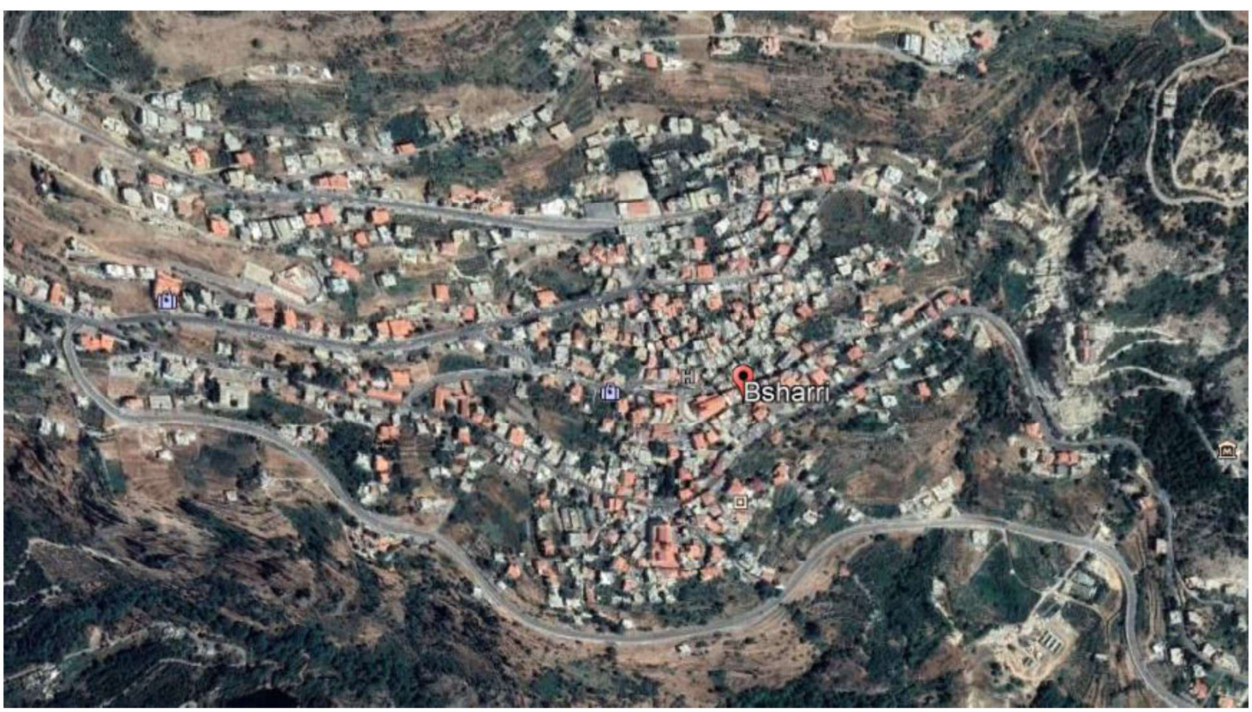



*Figure 5.7 Overall aerial view of Bcharre. Source: Google Earth Pro taken on 12-03-2020*


*Figure 5.8 Weather station location. Source: Revit Autodesk 2020. Taken on 11-03-2020*

| | |
|---|---|
| Weather Station: | **1258182** |
| Year: | 2006 |
| Latitude: | 34.25161743 |
| Longitude: | 36.00187683 |
| Elevation: | 1756 |

*Figure 5.9 Weather station details. Source: Revit Autodesk 2020. Taken on 11-03-2020*

All houses have the same occupancy pattern (unoccupied houses) and heating strategies (fuel reliance). The analysis was conducted on the twelve building elements models. They all have an area of 110 sqm gross floor area (GFA), and they also have the same location and orientation (East-West oriented towards south). The purpose is to test the performance of each design and to show the power of performing energy analysis form earlier phases, i.e., the project design. The chosen models were all single-family houses (fig. 5.10).

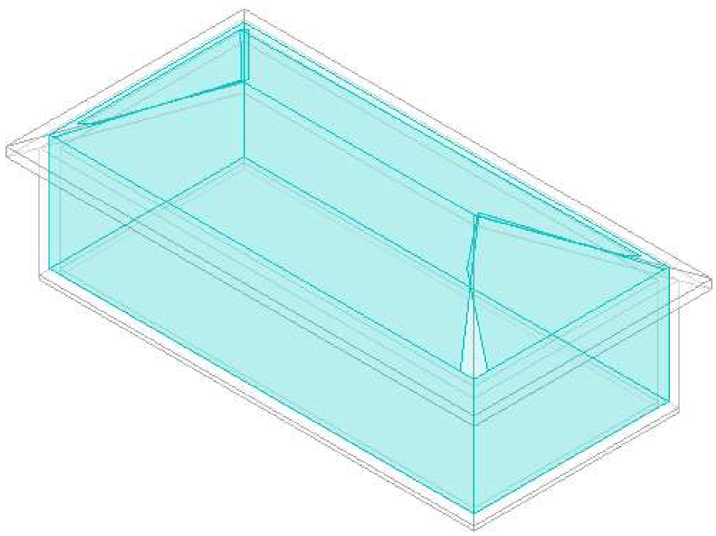


*Figure 5.10 conceptual mass of the single family house studied in this research. Source: Revit Autodesk 2020. Taken on 11-03-2020*

In terms of building codes and zoning regulations, Bcharre has different construction zones that specify the exploitation area per plot, the maximum height, and the allowed number of floors. It ranges from a single story and ends up with a maximum of three levels. This research analyzed the family house of one floor to avoid the impact on heat transfer between inside and outside when having multiple stories per buildings.

After finishing the modeling and inserting all the parameters and characteristics, the model has been energy simulated. The energy model is created, generated, and optimized in Revit, by which the analysis resulted in Insight 360 and Green Building Studio. By generating the energy model, energy analysis of the model can be viewed and extracted by visiting Insight 360 website, and green building studio (GBS) website. Insight 360 and GBS will show detailed energy analysis on the model and can be easily extracted. GBS allows to extract monthly energy demand for space heating, by which the thesis will focus on.

The preliminary outcomes are extracted from the used energy software and inserted in Excel to create tables and charts for the ease of analyzing and presenting the data.

### 5.4- Buildings Thermal Properties

The selection of materials in the study was decided according to their availability in the context. Therefore, to maximize the scope of research and to find the highest thermally properties suitable for such a cold climate, the studied construction materials were diversified as far as possible. The materials used in the study area were concrete, concrete masonry unit, limestone, and wood. These materials were combined to reach the lowest fuel consumption and fuel demand for space heating in the high mountains of Lebanon.

Table 5.1 summarizes all building's thermal properties from envelope construction to U-value. The U-values are extracted from Revit Autodesk 2020 software and used in the simulation through insight 360. All scenarios are East-West oriented towards the south to benefit from the maximum sun exposure during winter, monitored for all year round (appendix B).

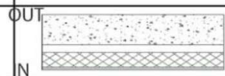
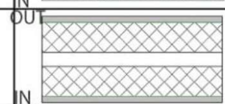
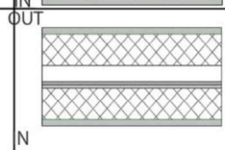
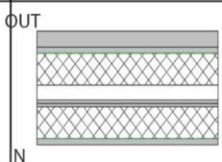
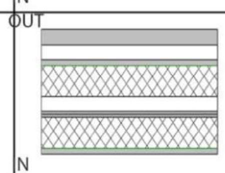
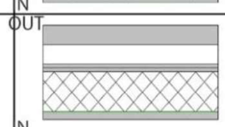
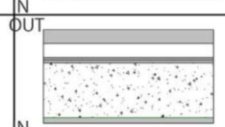
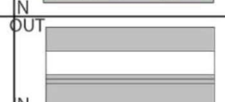
| Scenario | Section | Construction Type Materials mm | Heat Transfer Coesfficient U-Value w/m².k | Thermal resistance R-Value m².k/w | Wall Thickness mm |
|---|---|---|---|---|---|
| Scenario 1 |  | Concrete-200<br>Cmu-100<br>Plaster-20 | 0.4356 | 2.2959 | 370 |
| Scenario 2 |  | Plaster-20<br>Cmu-100<br>Cmu-100<br>Plaster-20 | 1.57 | 0.6369 | 290 |
| Scenario 3 |  | Plaster-20<br>Cmu-100<br>Insulation<br>Vapor barrier<br>Cmu-100<br>Plaster-20 | 0.3558 | 2.8109 | 310 |
| Scenario 4 |  | Plaster-20<br>Cmu-100<br>Insulation<br>Vapor barrier<br>Cmu-100<br>Plaster-20<br>Stone Cladding (Wet)-50 | 0.3558 | 2.8109 | 360 |
| Scenario 5 |  | Plaster-20<br>Cmu-100<br>Insulation<br>Vapor barrier<br>Cmu-100<br>Plaster-20<br>Stone Cladding (Mech)-50 | 0.3558 | 2.8109 | 410 |
| Scenario 6 |  | Plaster-20<br>Reinforced Concrete-200<br>Plaster-20 | 4.0525 | 0.2468 | 240 |
| Scenario 7 |  | Wood-50<br>Insulation<br>Vapor barrier<br>Cmu-100<br>Plaster-20 | 0.2125 | 4.7062 | 240 |
| Scenario 8 |  | Wood-50<br>Insulation<br>Vapor barrier<br>Concrete-200<br>Plaster-20 | 0.2075 | 4.8204 | 340 |
| Scenario 9 |  | Wood-50<br>Insulation<br>Vapor barrier<br>Wood-50 | 0.1515 | 6.6014 | 170 |
| Scenario 10 |  | Plaster-20<br>Cmu-200<br>Plaster-20 | 2.76 | 0.3623 | 240 |
| Scenario 11 |  | Lime Stone-350<br>Plaster-20 | 1.26 | 0.7936 | 370 |
| Scenario 12 |  | Wood-50<br>Insulation<br>Vapor barrier<br>Stone-350<br>Plaster-20 | 0.216 | 4.6292 | 490 |

*Table 5.1 Building's construction materials' physical and thermal properties. Source Revit Autodesk. Taken on 11-03-2020*

It is about not changing the materials used in the context of study, it is about studying the construction materials that are being used there and simulate them to show their impact on energy consumption.

First, Knowing the U-value of each building's envelope used is essential to compare the data with other thermal properties, which may also have its impact on the performance of the external envelope in a cold climate. According to the thermal standards of buildings in Lebanon (2005, p.10), the thermal transmittance of each wall component should meet a referenced value (table 5.2). In our case, the main building construction element is the wall of the built envelope, which is expressed as a maximum U-value. The minimum allowed u-value for walls in the high mountains of Lebanon climatic zone is 0.55 w/m²k. Ashrae 2013 propose in such a climatic cold zone a U-value of 0.32 w/m²k.

| Climatic Zone | Building Category | Maximum U-value[1] (W/m².K) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Roof | Wall | Vertical Glazing[2] | Skylight[2] | Exposed Floor[3] | Semi-Exposed Floor[4] |
| Zone 1: Coastal | 1 | 0.57 | 2.10 | 6.2 | 4.3 | 2.60 | 2.60 |
| | 2 | 0.57 | 2.10 | 6.2 | 4.3 | 2.60 | 2.60 |
| Zone 2: Western Mid-mountain | 1 | 0.57 | 0.77 | 4.3 | 4.3 | 0.76 | 1.35 |
| | 2 | 0.57 | 0.77 | 4.3 | 4.3 | 0.76 | 1.35 |
| Zone 3: Inland Plateau | 1 | 0.57 | 0.77 | 4.3 | 4.3 | 0.66 | 1.00 |
| | 2 | 0.57 | 0.77 | 4.3 | 4.3 | 0.66 | 1.00 |
| Zone 4: High Mountain | 1 | 0.44 | 0.55 | 2.8 | 2.8 | 0.55 | 0.80 |
| | 2 | 0.44 | 0.55 | 2.8 | 2.8 | 0.55 | 0.80 |

*Table 5.2 Reference thermal transmittance values per components. Source: Thermal standards for buildings in Lebanon 2005. Accessed on: 11-03-2020*

The method applied takes for each scenario, different configurations (wall dimensions and materials) to study all possibilities and combinations of construction materials that can be tested to obtain the highest thermal performance material or combination of materials. For testing the performance of various scenarios, a benchmark will be taken according to ASHRAE 140 through insight 360 representing the minimum that a wall envelope should reach to minimize heating consumption and heating demand. This benchmark will be applied and compared to all scenarios. Moreover, each scenario will be analyzed in two different cases; the first case is when having openings, and the second case is without any opening.

The following table summarizes the energy simulation outcomes (table 5.3). The observation of each scenario's energy behavior comparison taking ASHRAE 140 as a reference shows a response to the total energy consumed in the simulated house. Furthermore, materials energy consumption is explained and compared with all parameters such as degree day (DD), orientation, type of openings (window to wall ratio, type of glass), roof construction, space heating, space cooling, and lighting efficiency. The energy simulated in each scenario shows a relation between the mentioned factors. Thus, it is possible to establish space heating consumption and demand based on the fuel and electricity charts through insight 360 and based on the thermal properties of each material of the external walls.

| Scenario # | Benchmark | Results in kwh/m²/yr | Comparison to Benshmark in kwh/m²/yr |
|---|---|---|---|
| 1 | 224 | 227 | 3 |
| 2 | 224 | 226 | 2 |
| 3 | 224 | 225 | 1 |
| 4 | 222 | 222 | 0 |
| 5 | 222 | 222 | 0 |
| 6 | 223 | 240 | 17 |
| 7 | 222 | 222 | 0 |
| 8 | 224 | 223 | 1 |
| 9 | 222 | 222 | 0 |
| 10 | 222 | 222 | 0 |
| 11 | 223 | 235 | 12 |
| 12 | 221 | 219 | -2 |

*Table 5.3 Showing the results of the twelve scenarios. Source: Author*

Table 5.3 shows the results of all simulated scenarios according to the benchmark ASHRAE 140 set by Insight 360. According to the observation, scenario number twelve, which is Timber wood with an external limestone wall, had the lowest energy consumption among all scenarios by two kwh/m²/yr. under the benchmark. As a result, this scenario is the proper scenario that ensures minimum energy consumption. The outcomes mentioned in table 12 will be further discussed in the following chapter.

### 5.5- Degree Day (DD) Methods for Analysis

To assess the impact of the external building envelope on the internal air temperature in the twelve selected scenarios, similar ambient external air temperatures (threshold 18.3 °C) (chart were simulated according to the temperature degrees and the data simulated from the weather station through insight 360 (table 5.4).

| Cooling Degree Day | | Heating Degree Day | |
|---|---|---|---|
| Threshold | Value | Threshold | Value |
| 18.3 °C | 163 | 18.3 °C | 2493 |
| 21.1 °C | 20 | 15.6 °C | 1803 |
| 23.9 °C | 0 | 12.8 °C | 1207 |
| 26.7 °C | 0 | 10 °C | 708 |

*Table 5.4 Heating degree day chart. Source: https://gbs.autodesk.com/GBS/Weather?ProjectID=s9T9ZZn5vAQ%3d accessed on 15-03-2020*

To study the degree day (DD), Two methods were followed: the cumulative temperature below 18.3 °C for each month (table 5.5) or separated into daytime and night-time to

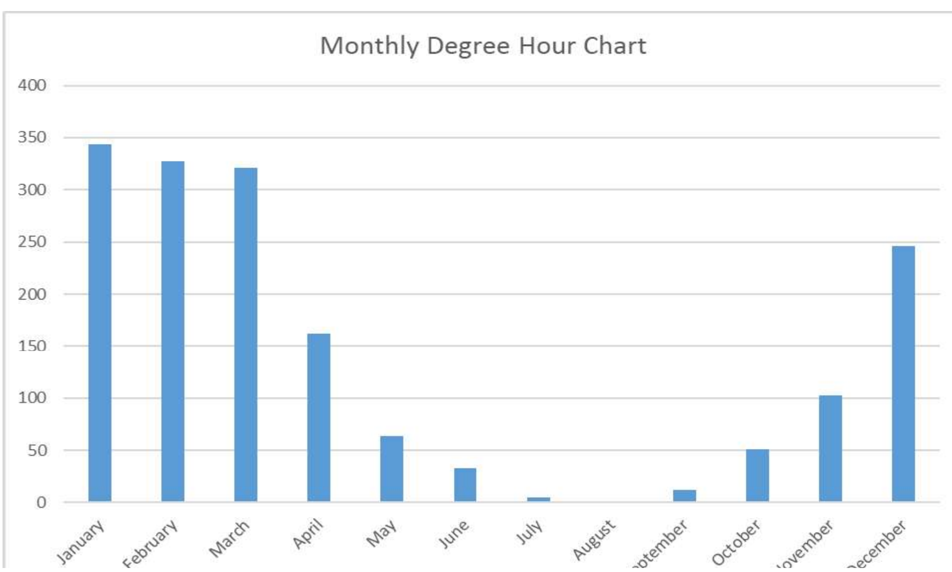



*Table 5.5 Monthly heating degree day. Source: done by author*

analyze precisely the trends in temperature fluctuations (Table 5.6). The cumulative monthly degree day (DD) of the external temperature during January, which simulated 343.3 DD, clearly shows that the highest degree day month during the year. In the second place, we have February, which filed 327 DD, followed by March with 321.1 DD, December with 246.3 DD, April with 162.2 DD, November with 102.2 DD, May with

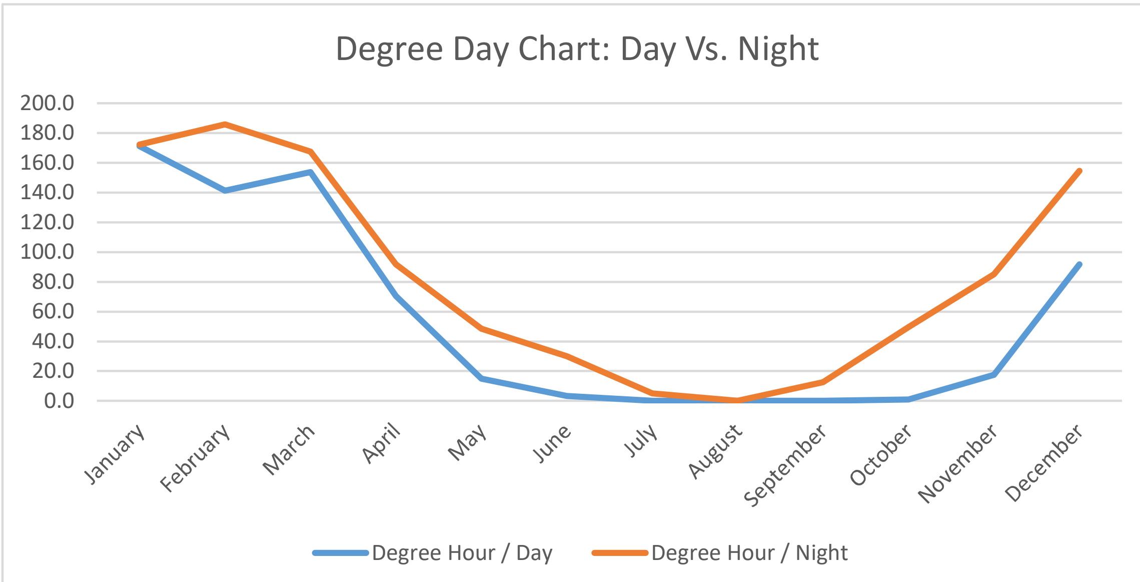



*Table 5.6 Monthly heating degree day VS. Night. Source: done by the author*

63.4 DD, October with 50.6 DD, June with 33.2 DD, September 12.6 DD, and July 5 DD. August is the only month per year that the degree day simulated zero, where no heating is required. Thus, the night-time of all months during the year shows clearly that the temperature at night is lower than daytime and needs more DD.

Two methods could follow degree day (DD). The first method is the cumulative temperature for each month or as a second method, which is separated into daytime and night-time for a better appreciation of the different temperatures (Saleh, P. 2018).

## 5.6- Chapter Conclusion

The observation done on the selected area helped to collect data about to identify the construction materials used for external envelope in the study area. The energy modeling simulated outcomes is inserted into Excel in order to create tables and charts for analysis. The results of the models assessed the impact of the construction materials on energy demand for space heating.

## 6- Mixed Mode Heating

### 6.1- Introduction

This chapter presents the simulated energy consumption throughout the year of each scenario to obtain the least construction materials that decrease energy consumption for space heating. Each section shows the data simulated from the simulation tool Green Building Studio. The heat loads for space heating is directly influenced by the thermal properties of the material, as well as the difference between indoor and outdoor temperatures. Every heating method could be affected by several factors, such as the internal air temperature (actual or to be reached), the external temperature, and the thermal properties of the wall itself. The wall's U-value influences energy consumption and demand; hence the construction materials with lower u-value are more likely to be affected by the temperature's warmth or coolness. The simulated scenarios showed that each one of the studied houses performed differently with a significant difference in energy consumption. All test scenarios energy consumption and demand are fuel consumption in Mega Joule (MJ), and electricity consumption in Kilowatt Hour (KWH).

### 6.2- Winter Season Space Heating Loads

During each month, every scenario had different fuel Heating Loads. First, the winter season simulated the highest number of fuel consumption, where the temperature drops to reach the lowest records between all seasons. Monthly consumptions are referenced in appendix. Scenario number 1 simulated 22665 MJ, scenario number 2 simulated 23139 MJ, scenario number 3 simulated 23393 MJ, Scenario number 4 22787 MJ, scenario number 5 23917 MJ, scenario number 6 23590 MJ, scenario number 7

23063 MJ, scenario number 8 22609 MJ, scenario number 9 23277 MJ, scenario number 10 23590 MJ, scenario number 11 22171 MJ, and finally, scenario number 12 simulated 22146 MJ. As shown in Table 13, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table 6.1).

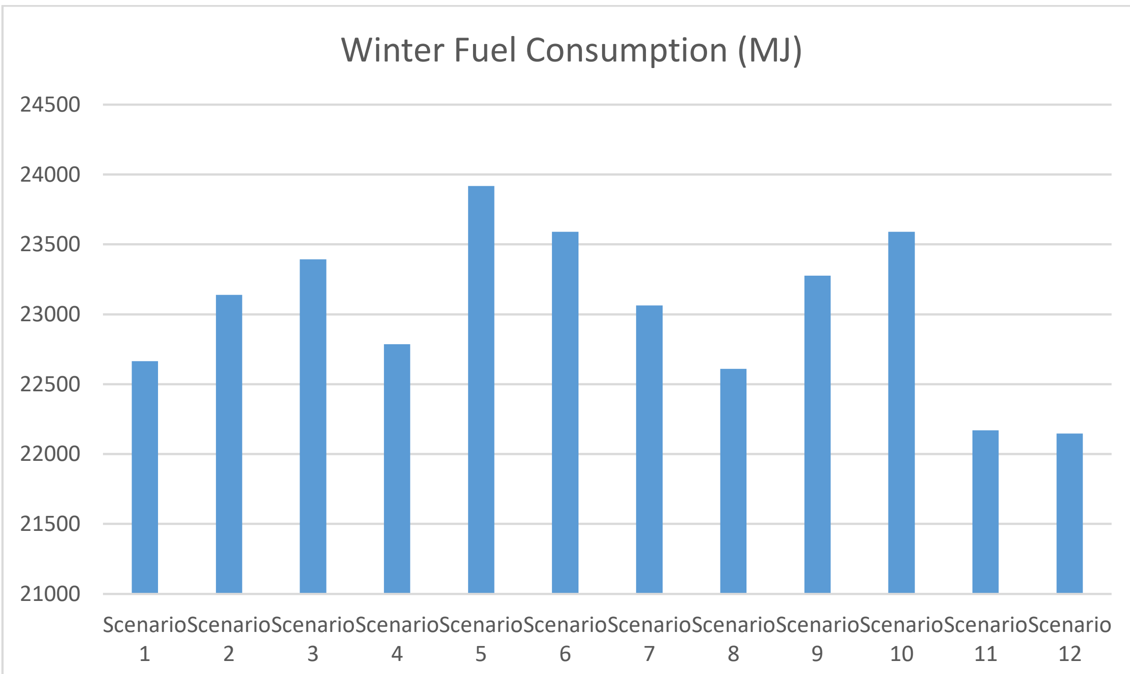



*Table 6.1 January fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, Table 14 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest consumption and simulated 270 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 250 KWH. Then comes scenario number 8, and 11, which simulated 255 KWH. Scenario number 1 simulated 256 KWH. Scenario number 2 simulated 265 KWH, scenarios number 6 and 10 simulated 266 KWH, scenario number 9 simulated 263 KWH, and scenario number 3 simulated 264 KWH, scenario number 4 simulated 259 KWH, and scenario number 7 simulated 260 KWH (table 6.2).

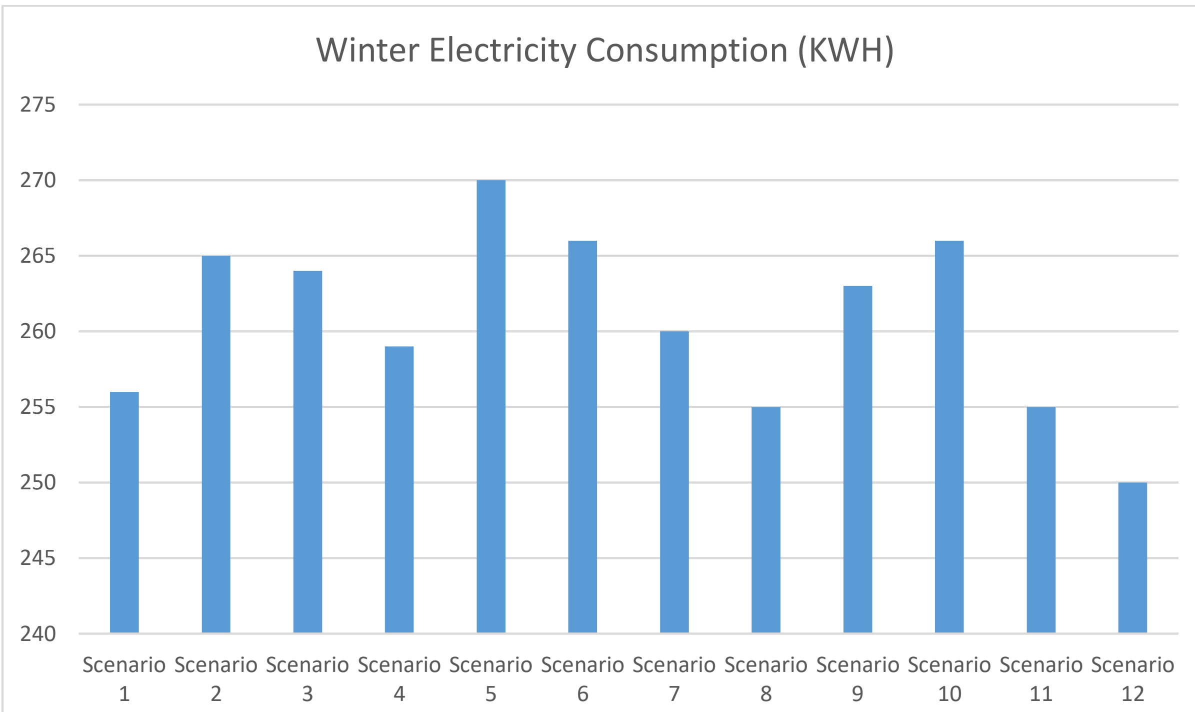



*Table 6.2 January electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in winter season in scenarios number 1, 4, 6, 7, 8, 9, 11, and 12 is 64 %. Whereas Scenario number 2, 3, and 5 simulated 65 % (table 6.3).

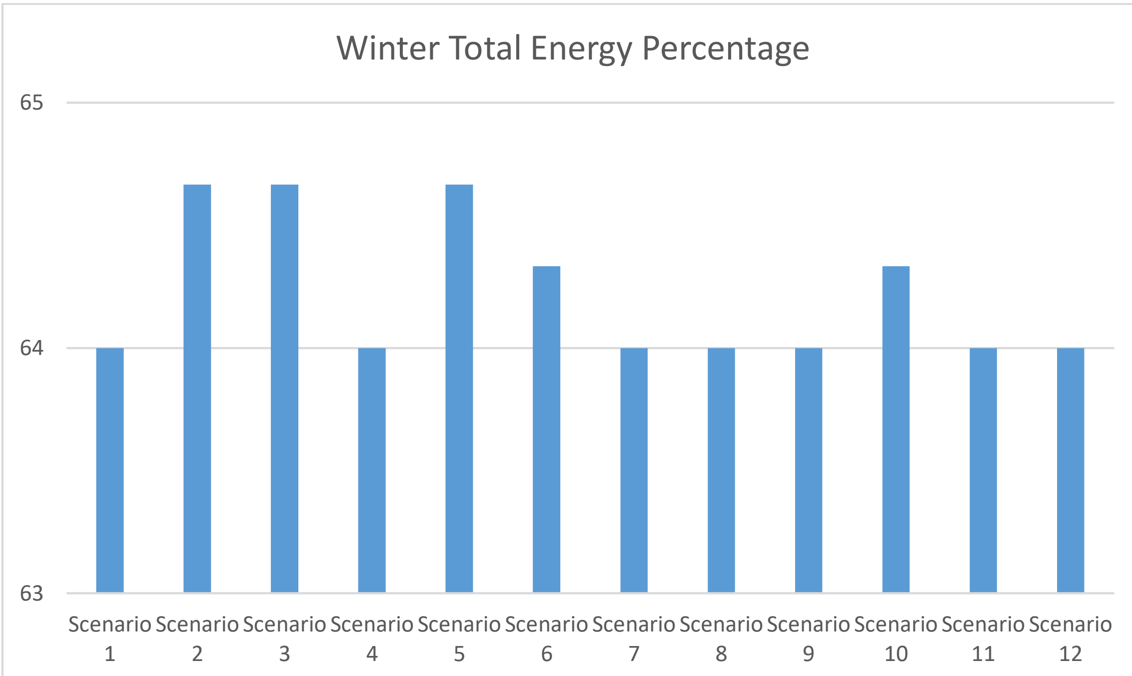



*Table 6.3 January total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

### 6.3- Spring Season Energy Consumption for Space Heating

During each month, every scenario had different fuel consumption percentages. Spring season simulated the third highest number of fuel consumption, where the temperature drops to reach the lowest records between all seasons. Monthly consumptions are referenced in appendix. Scenario number 1 simulated 6665 MJ, scenario number 2 simulated 6890 MJ, scenario number 3 simulated 6874 MJ, Scenario number 4 6550 MJ, scenario number 5 7036 MJ, scenario number 6 6928 MJ, scenario number 7 6713 MJ, scenario number 8 6601 MJ, scenario number 9 6775 MJ, scenario number 10 6928 MJ, scenario number 11 6576 MJ, and finally, scenario number 12 simulated 6470 MJ. As shown in Table 13, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table 6.4).

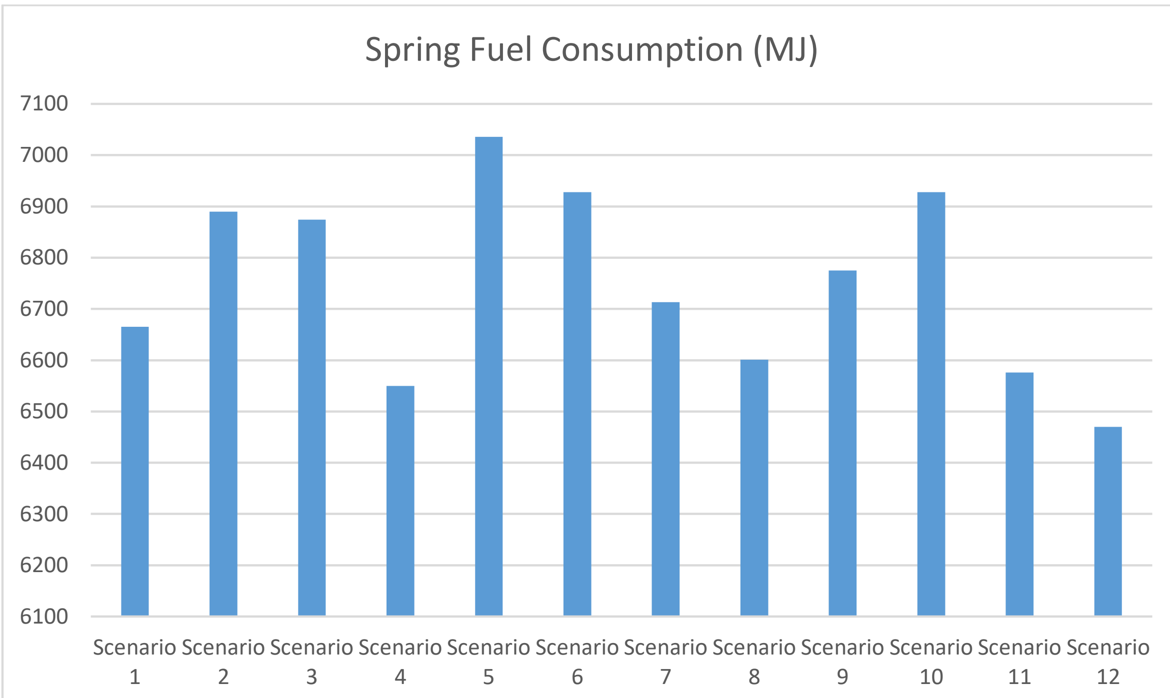



*Table 6.4 January fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, Table 14 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenarios number 5, 6, and 10 was the highest consumption and simulated 46 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 43 KWH. Then comes scenarios number 1, 4, 8, and 11, which simulated 44 KWH. Scenarios number 2, 3, 7, and 9 simulated 45 KWH (table 6.5).

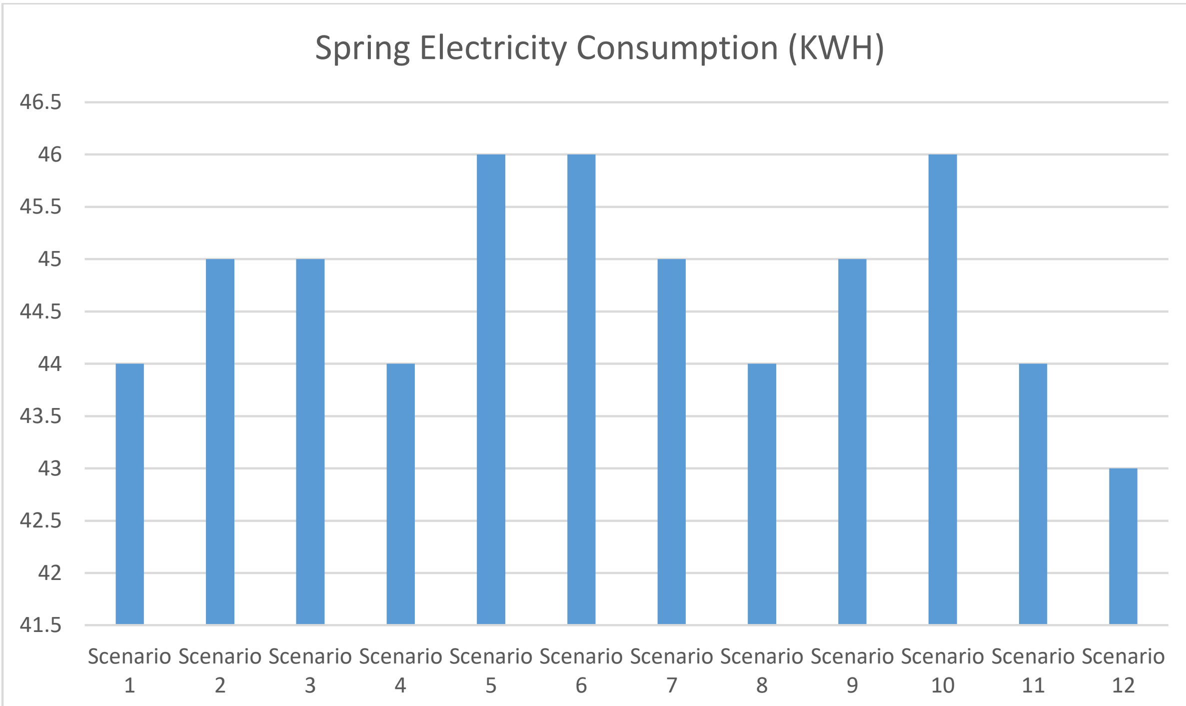



*Table 6.5 January electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in spring season in scenarios number 1,2, 5, 6, and 10 simulated 31 % of the total energy. Scenarios number 4, 7, 8, 9, 11, and 12 is 30 %. Whereas Scenario number 3 simulated 41 % (table 6.6).

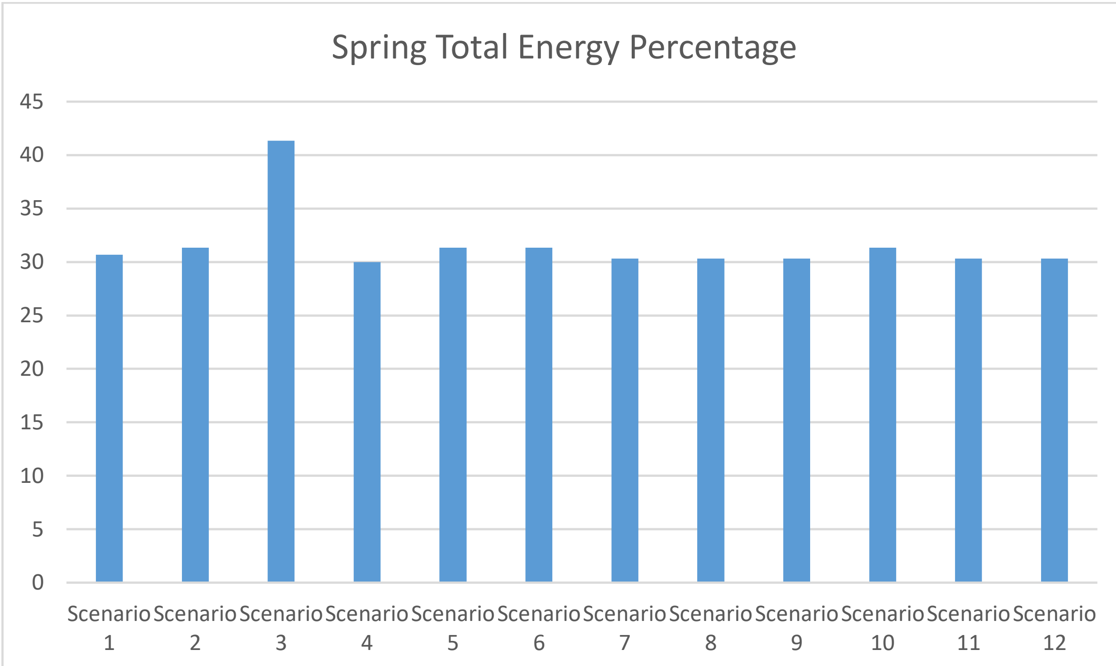



*Table 6.6 January total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

### 6.4- Summer Season Energy Consumption for Space Heating

Summer season simulated the lowest number of fuel consumption, where the temperature reaches the highest records between all seasons. Monthly consumptions are referenced in appendix. Scenario number 1 simulated 1784 MJ, scenario number 2 simulated 1836 MJ, scenario number 3 simulated 1832 MJ, Scenario number 4 1732 MJ, scenario number 5 1871 MJ, scenario number 6 1842 MJ, scenario number 7 1792 MJ, scenario number 8 1763 MJ, scenario number 9 1808 MJ, scenario number 10 1842 MJ, scenario number 11 1757 MJ, and finally, scenario number 12 simulated 1733 MJ. As shown in Table 13, the scenario that had the lowest fuel consumption was scenario number 4, followed by scenario number 12. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table 6.7).

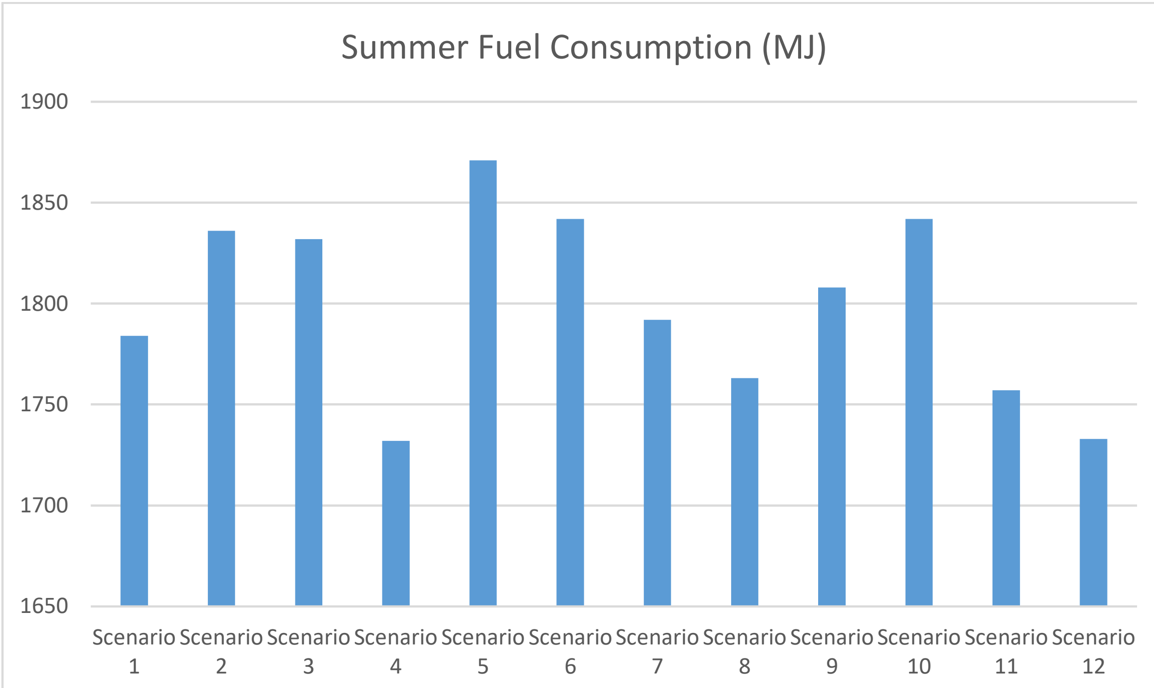



*Table 6.7 January fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, there is no electricity spent on heating.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in summer season in all scenarios is 10 % (table 15).

### 6.5- Fall Season Energy Consumption for Space Heating

Fall season simulated the second highest number of fuel consumption, where the temperature drops to reach the lowest records between all seasons. Monthly consumptions are referenced in appendix. Scenario number 1 simulated 16142 MJ, scenario number 2 simulated 16739 MJ, scenario number 3 simulated 16682 MJ, Scenario number 4 16207 MJ, scenario number 5 17040 MJ, scenario number 6 16807 MJ, scenario number 7 16377 MJ, scenario number 8 16067 MJ, scenario number 9 16521 MJ, scenario number 10 16807 MJ, scenario number 11 16004 MJ, and finally, scenario number 12 simulated 15730 MJ. As shown in Table 13, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table 6.8).

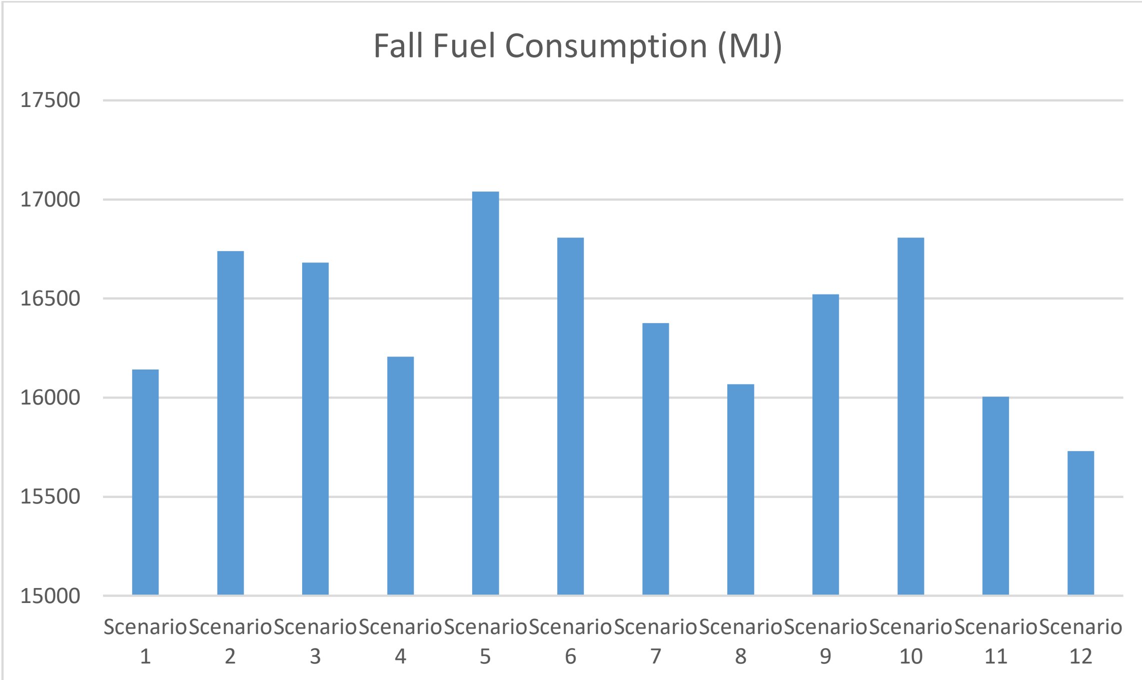



*Table 6.8 January fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, Table 14 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest consumption and simulated 164 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 152 KWH. Then comes scenario number 1 and 8 simulated 155 KWH. Scenario number 2 and 3 simulated 161 KWH. Scenario number 4 simulated 157 KWH, scenarios number 6 and 10 simulated 162 KWH, scenario number 9 simulated 160 KWH, and scenario number 7 simulated

159 KWH, scenario number 8 simulated 155 KWH, and scenario number 11 simulated 154 KWH (table 6.9).

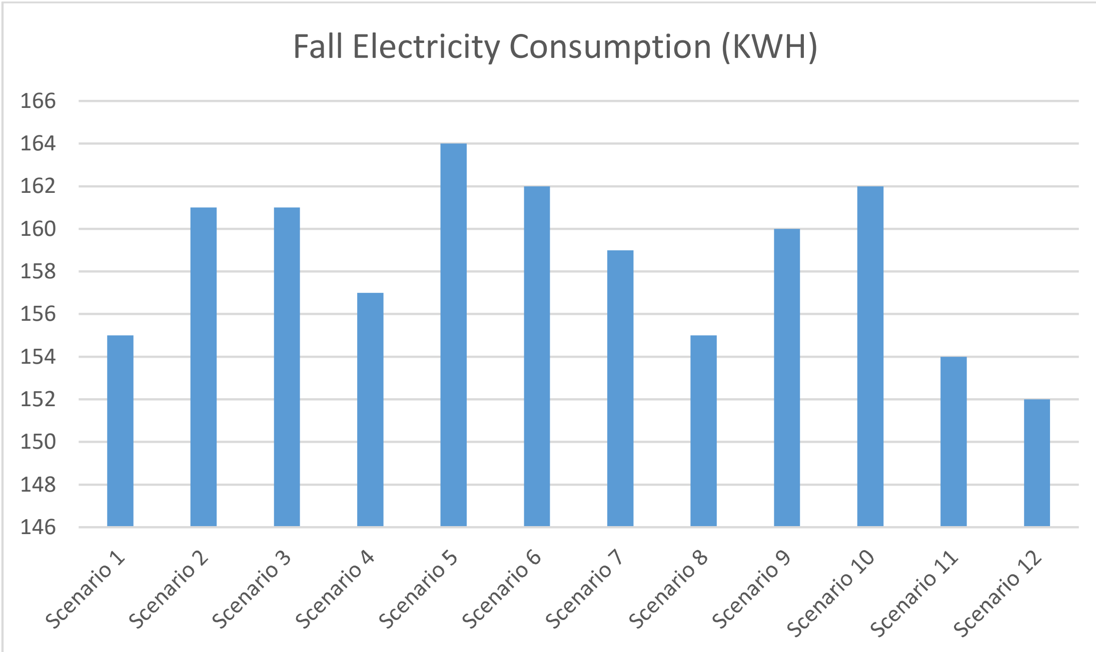



*Table 6.9 January electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in winter season in scenarios number 1, 4, 8, 11, and 12 is 52 %. Whereas Scenario number 2, 3, 5, 6, 7, 9, and 10 simulated 53 % (table 6.10).

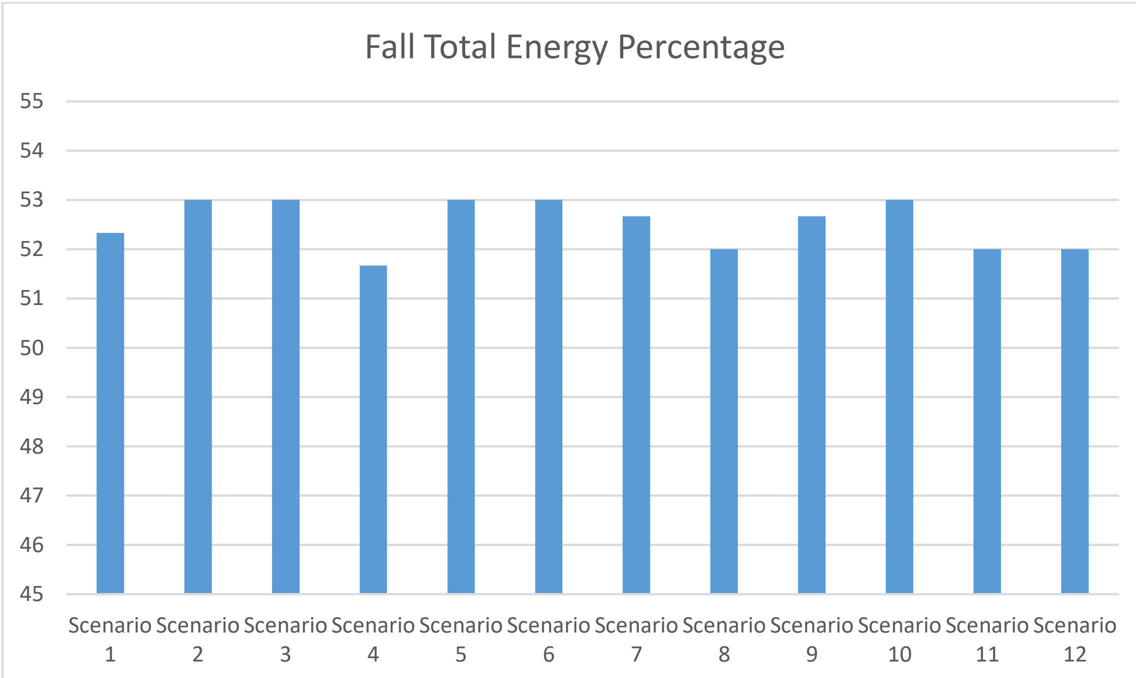



*Table 6.10 January total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

### 6.6- Yearly Energy Consumption for Space Heating Comparison

Further figures and chart observations of scenario 12 show that this scenario has the lowest fuel consumption among all scenarios (table 6.11; 6.13). Remarkably, this

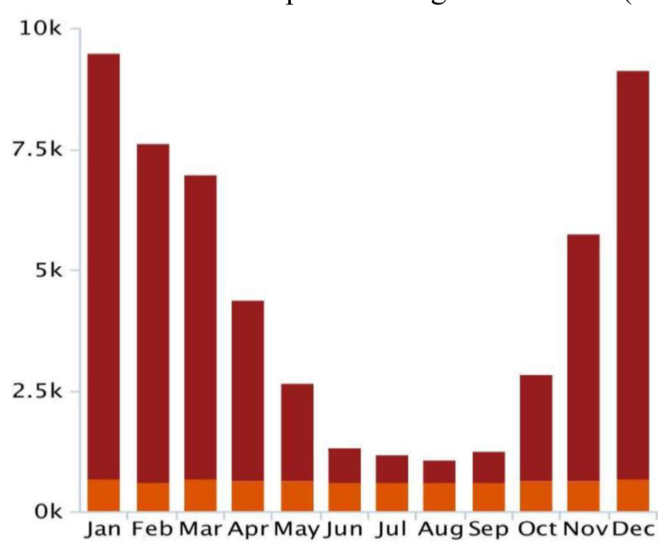



*Table 6.11 Scenario 12 fuel consuption monthly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

scenario marked different fuel consumption percentages through the months of the year to sustain the same indoor air temperature (table 6.12). First, the winter season marked the highest number of fuel consumption per year, followed by the fall season. In the third place falls the spring season, and finally, the Summer season showed the lowest energy consumption rates (table 6.11). Accordingly, the peak in fuel consumption between the highest consuming month (January) or season (winter) and the least ones (August; summer) becomes larger. The total yearly fuel consumption on space heating for scenario number 12 is 46079 MJ, followed by scenario number 11 for 46508 MJ, then scenario number 8 for 47040 MJ. Scenario number 5 simulated the highest fuel consumption per year, which is equal to 49341 MJ.

| Season | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 | Scenario 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter | 22665 | 23139 | 23393 | 22787 | 23917 | 23590 | 23063 | 22609 | 23277 | 23590 | 22171 | 22146 |
| Spring | 6665 | 6890 | 6874 | 6550 | 7036 | 6928 | 6713 | 6601 | 6775 | 6928 | 6576 | 6470 |
| Summer | 1784 | 1836 | 1832 | 1732 | 1871 | 1842 | 1792 | 1763 | 1808 | 1842 | 1757 | 1733 |
| Fall | 16142 | 16739 | 16682 | 16207 | 17040 | 16807 | 16377 | 16067 | 16521 | 16807 | 16004 | 15730 |

*Table 6.12 Scenarios seasonal fuel consumption yearly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

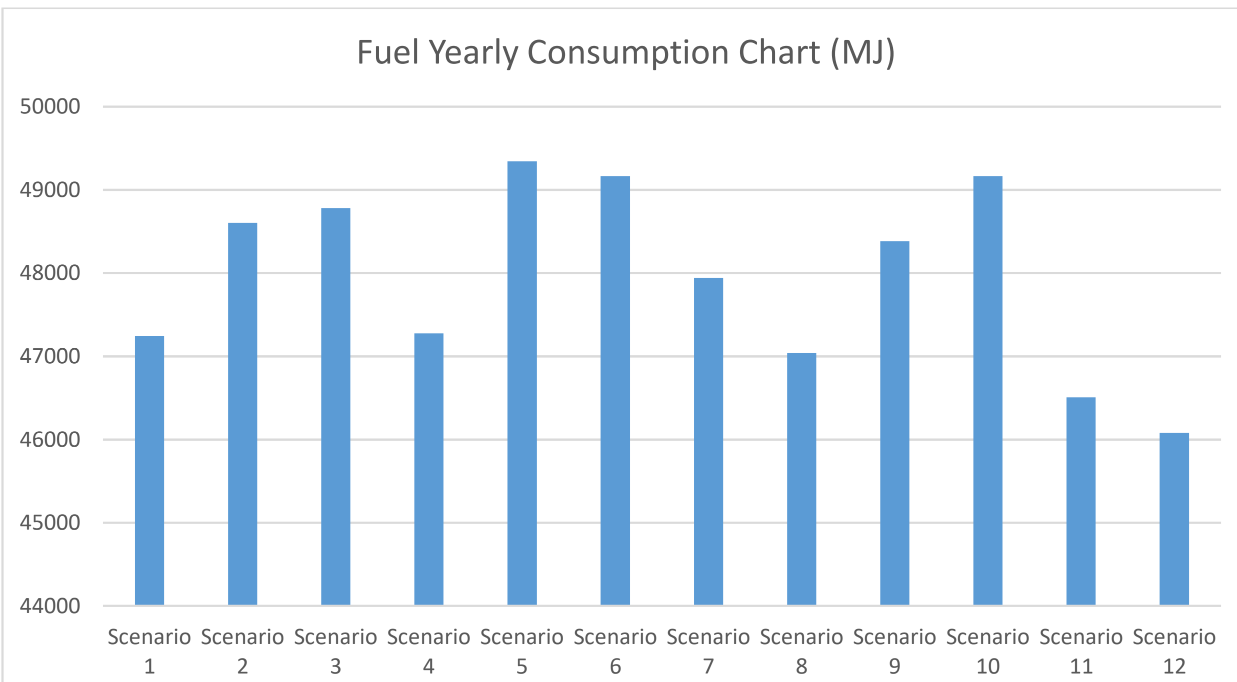



*Table 6.13 Scenarios fuel consumption yearly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, observation of graphs and figures shows that electricity spent on heating registered the lowest between all other usages. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. The electricity consumption in the winter season was the highest, followed by the fall season, then by spring. Finally, the summer season has the lowest consumption among all seasons, where electricity consumption on space heating is equal to 0 KWH (table 6.14; 6.15).

| Season | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 | Scenario 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter | 256 | 265 | 264 | 259 | 270 | 266 | 260 | 255 | 263 | 266 | 255 | 250 |
| Spring | 44 | 45 | 45 | 44 | 46 | 46 | 45 | 44 | 45 | 46 | 44 | 43 |
| Summer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fall | 155 | 161 | 161 | 157 | 164 | 162 | 159 | 155 | 160 | 162 | 154 | 152 |

*Table 6.14 Scenarios seasonal Electricity consumption yearly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

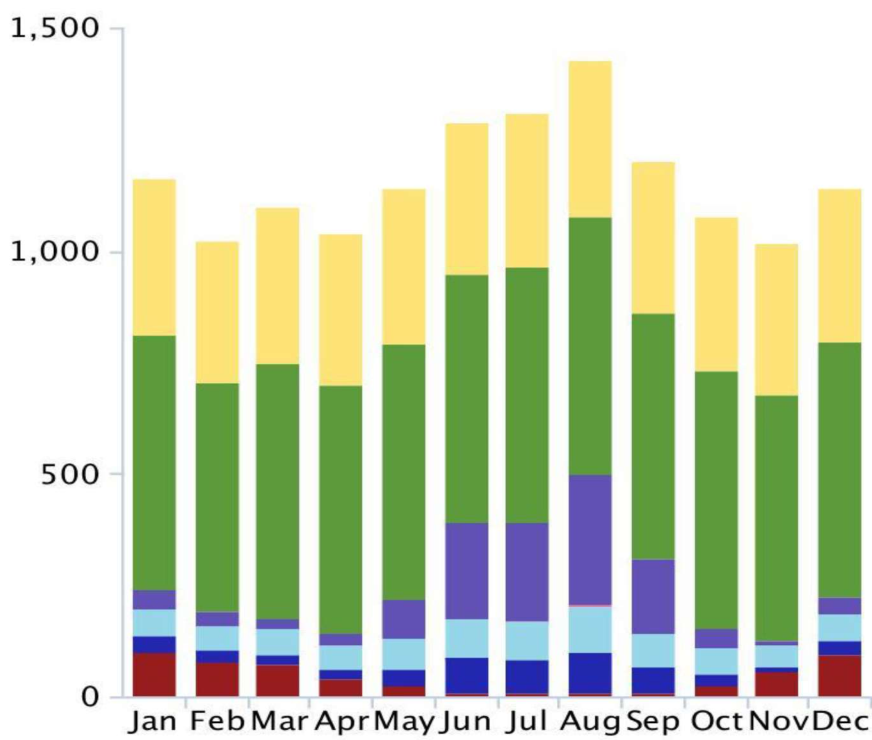



*Table 6.15, Scenario 12, electricity consumption monthly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

Scenario number 12 total's electricity consumption for space heating per year is 334 KWH, followed by scenario number 8 for 448 KWH, then comes scenario number 11 with 453 KWH. Scenario number 5 simulated the highest electricity consumption per year, which is equal to 480 KWH (table 6.16).

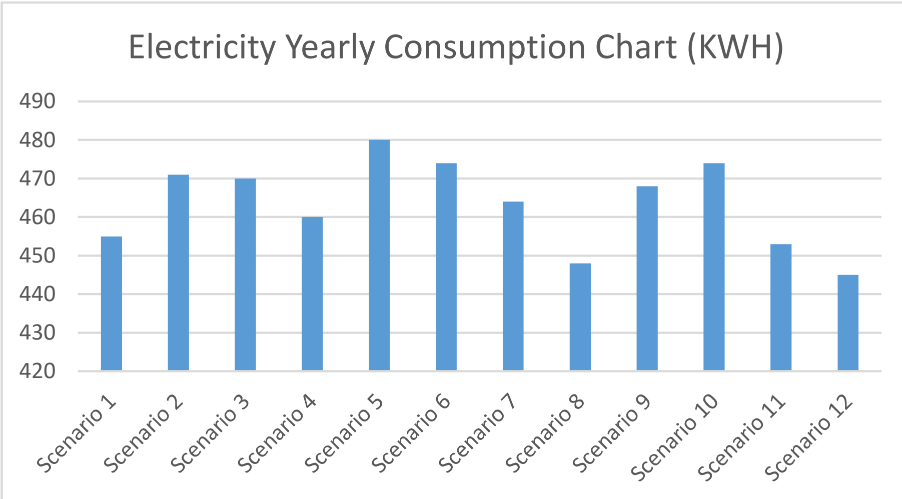



*Table 6.16 Scenarios Electricity consuption yearly. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

**6.7- Chapter Conclusion**

The methodology implemented targeted the objectives of the thesis. The simulation done on different scenarios helped to record data about the thermal properties of each materials which will affect the energy demand and consumption for space heating to identify the proper construction materials used for external envelope in the study area. The energy modeling simulated outcomes that will be further inserted into Excel in order to create tables and charts for analysis. The results of the models assess the impact of the construction materials on energy demand for space heating.

# 7- Life-Cycle Cost Analysis

## 7.1- Introduction

The following chapter presents the life-cycle cost analysis of each scenario to return-on investment the cost of construction materials with respect to the energy spent on space heating. The sections of this chapter show the cost of construction materials and the energy cost. Two types of energy and cost analyses were conducted to represent the current methods and their costs in Lebanon. First, a set of energy and cost parameter analysis is done separately according to fuel (in Liters) measures for space heating. Then, the envelop construction materials parameters were compared using cost analysis to calculate the material and labor cost. These two methods present the payback period of energy consumption in the climatic region of the high mountains of Lebanon. The goal is to find out the proper construction material for the external envelope.

## 7.2- Energy Consumption

As mentioned in the literature review, each one of the studied scenarios showed a different behavior of consumption. After establishing the heater type (diesel fuel) stove used in Becharre (as mentioned in chapter II), the next step is to set up the energy content in such type of heating. According to (Energy Content in Some Common Energy Sources, 2020), diesel fuel energy source energy content is 139 000 Btu (British Thermal Unit) per 1 Gallon (table. 7.1), where 1 gallon is 3.785 L.

| Energy Source | Unit | Energy Content (Btu) |
|---|---|---|
| Electricity | 1 Kilowatt-hour | 3412 |
| Butane | 1 Cubic Foot (cu.ft.) | 3200 |
| Coal | 1 Ton | 28000000 |
| Crude Oil | 1 Barrel - 42 gallons | 5800000 |
| Fuel Oil no.1 | 1 Gallon | 137400 |
| Fuel Oil no.2 | 1 Gallon | 139600 |
| Fuel Oil no.3 | 1 Gallon | 141800 |
| Fuel Oil no.4 | 1 Gallon | 145100 |
| Fuel Oil no.5 | 1 Gallon | 148800 |
| Fuel Oil no.6 | 1 Gallon | 152400 |
| Diesel Fuel | 1 Gallon | 139000 |
| Gasoline | 1 Gallon | 124000 |
| Natural Gas | 1 Cubic Foot (cu.ft.) | 950 - 1150 |
| Heating Oil | 1 Gallon | 139000 |
| Kerosene | 1 Gallon | 135000 |
| Pellets | 1 Ton | 16500000 |
| Propane LPG (Liquid Petroleum Gas) | 1 Gallon | 91330 |
| Propane gas 60°F | 1 Cubic Foot (cu.ft.) | 2550 |
| Residual Fuel Oil [1)] | 1 Barrel - 42 gallons | 6287000 |
| Wood - air dried | 1 Cord | 20000000 |
| Wood - air dried | 1 pound | 8000 |

*Table 7.1 Energy content in some commonly used energy sources. Source: https://www.engineeringtoolbox.com/amp/energy-content-d_868.html. Accessed on 29-03-2020*

The next step is to establish and convert the consumption from MJ to KWH/m²/year and then to determine the energy source's efficiency. According to ("Stove heating. Diesel heating. Disadvantages", 2020), stove heating is not very efficient, where its efficiency factor is only 25 %. After setting all parameters, and in order to reach the cost of energy spent in each scenario, the amount of energy established from the insight 360 should be divided by the efficiency percentage. The next step is to convert this volume according to the energy content produced by the energy source. Finally, the last step is to compare all scenarios to show the least scenario consumption in terms of KWH/m²/year.

The fuel consumption analysis highlights the effect of the external wall envelopes thermal properties. It also helps in comparing all scenarios to choose the proper one among them by specifying the amount spent (per square meter) on fuel energy throughout a full year. Table 7.2 illustrates the yearly fuel consumption in all scenarios based on the data exported from Insight 360 and calculated (as mentioned previously) broken into each scenario. As shown in table 7.2, scenario number twelve has the lowest fuel consumption (128 KWH/m²/year), and the least cost on fuel per year (table 7.2). Whereas, the most energy-consuming scenario is number 6 (171 KWH/m²/year), which has the highest demand per square meter when compared to all scenarios. The difference between the lowest and highest fuel consumption scenario is 43 KWH/m²/year due to the difference in external wall thermal properties.

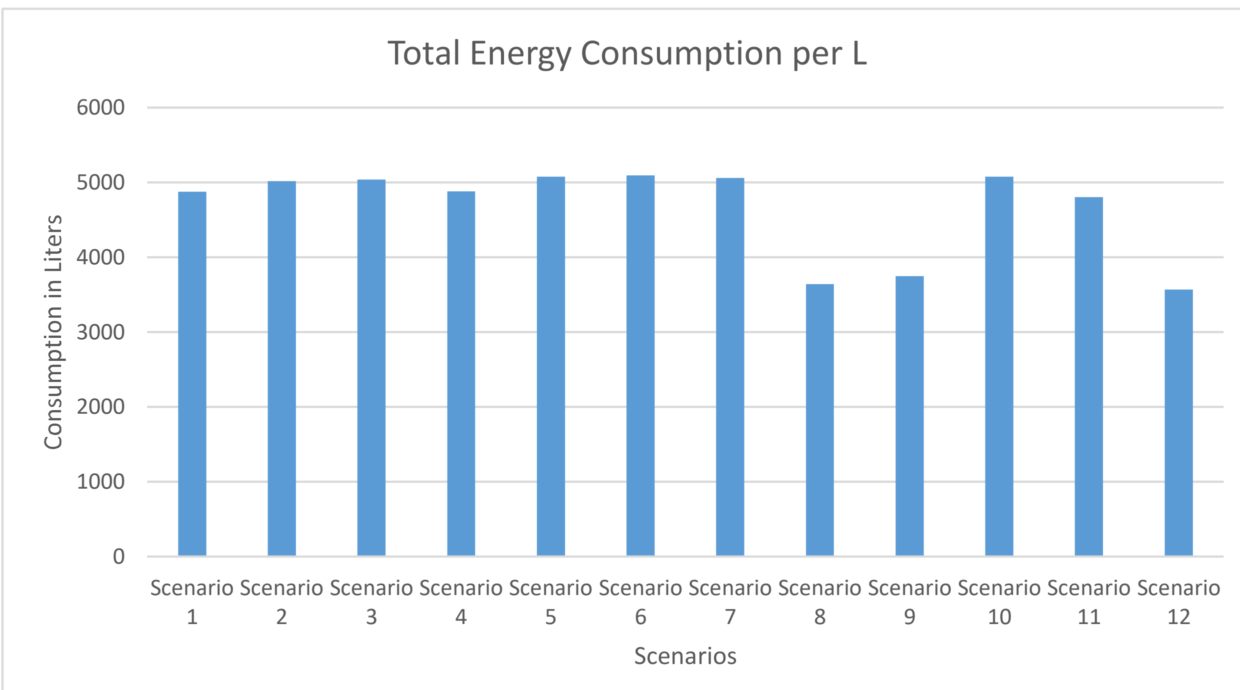



*Table 7.2 Fuel yearly cost in Liters. Source: Author*

The lowest fuel consumption in scenario 12, which is equal to 128 KWH/m²/year, is less than the standard average (194 KWH/m²/year). Table 7.3 shows each scenario's fuel

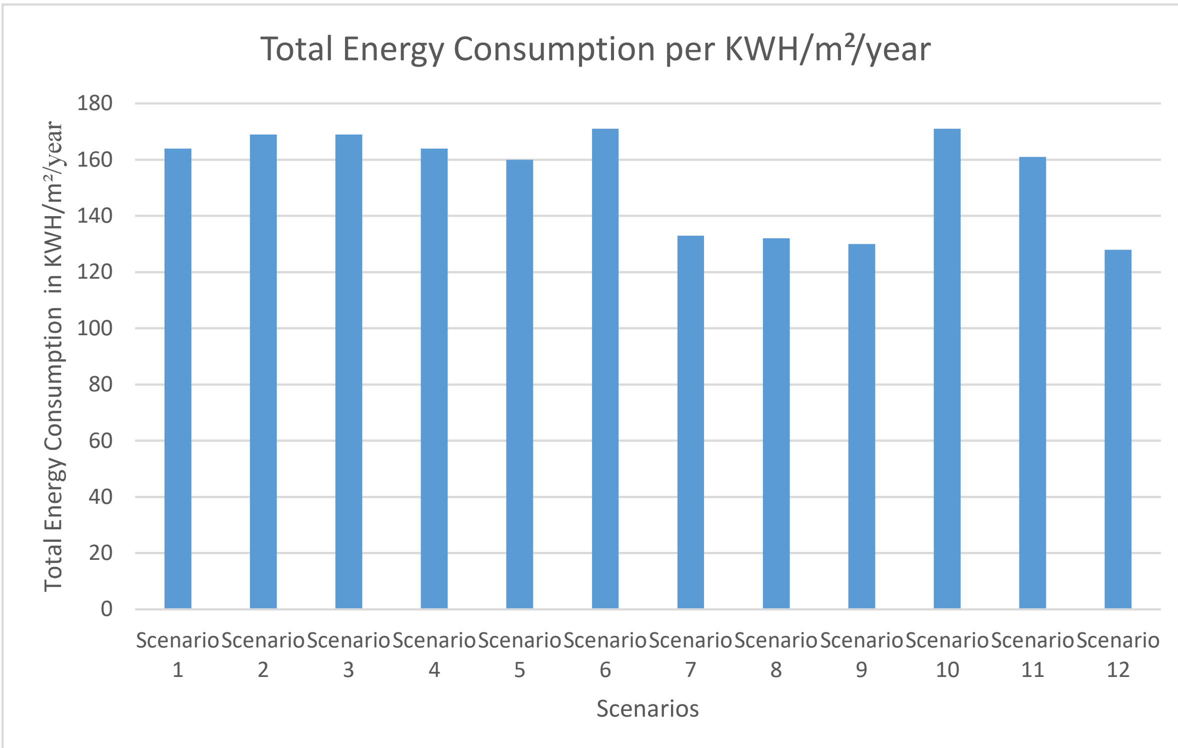



*Table 7.3 Fuel yearly consumption in KHW. Source: Author*

consumption that is calculated according to the demand. After comparing the highest and lowest scenario, the results are the following: Scenario number twelve consumed 3568 L per year on space heating, whereas scenario number six consumed 5094 L. This huge difference means that by adopting scenario number 12, fuel consumption can be reduced by 34%.

The second method used to track energy cost and compare it among each scenario is electricity consumption (in KWH). Similarly, electricity consumption for space heating differs between the studied scenarios. More so, scenario number twelve also has the lowest energy consumed during a full year. This indicates that it has the lowest cost of energy, where it simulated 334 KWH. However, scenario number six has the highest electricity consumption, and it registered 480 KWH (table 7.4).

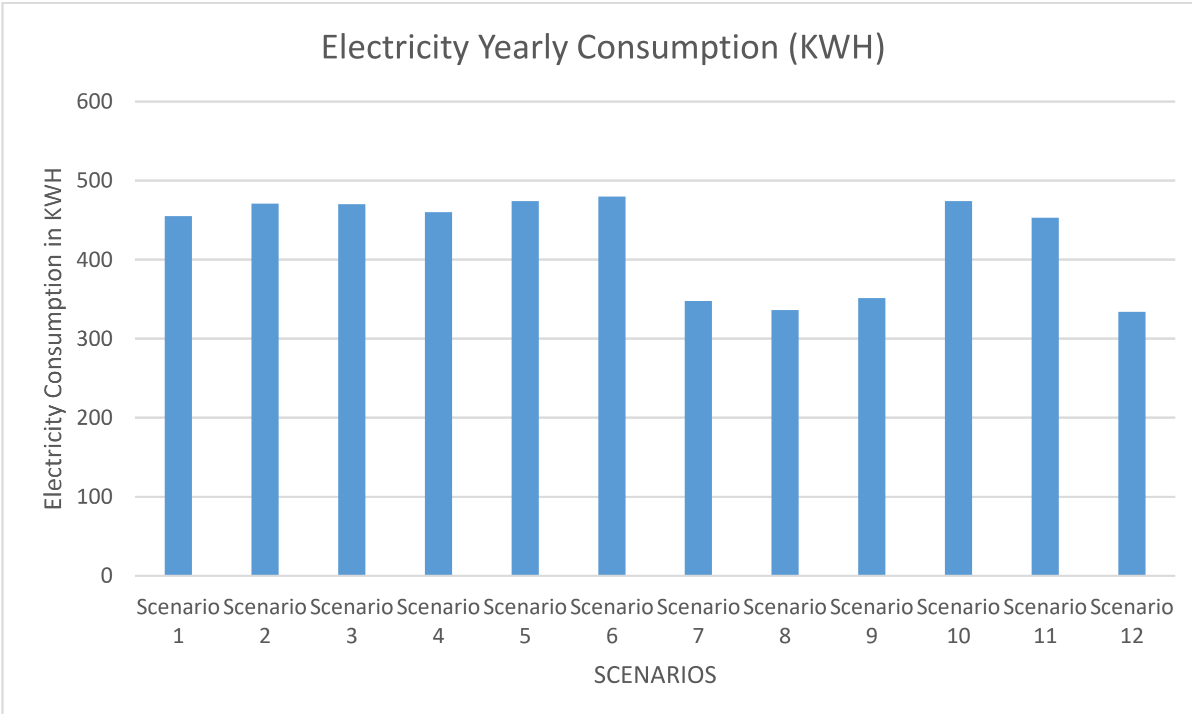



*Table 7.4 Electricity yearly cost in LBP. Source: Author.*

All studied scenarios are simulated through the same parameters. Therefore, it is clear that the less energy needed for space heating, the less cost will decrease. The difference in consumption between scenarios depends on the external envelope materials. As a result, it is noticed that scenario number twelve has the lowest energy consumption on space heating between all scenarios studied. The effect of outdoor insulation and inner thermal mass has a significant impact on minimizing heat loss, which means decreasing the cost spent on energy. This amount is related to the area of the house, which is equal to 110 sqm. Thus, when the area increase, the energy needed for space heating will increase, and of course, the cost will increase accordingly. Finally, the difference between the lowest energy-consuming scenario (scenario number twelve) and the most energy-consumed scenario (scenario number six) is 146 KWH per year, around 45 %.

The peak heating load is a direct parameter for all levels of energy consumption in buildings. Reducing load demand would reduce fuel operating, electricity consumption, and would promote energy saving. However, it is essential to determine the best energy-saving scenario depending on the external wall envelope (u-value and thermal properties) and having the same location, orientation, area, window to wall ratio, and usage. Using the proper materials to reduce energy demand also depends on the climatic zone, where scenarios share the same exposure, geographic location, and climate, degree day (DD). According to this section, the results proved that choosing the proper materials can help to reduce 34 % of energy for space heating, which means ensuring energy conservation to optimize energy bills (fuel and electricity). Scenario number twelve has the minimum results and the lowest energy consumption to decrease operating costs.

### 7.3- Construction Materials Cost

According to (Platace, L. & Gusta, S., 2016), Construction cost is essential to control the process and budget in any project (pp. 116-125). Until now, there are no regulations in Lebanon that specify and define clearly construction cost estimations. Moreover, cost estimation has a direct effect on the quality of construction (Platace, L. & Gusta, S., 2016, pp. 116-125). Unfortunately, people tend to lower the cost, which is translated into a low-quality construction. In this section, the study tries to analyze cost analysis to show the cost effect on the life cycle compared to the energy consumed during the same period. In this thesis, the cost of building construction materials costs was analyzed to compile the price per square meter. This process will help to show the payback period, which minimizes the total cost, including construction materials and energy consumption.

As mentioned previously, in Lebanon, there are no guidelines to follow to check materials or labor costs or for any type of construction works. For this reason, the prices were chosen according to experience in the field, knowledge, and choice of technicality. During this section, construction materials cost was estimated for individual house construction to compare the different types of construction materials per square meter. The types of used construction materials are the following:

- Concrete masonry units (15 $/sqm): 13 units constitutes a square meter and costs 7$ / sqm. Labor cost: 5 $/sqm, and lintels cost 3 $/sqm.
- Plastering (8 $/sqm): material costs: 2 $/sqm, and labor cost 6 $/sqm.
- Paint (8 $/sqm): material costs: 3 $/sqm, and labor cost 5 $/sqm.
- Cladding (50 $/sqm): stone and materials cost 35 $/sqm, and labor costs 15 $/sqm.
- Insulation (28 $/sqm): material costs 12 $/sqm, and labor costs 8 $/sqm.
- Thermal barrier (8 $/sqm) as a material cost.
- Water sealant for external stone cladding (13 $/sqm): material cost 6.5 $/sqm, and labor costs 6.5 $/sqm.
- Wood (timber) (160 $/sqm).
- Limestone (76 $/sqm): material and transportation: 27 $/sqm, labor cost 30 $/sqm, materials such as mortar 3 $/sqm, plaster 8 $/sqm, and paint 8 $/sqm.

As shown in table 7.5, it was found that there is a difference in the construction costs of the selected and studied materials. Also, according to the energy consumption analysis, it can be noticed that while energy consumption decrease, the construction cost increase. Taking scenario twelve as a reference due to the lowest energy consumption and demand between all scenarios, it has the second-highest cost after scenario number one and nine. The cost of this scenarios is higher than scenario two by 380 % than scenario three by 240 %, than scenario four and five by 54 %, than scenario seven by 23 %, than scenario eight by 7 %, than scenario ten by 500 %, and finally higher than scenario elven by 56 %.

| Scenario | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 | Scenario 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost in $ | 251 | 62 | 98 | 153 | 153 | 60 | 191 | 220 | 320 | 47 | 92 | 236 |

*Table 7.5 Scenario's cost according to each material price.*

For instance, heat energy costs during operation are the costs of the "life cycle" of building. For this reason, choosing low-quality construction material will save costs in the construction phase. Still, in the long run, savings would be lost when walls would not comply with energy efficiency requirements (Bull, 1992).

### 7.4- Chapter Conclusion

By following this methodology, the proper construction materials that decrease energy consumption and return-on investment can be obtained. In addition, using this method will allow the long energy and cost savings, and thus the objectives of the thesis can be answered and analyzed. The life-cycle cost analysis done on all the construction materials and scenarios helped to show the return cost of each scenario will affect the running cost of the building in the study area.

# 8- Analysis and Discussion

## 8.1- Introduction

The following chapter describes and analyzes the gathered data from the building modeling and energy simulation done on different types of construction materials scenarios in the cold climate of Lebanon especially Bcharre. In this chapter, the gathered data was divided according to the scenarios of the construction materials of the external envelopes. These scenarios will be analyzed and compared. The first section will describe, analyze, and compare the simulated data in all the scenarios in terms of energy used intensity (EUI). The second section will further focus on energy per Liter (L) and Kilowatt-hour (KWH). The third section will focus on the least energy consumption scenario which reduce energy demand and consumption to show the effect of its construction materials. The experimental Chapter of this research used the simulation method mentioned in the previous studies (literature review chapter), to compare different construction material envelopes in the high mountains of Lebanon. This method provided a detailed study of energy consumption and demand for external building envelopes in a Lebanese cold climatic region. The simulated building envelopes share four construction materials with different u-value, resistance, thermal mass, same heating modes, and occupancy. The simulation tested their behavior in terms of heating consumption throughout the year. The study concentrated on the fall and winter seasons, where the consumption is much more significant to reach a suitable indoor environment. The factors that played a vital role were mainly the low u-value, the high material resistance, and the presence of insulation, which contributed to minimizing the heat loss of temperature difference between inside and outside.

## 8.2- Scenario Simulation Analysis in terms of EUI

This section analyses and compares the recording of space heating and energy consumption in each scenario. The simulation is done through Insight 360 (Autodesk) in order to further compare the construction materials in the twelve different scenarios. Therefore, the focus will be on the impact of construction materials on the energy demand and consumption for space heating.

It is crucial to focus on the impact of the construction materials for energy consumption since the external envelope has its direct impact on heat transfer between inside and outside.

Insight 360 gives results in EUI (Energy Use Intensity) per unit of the built area. It means that this software provides an evaluation of the building's annual energy consumption according to the gross floor area. This process is applied to all types of energy used in the building, such as space heating, space cooling, plugins, lighting, and hot water. The prominent concern of this thesis is to assess space heating since it has the highest share of energy consumption in the cold climatic zone of Lebanon. For this reason, these measurements should be taken into consideration while selecting the external envelope building's material according to the benchmark set by insight 360, which is ASHRAE 140.

The simulation of all scenarios on Insight 360 showed that each building envelope performed differently with a significant benchmark and wall configuration differences. All scenarios are similar in terms of openings (types and window to wall ratio), orientation (East-West towards South), and occupancy.

Under those circumstances, Scenario number twelve presented the lowest energy consumption peak (-2 kwh/m²/yr.) below ASHRAE 140 benchmark, followed by scenario number eight with (-1 kwh/m²/yr.) energy consumption peak below ASHRAE 140. In contrast, scenarios number four, five, seven, and nine were equal to the benchmark. Scenario one, two, and three had their energy consumption above ASHRAE 140 baseline by (1, 2, and 3 kwh/m²/yr.). And finally, Scenario six and eleven were far away from the benchmark (Table 9.1).

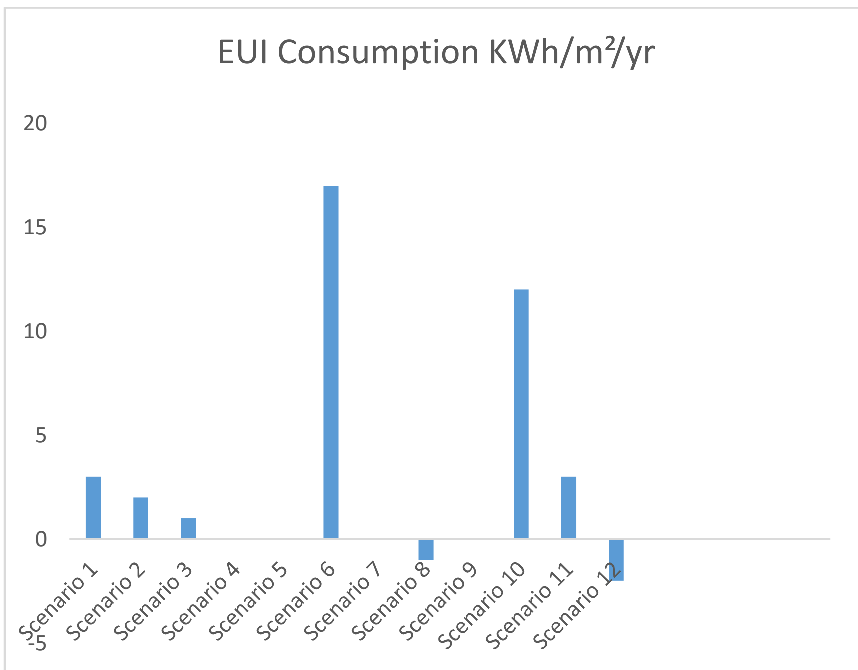



*Table 8.1 Scenarios energy consumption comparison. Source: https://insight360.autodesk.com/oneenergy/Insight/106031Accessed on 18-03-2020*

“The external surface temperatures are directly influenced by the physical properties of the material” (Saleh, P., 2019, p. 95). Besides, energy consumption is also influenced by internal air temperature and thermal properties of the wall itself that transfer heat from inside to outside. It was shown that wooden materials have a higher value of thermal properties among the studied materials due to the insulation layers that act as a barrier of heat transfer from inside out. The use of insight 360 helped in assessing energy consumption precisely. Regardless, the degree day data mentioned in the previous chapter has its influence on energy demand.

**8.3- Scenario's Energy Consumption**

The following section will analyze the recording energy consumption of the twelve scenarios. The analysis will include the annual total space heating demand in each scenario. The energy demand for space heating will be discussed focusing on the impact of external envelope's construction materials on the impact of energy consumption. Further details on each model will be found and referred to from the appendix O till appendix Z.

The heating demand increasing according to the drop of the outdoor temperature of the context especially in fall and winter seasons. As the temperature decreases, the space heating increases. The increase in operation space heating is to provide indoor thermal comfort, and to compensate the heat exchange through the external envelope's construction materials used.

Moreover, the results were interesting and unusual, where the lowest energy consuming scenario was not the one that has the lowest u-value and the highest resistance. Scenario number twelve that has an external envelope composed of timber wood (5 cm), insulation, vapor barrier, void (5 cm), limestone (35 cm), and a 2cm layer of plaster (from outside to inside) showed the lowest fuel and electricity consumption. Space heating consumption for this scenario reached 3568 L per year (Table 9.2). Scenario number eight falls in second place, marking 3643 L per year of fuel consumption. Accordingly, the difference in fuel consumption between the studied scenarios becomes more significant to reach a peak for 5094 L in scenario number six.

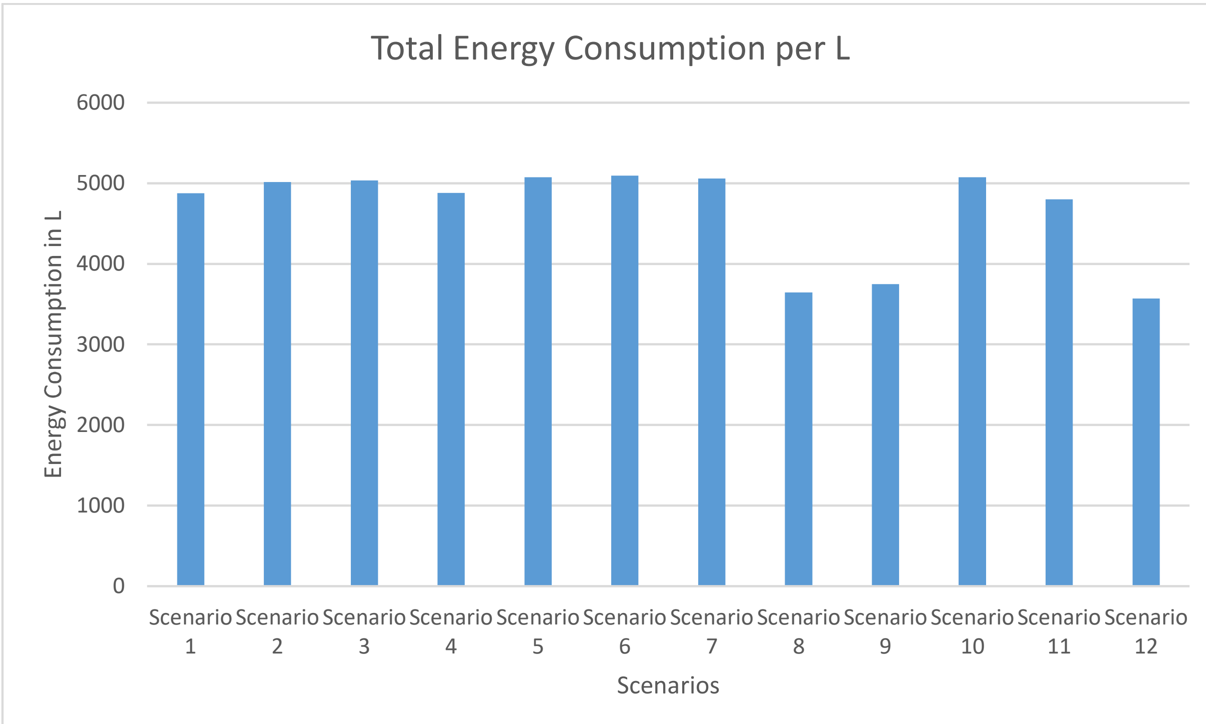



*Table 8.2 The simulated fuel consumption per year of the twelve scenarios. Source: author.*

Fall and Winter seasons (January, February, March, October, November, and December) showed the highest fuel consumption for space heating followed by spring then summer season (table 9.3). January simulated 8808 MJ, followed by December 8443 MJ, then February 7028 MJ, March 6310 MJ, November 5091 MJ, and finally October 2196 MJ.

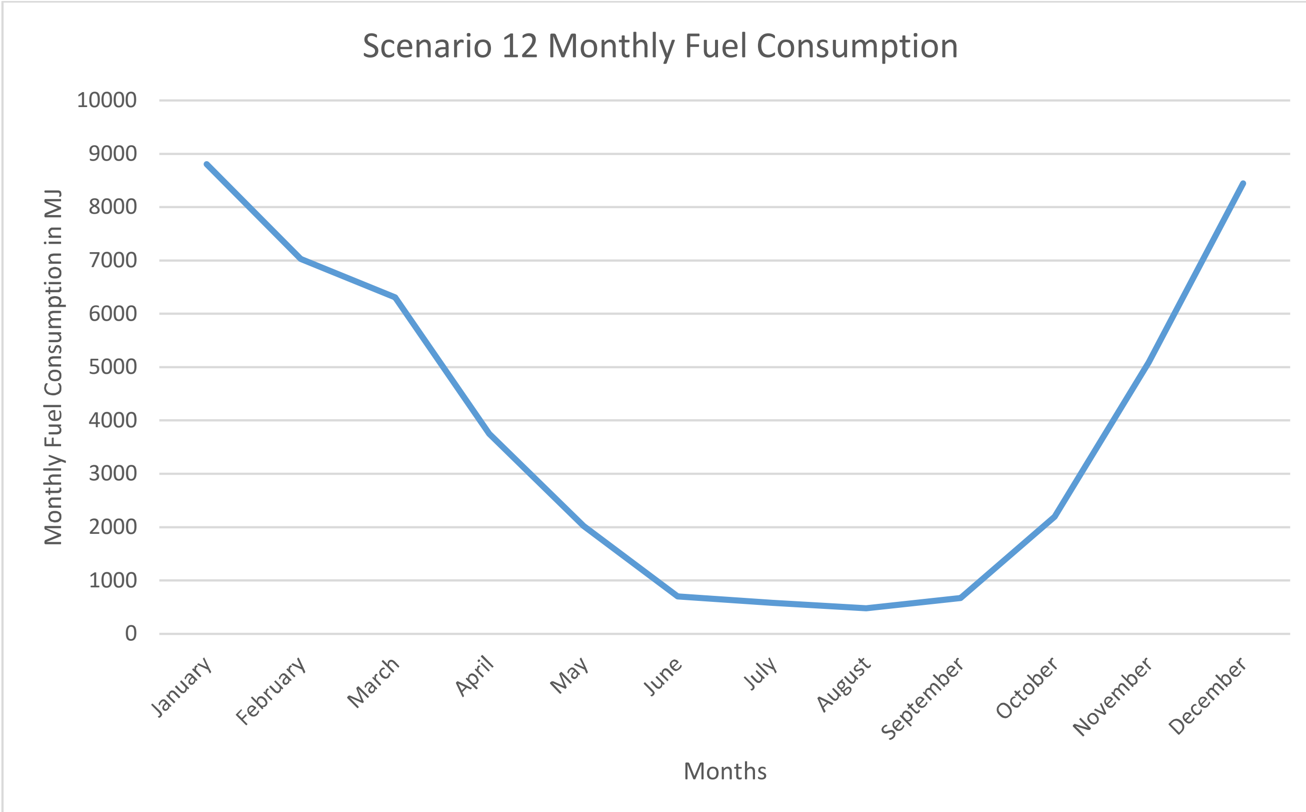



*Table 8.3 The simulated monthly fuel consumption of the twelve scenarios. Source: author.*

So far, the simulation analysis of the twelve scenarios showed that scenario number twelve also has the lowest electricity consumption among all scenarios, where electricity demand for space heating simulated 334 KWH. Scenario number eight falls in second place, registering 336 KWH per year as electricity consumption. Accordingly, the consumption difference between scenarios became large until reaching a peak in scenario number 6 for 480 KWH (table 9.4).

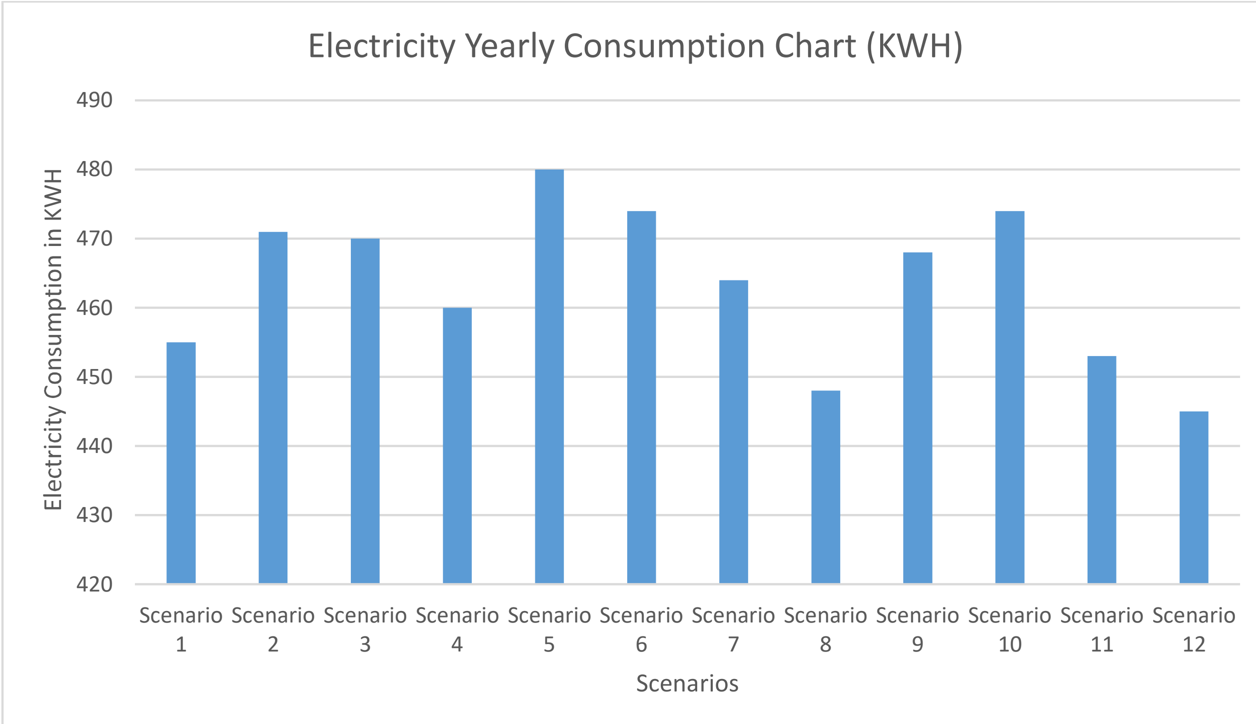



*Table 8.4 The simulated electricity consumption per year of the twelve scenarios. Source: author.*

Fall and Winter seasons (January, February, March, October, November, and December) showed the highest electricity consumption on space heating, whereas spring and summer seasons simulated 0 demand (table 9.5). January marked 99 KWH, followed by December by 94 KWH, February filed 79 KWH, March 72 KWH, and November 58 KWH. It is noticeable that between May and October, there was no demand for electricity for space heating.

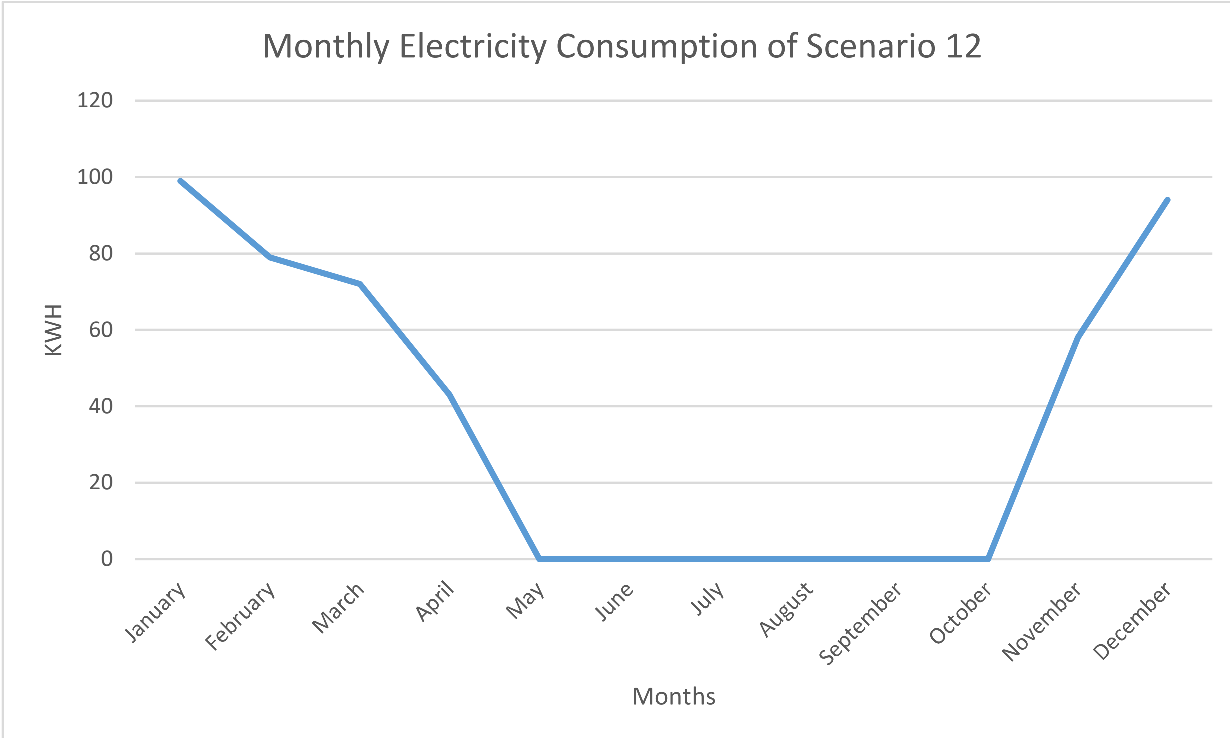



*Table 8.5 The simulated electricity monthly consumption of scenario number twelve. Source: author.*

After doing the fuel and electricity consumption analysis and simulating the demand and performance of each scenario, the gap between these two types of energy was found to be significant in comparison with the total percentage of energy consumption or demand. This finding can be derived through the observation and analysis of (table 9.6). Each month has a specific energy consumption chunk spent on space heating among the warmest and coldest months of the year. In the case of January, it simulated the highest month in terms of fuel and electricity needs, while August required minimal energy for interior space heating. It was also found that there is a significant gap between these two months. In the first month of the year, 67% of the total energy spent in the house was on space heating, while in August, this share decreased to record only 8% of the total energy spent. This is due to the high fluctuations in temperature throughout the months of the year in this climatic region. Given these points, it is crucial to acknowledge the importance of the building's external envelope and its impact on increasing the costs spent on energy heating for indoor spaces.

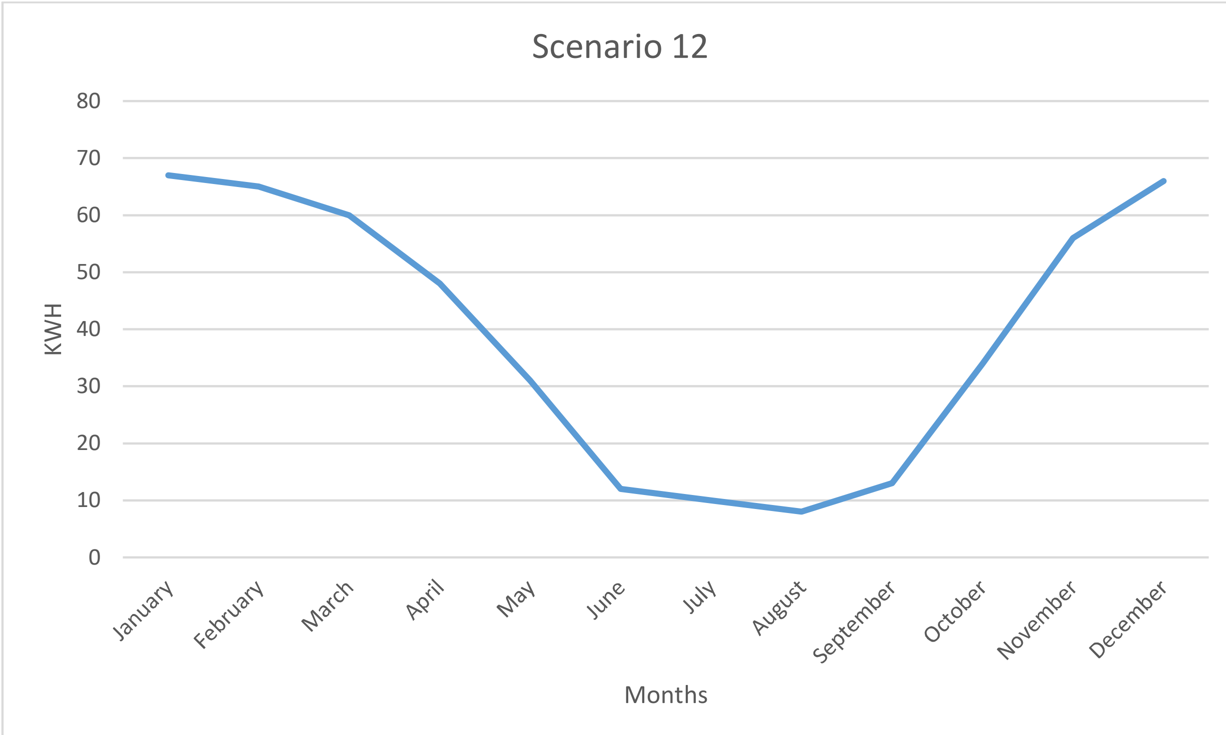



*Table 8.6 Total energy consumption per month of the twelve scenarios. Source: author.*

The studied scenarios showed that each one of these scenarios performed differently with significant differences in u-value, insulation, and thermal mass. According to the local and international references mentioned in this study, the maximum heat transfer coefficient that should be reached in a similar climatic zone is 0.55 w/m².k. Whereas, the majority of the scenarios studied in this research had their u-value below that benchmark. The lowest demand and consumption were found in scenario number twelve, which did not have the lowest u-value among the rest of the studied scenarios (table 9.7). The comparison showed their behavior in terms of energy consumption. The only scenario that has its u-value above the benchmark set by studies (u-value = 4.05 w/m². k) was scenario number ten that also presented the highest energy consumption and demand between all scenarios. The outcome can be related to the effect of the u-value and resistance of materials in such a cold climate. As mentioned before, Scenario number twelve simulated the lowest energy demand and consumption. This scenario consists of insulation from the outside while having thermal mass from the inner side, which stores heat and releases it later on. The insulation on the outer surface is directly influenced by the low temperature and difference between inside and outside. Besides, the internal temperature is affected by the wall's physical and temperature properties and by the internal conditions, especially when heating is on.

Nonetheless, results show that outer insulation cavity walls produce less overcooling compared to higher u-values or lower u-values (not insulated). The observation of scenario number 12, with its energy consumption and demand outcomes, provided valuable data on this specific building construction material. All these factors led to a cumulative value of 0.216 w/m². k with outer insulation.

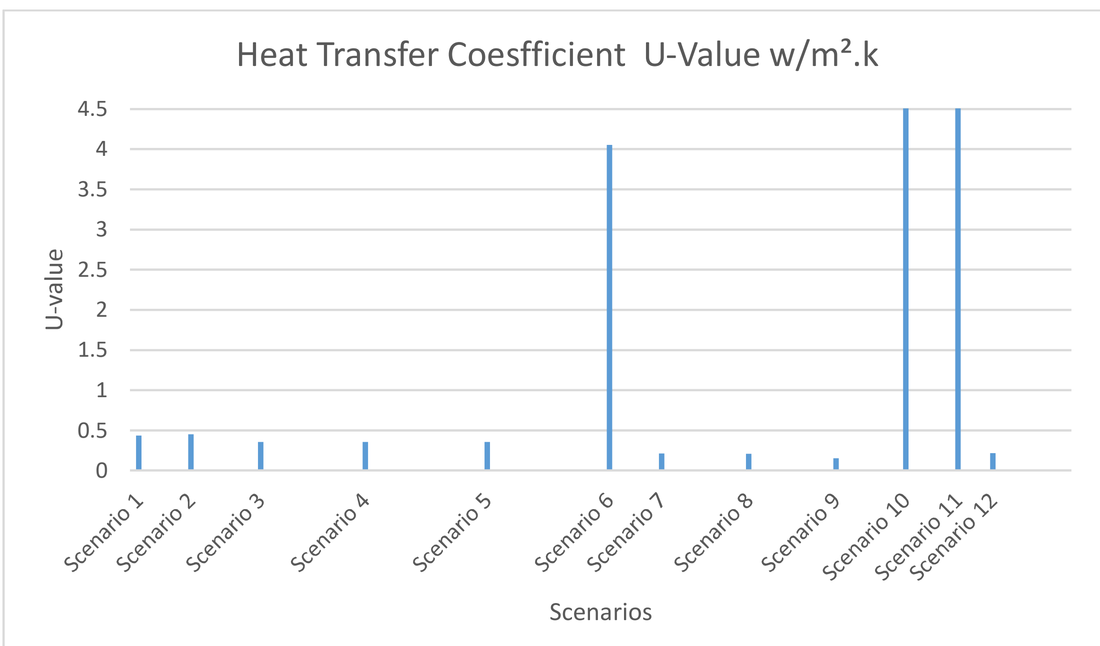



*Table 8.7 Scenarios u-value comparison. Source: author*

The purpose of this comparison is to prove that, in a cold climatic region such as the high mountains of Lebanon, having an insulating construction material from the outer side of the wall coupled with a thermal mass construction material from the inner side, can tremendously decrease energy consumption. Especially during the periods that require indoor space heating like winter and fall. The difference between the lowest energy-consuming scenario and the highest energy-consuming one was 43 KWH/m²/year. This number can be translated into a 34% energy reduction for space heating below the benchmark set by the local studies. In other terms, they were consuming 1526 L less during a whole year. The cost of 1 square meter of scenario number twelve is four times higher than the price of the same size of square meter of scenario number six. However, the payback period, which is equal to elven years, the households will return their money from decreasing energy consumption spent on space heating.

**8.4- Chapter Conclusion**

The energy consumption for space heating differs in each scenario. By examining the twelve scenarios, it is noted that scenario number twelve (timber wood and limestone) has the lowest energy consumption for space heating compared to all other scenarios. This is due to the insulation materials from the outside and the thermal mass from inside. As the insulation is found, the energy consumption decrease. This explains why scenario number twelve simulated the least heating demand in all seasons, especially in fall and winter seasons. Although, such external envelope resulted in low energy usage, minimizes the performance of heating methods used in cold climates. Therefore, insulated materials as timber wood form outside and thermal mass from inside as limestone used for buildings in such context are suitable for the climate to decrease energy demand and consumption.

Briefly, the use of timber wood and limestone construction materials for external buildings envelope in cold climate and especially Bcharre directly affects the heating demand. This can efficiently decrease up to 45 % of the annual heating demand.

## 9- Conclusion

The main research question was to find the best thermally performing wall component in terms of materiality and construction in the residential sector. This material should produce a minimal heat exchange in the high mountains of Lebanon area that has a cold and long winter, moderate and short summer. The built environment of this zone has primarily consisted of concrete product construction materials. All these factors lead to relying on excess energy consumption for space heating to achieve a suitable indoor environment.

To assess the problematic, this study reviewed Lebanon's geographic context and climate, in addition to heating and construction methods, as well as analyzing previous studies. The study also focused on simulation comparison experiments for a single-family house in the studied context, Bcharre, during a full year. In conclusion, results showed that the insulated wooden wall (from the outer side) coupled with stone thermal mass (from the inner side) minimized the energy consumption and demand. The insulated wooden wall (from the outer side) coupled with concrete thermal mass (from the inner side), then insulated wood from both sides, presented the proper results. In summary, the external insulated wood can reduce energy demand and consumption by 34% with a difference in degree days (DD). This result has not been mentioned in any previous study where, according to publication, the wooden construction material was the proper solution.

During the process of answering the main question, this study came with the following outcomes:

1- Improving the understanding of concrete and their derivatives, stone, and timber wood construction materials thermal performance of local construction in the High Mountains of Lebanon.

   The simulation showed energy demand for space heating behavior in terms of outdoor cooler than indoor, to be always warmer than outside, and to have a suitable indoor environment. This due to the combined effect of thermal mass storing heat from inside and insulation from outside to prevent heat from breaking through the wall. Similarly, to slow response of internal temperature to sudden excess cooling temperature fluctuation.

2- The study showed the expectations and limitations of thermal software when simulating construction materials in cold climates.

   Software simulation showed that Insight 360 does provide a fair overall thermal behavior representation for construction materials in cold climates. When looking at single cases alone, the lower resistance a construction material has, the more energy demand is needed. Similarly, the effect of having a combination of low U-value, insulating materials, and thermal mass reduces energy consumption. Nevertheless, when comparing different construction materials (different scenarios) at the same time, the study showed many exceptions within the different simulations. The ranking is constantly being shuffled with low and high U-values. This is happening due to the software's simplification of the complex thermal behavior of construction materials, especially when various construction materials are compared.

The purpose of studying twelve scenarios was to show that the scenario that presented the least energy demand for space heating is the model that has insulation from outside and a thermal mass from inside. This scenario helped in a 34 % reduction of energy demand and consumption with a difference in degree days (DD). The main components that helped are the capacity of both the thermal mass walls to store and release heat into the house and the insulation from outside to prevent releasing heat outside the house.

The different methods followed within the study showed three contributions to the knowledge:

1- A good understanding of the behavior of construction materials in a cold climate. This understanding helps to produce a solid knowledge of how construction materials will perform, as well as knowing the factors that influence space heating. This knowledge is not only limited to Lebanon; it could be applied in similar zones.

2- Assessment of the software simulation and examining the expectations and limitations.

3- Finally, scenarios proved that outdoor insulation and indoor thermal mass provide the least energy demand precisely for such climatic zone, where energy reduction studies focus on having only insulated construction materials for energy reduction.

The observed simulation of the different twelve scenarios is limited to the area of the studied model, which is a 110 sqm construction. Therefore, energy demand reflects the size of the house. Additionally, the study mainly focused on only energy spent on space heating. The purpose of this comparison is to prove that, in a cold climatic region such as the high mountains of Lebanon, having an insulating construction material from the outer side of the wall coupled with a thermal mass construction material from the inner side, can tremendously decrease energy consumption. Especially during the periods that require indoor space heating like winter and fall. The difference between the lowest energy-consuming scenario and the highest energy-consuming one was 43 KWH/m²/year. In other terms, they were consuming 1526 L less during a whole year. The cost of 1 square meter of scenario number twelve is four times higher than the price of the same size of square meter of scenario number six. However, the payback period, which is equal to elven years, the households will return their money from decreasing energy consumption spent on space heating. Further research should focus on the effect of openings and roof on minimizing energy consumption. The study could be combined with this one to reach a whole combination of external envelope impact on energy demand for space heating in the High Mountains of Lebanon.

This research can be implemented in practicality in the future by working with local authorities to adapt such materials to urban and rural rules and regulations.

The observed and simulated temperature differences between the different scenarios are relatively small; furthermore, dimensional similarities and occupation (as relationship between size of each house and internal gains) do not necessarily reflect real buildings. Additionally, the study mainly focused on full year temperature performance. No wind and humidity data were collected or included. Further research should focus on construction materials workmanship to compare the heat loss due to building problems and then compared to the cost.

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## A. Appendix A: Zoning in Bcharre Lebanon

According to the Lebanese building rules and regulations, each city or town has its zoning. Bcharre has 12 zonings. Each zone has a specific exploitation area (total and per floor), number of floors, and maximum height. Zone B, C, C1, D, and E3 are set for private and commercial buildings. The allowed floors range between 1 to 3 floors, according to table A.1. In this study, a single house of 110 sqm for one family has been studied.

التصميم التوجيهي والنظام التفصيلي العام

لقسم من منطقة بشري العقارية - قضاء بشري -

نظام البناء والفرز والضم والاستثمار

| علو البناء الاقصى من ادنى نقطة من الارض الطبيعية للعقار بمحاذاة احدى واجهاته | عدد الطوابق | عوامل الاستثمار | | التراجع الادنى | | القطع الموجودة الصالحة للبناء | | | الافراز | | | المنطقة الارتفاقية | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | عامل الاستثمار العام الاقصى | معدل الاستثمار السطحي الاقصى % | عن حدود الجانبي والخلفي م.ط | عن حدود التخطيط والطرق م.ط | العمق الادنى بعد التخطيط م.ط | الواجهة الدنيا بعد التخطيط م.ط | المساحة الدنيا بعد التخطيط م.م | العمق الادنى م.ط | الواجهة الدنيا م.ط | المساحة الدنيا م.م | | |
| 9.50 | 2 | 1 | 50 | 3 | وفقا للمراسيم الفرعية الأجراء مع حد ادنى ثلاثة امتار عن حدود الطرق او التخطيط | 13 | 13 | 250 | 18 | 18 | 600 | تراث معماري وتجارة | A1 |
| 10.50 | 3 | 0.9 | 30 | 3 | | 15 | 15 | 500 | 20 | 20 | 800 | سكن وتجارة | B |
| 9.50 | 2 | 0.60 | 30 | 3 | | 16 | 16 | 600 | 20 | 20 | 800 | سكن وتجارة | C |
| 9.50 | 2 | 0.60 | 30 | 3 | وفقا للمراسيم الفرعية الأجراء مع حد ادنى اربعة امتار عن حدود الطرق او التخطيط | 16 | 16 | 600 | 22 | 22 | 1000 | المنطقة السكنية الاولى | C1 |
| 9.50 | 2 | 0.50 | 25 | 3 | | 18 | 18 | 700 | 22 | 22 | 1000 | امتداد سكني مباشر | D |
| 7.50 | 2 | 0.40 | 20 | 4 | | 20 | 20 | 800 | 25 | 25 | 1500 | امتداد اول | E1 |
| 6.50 | 2 | 0.30 | 15 | 4.5 | | 20 | 20 | 1000 | 30 | 30 | 2000 | امتداد ثاني | E2-E2' |
| 6.50 | 1 | 0.10 | 10 | 6 | | 25 | 25 | 1200 | 50 | 50 | 5000 | سكن خفيف | E3 |
| 4.50 | 1 | 0.05 | 5 | 8 | وفقا للمراسيم الفرعية الأجراء مع حد ادنى ثمانية امتار عن حدود الطرق او التخطيط | 40 | 40 | 3000 | 70 | 70 | 10000 | زراعية - طبيعية | F-1 |
| 3.50 | 1 | 0.01 | 1 | 10 | | 70 | 70 | 10000 | 120 | 120 | 25000 | طبيعية - حرجية | F-2 |
| 3.50 | 1 | 0.025 | 2.5 | 8 | | 50 | 50 | 5000 | 70 | 70 | 10000 | طبيعية - حرجية | F-2' |
| 6.00 | 2 | 0.3 | 15 | 4.5 | وفقا للمراسيم الفرعية الأجراء مع حد ادنى خمسة امتار عن حدود الطرق او التخطيط | 20 | 20 | 800 | 25 | 25 | 3000 | سكن | D4a |

*Table A.1 Table showing the maximum allowed floors for each zone in Bcharre. Source: Bcharre's municipality*

## B. Appendix B: Scenarios Model

The following twelve models are designed and simulated, having similar plans, occupancy, area, height, and number of floors. The only difference is the external envelope construction materials that vary between each scenario. Each model of the twelve scenarios will undergo two variables to be simulated: the first case having between 15% to 30 % openings, and the second having no openings at all. Each scenario and variables undergo similar steps; therefore, one model will be explored as a sample of other models.

The scenarios are located in Bcharre, North Lebanon, where most of the buildings are low and mid-rise. The building's orientation is East-West towards the South overlooking the Kadisha Valley (fig. B.1). Accordingly, buildings have three types of construction materials, which are investigated in this study. Hence, similar building construction materials are modeled in Revit 2020 to remains and study the behavior of the used construction materials in this context.

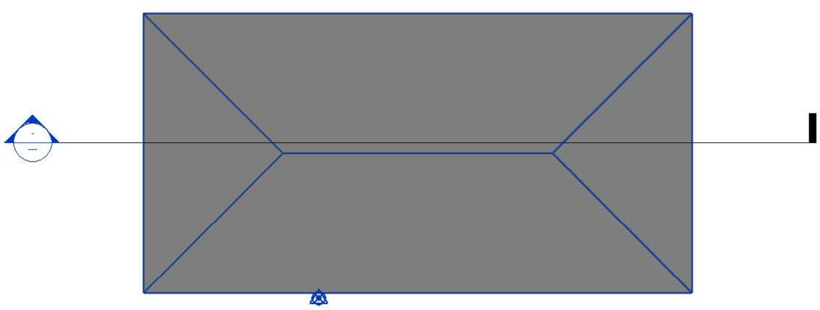

*Figure B.1 Mass plan of the models showing the orientation East-West towards South. Source: Revit 2020 on 31-05-2020*

Revit 2020 is used to design and model each scenario, since, it is an architectural tool that allows drawing plans, sections, elevations, 3D rendering, and other benefits. Starting by drawing each scenario, inserting external envelope materials will be taking into consideration the U-value and resistance of each material. After drawing the model, adding location, orientation, and selecting weather station for weather data, using Energy Plus (Energy Engine for Revit) to create energy model (fig. B.2) and inserting energy settings (fig. B.3). Then, optimizing the model to be uploaded on Insight 360, which is a plug-in for Revit, which will simulate and analyze data and setting for each scenario to estimate the energy consumption of the total model (fig. B.4).

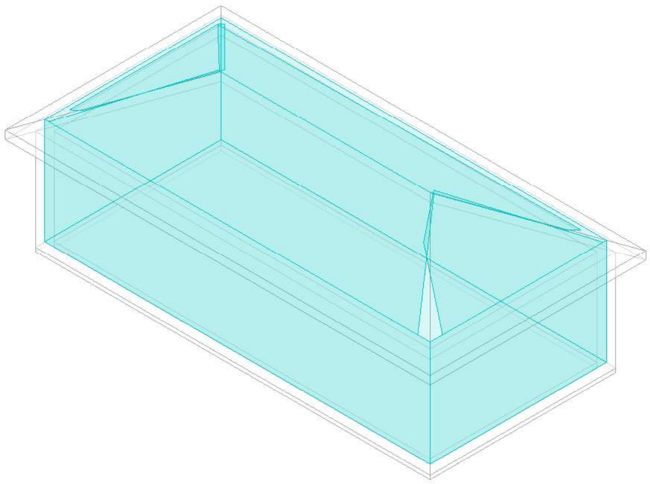

*Figure B.2 Energy model showing the analytical Space. Source: Revit 2020 on 31-05-2020*

Orientation (true North) is the first variable, followed by the wall to wall ratio (WWR) where they have an impact on the heat transfer between inside and outside. Two factors are studied in each scenario. The first one has no openings, which is not possible in the Lebanese building rules and regulations. The purpose of such simulation is to observe the impact of the window sizes on heat transfer. The second one has a window to wall ratio between 15 % and 30 % to benefit from

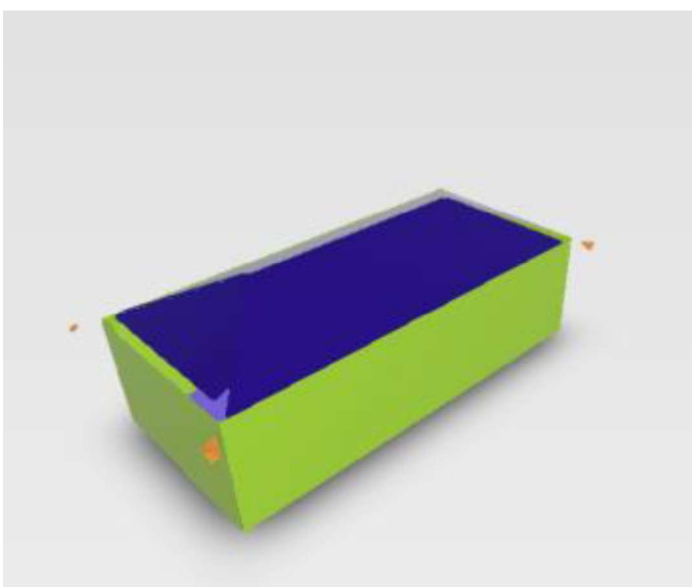

*Figure B.3 Building form analyzed through Insight 360. Source: https://insight360.autodesk.com/oneenergy/Model/201426. on 31-05-2020* daylight and ventilation. According to the Lebanese building rules and regulations, the minimum window to wall ratio is 10 % of the total room area. Therefore, by having this window to wall ratio, local building codes are applied to the model.

| Parameter | Value |
|---|---|
| **Energy Analytical Model** | |
| Mode | Use Conceptual Masses and Building Elements |
| Ground Plane | 00-GROUND FLOOR CL |
| Project Phase | New Construction |
| Analytical Space Resolution | 457.2 |
| Analytical Surface Resolution | 304.8 |
| Perimeter Zone Depth | 4572.0 |
| Perimeter Zone Division | ☑ |
| Average Vertical Void Height Threshold | 1828.8 |
| Horizontal Void/Chase Area Threshold | 0.093 $m^2$ |

*Figure B.4 Energy settings of the models studied. Source Revit 2020 on 31-05-2020*

While studying the thermal performance of each external envelope on energy spent on space heating, various information and inputs should be inserted to ensure the proper outcome of energy demand per m². First, we start by adding the window to wall ratio of each model façade, type of openings, roof construction, daylighting and occupancy controls, and operation schedule. These inputs are inserted into all scenarios to ensure a parallel simulation and analysis.

We are starting by the window to wall ratio, as mentioned in the previous paragraph (fig. B.5; 6; 7;8;9;10;11;12;13). Having opening as triple glazed low-e (fig. B.8; 9), and

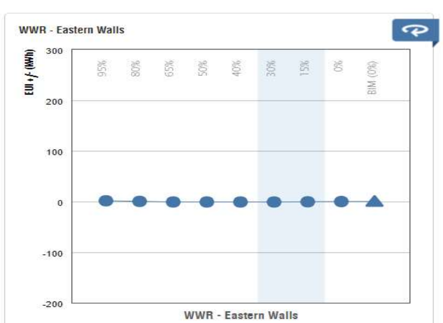


*Figure B.5 Inputs of window to wall ratio for the Southern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

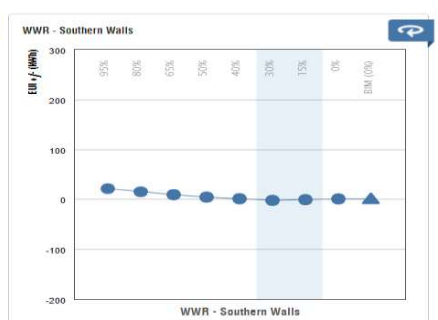


*Figure B.6 Inputs of window to wall ratio for the Eastern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

24/7 of building operation. All of these variables will result in having a simulation of the twelve scenarios to be analyzed and assessed.

The typical house model drawn on Revit implemented for all scenarios. The model is designed according to the typology, area, orientation, and appearance of the buildings found in the observation. The thermal properties of the construction materials used in the study are taken from Revit 2020 (fig. 82).


*Figure B.8 Inputs of window to wall ratio for the Western walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

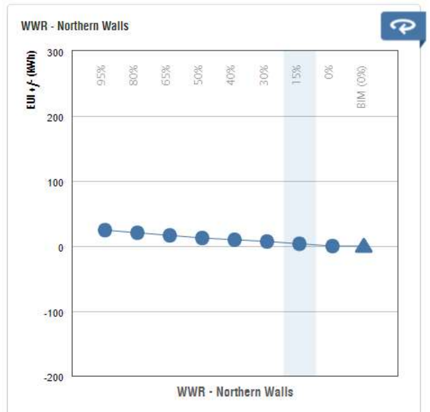


*Figure B.7 Inputs of window to wall ratio for the Northern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

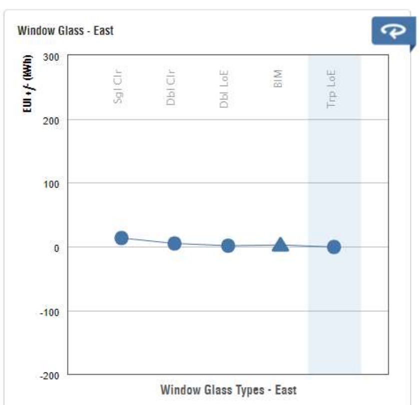


*Figure B.10 Inputs of window glass for the Eastern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

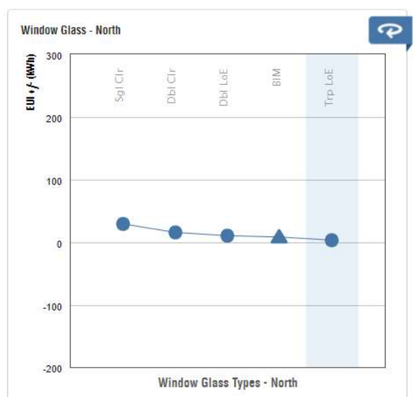


*Figure B.9 Inputs of window glass for the Northern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

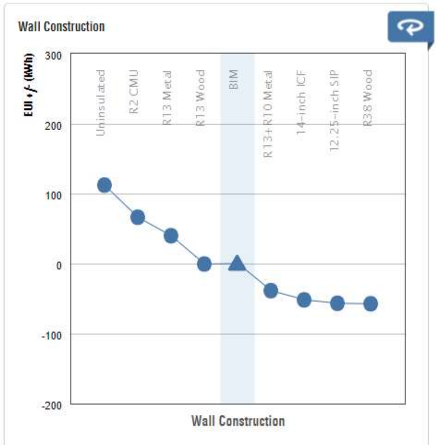


*Figure B.12 Inputs of window glass for the Southern walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-*

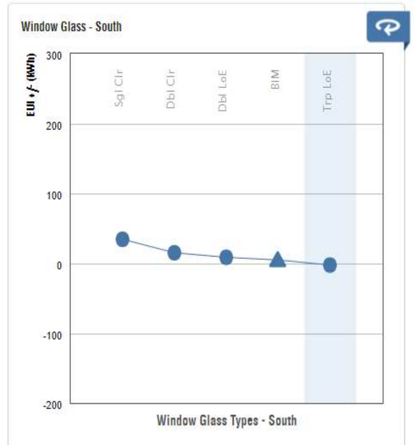


*Figure B.11 Inputs of window glass for the Western walls. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

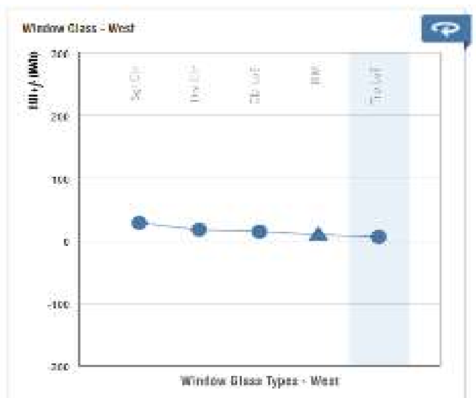


*Figure B.13 Inputs of wall construction. Souce: https://insight360.autodesk.com/oneenergy/Model/201426 on: 31-05-2020*

The location was inserted in Bcharre, North Lebanon, and the nearest weather station was chosen (fig. B.14). The mentioned data will be similar to all scenarios to be analyzed.

After analyzing each scenario on Insight 360 and inserting all data and parameters mentioned above, all results are extracted through Insight 360 or GBS website. The two software will give a detailed energy analysis on each scenario to analyze energy demand for space heating.

Insight indicates several modifications and factors that have a direct impact on energy consumption, while GBS gives detailed charts for each scenario to show the purpose of energy consumed by percentages and numbers.

After finishing simulating each scenario, data and results could be analyzed through tables and charts. Moreover, all scenarios can be designed and simulated similarly.

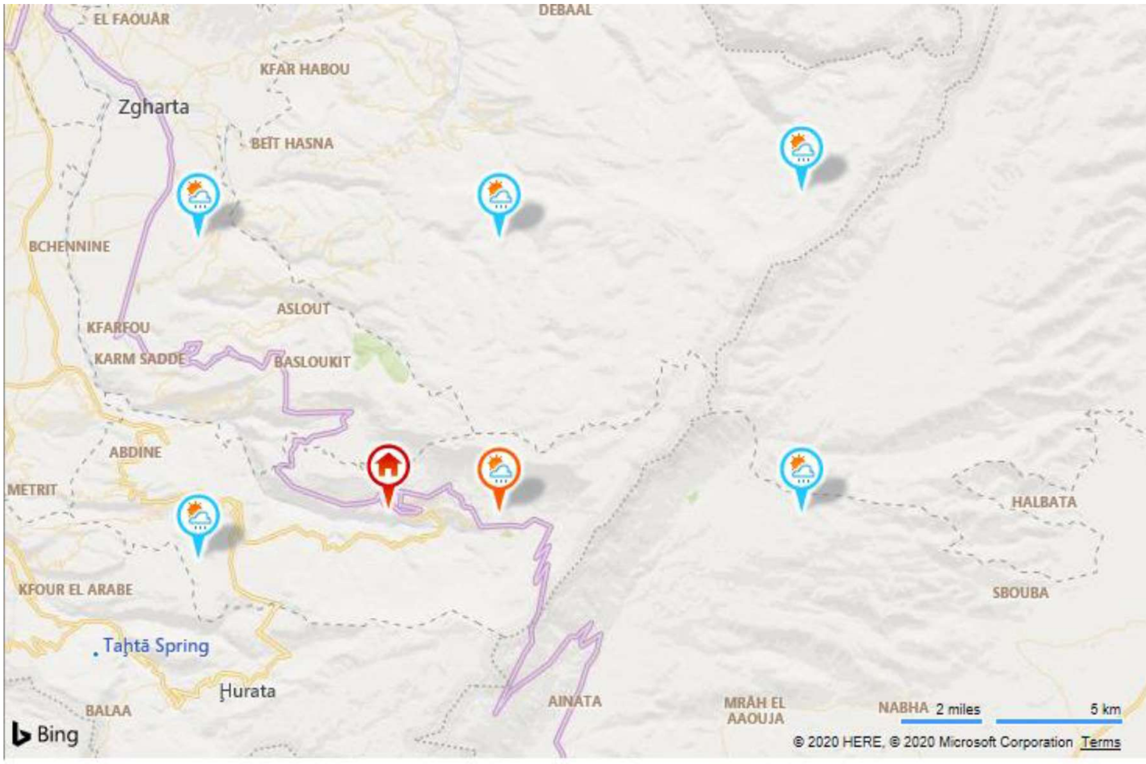


*Figure B.14 Location of the studied model and of the weather station chosen. Source: Revit 2020 on 31-05-2020*

## C. Appendix C: Scenario Number 1 (Reinforced Concrete and CMU)

The first scenario consists of this combination of wall components, 20 cm concrete, 5 cm void, 10 cm concrete masonry unit, and a 2cm layer of plaster (from outside to inside) (fig. C.1). The wall heat transfer coefficient is 0.4356 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

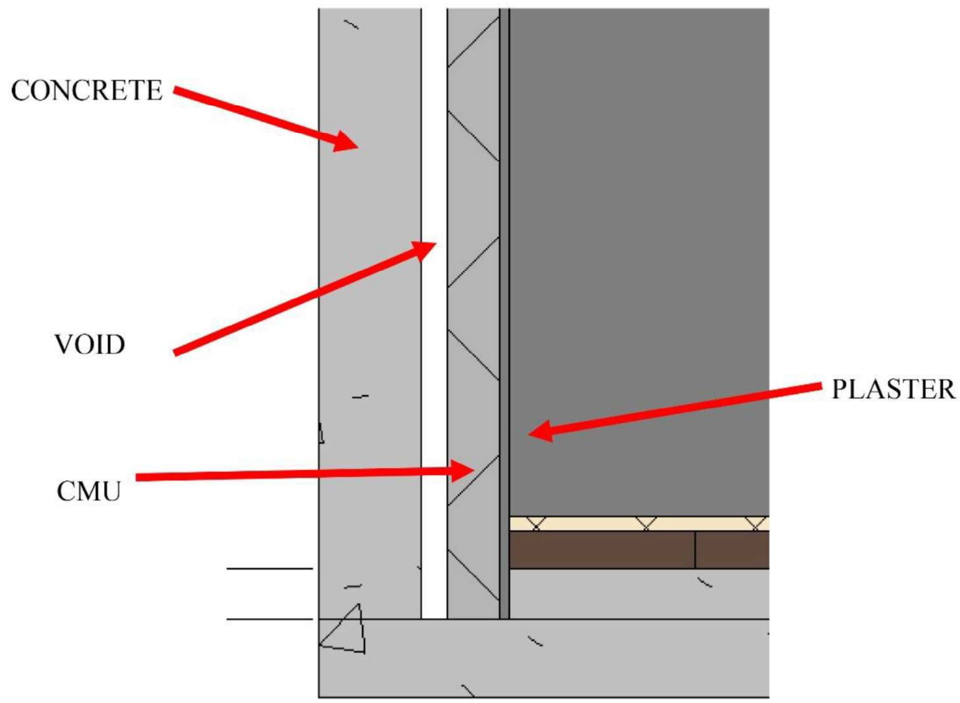


*Figure C.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing scenario number 1 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was put: building orientation East-West towards the south; Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is at15%. Window to wall ratio of the western and eastern walls is at 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. Under those circumstances, the obtained result is 227 kwh/m²/yr (fig. C.2).

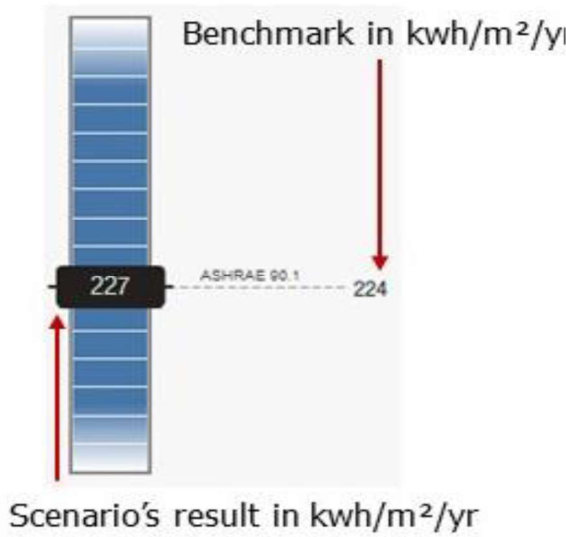


Figure C.3 Benchmark comparison of scenario 1. Source: https://insight360.autodesk.com/oneenergy/Model/201426. Accessed on: 13-03-2020

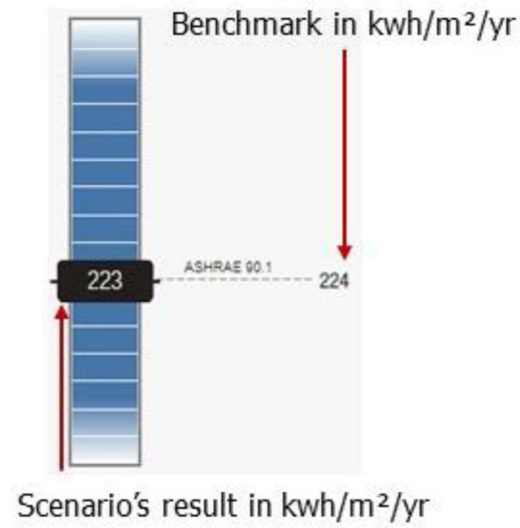


Figure C.2 Benchmark comparison of scenario 1. Source: https://insight360.autodesk.com/oneenergy/Model/201426. Accessed on: 13-03-2020

The second analysis of scenario number 1, combined with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations to was converted to 0 while all other characteristics were kept the same. The second simulation, which has no openings at all, showed minor lower consumption. The obtained result is 223 kwh/m²/yr (fig. C.3). Besides, having a house with no opening will have a critical impact on ventilation and will cause daylight problems. At the same time, the results differ only by four kwh/m²/yr, showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 223 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of outcomes, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140. This situation is resulting from the insufficient thermal properties combined with a low u-value of un-insulated walls. The consumption is higher than the minimum that should be reached by three kwh/m²/yr.

### D. Appendix D: Scenario Number 2 (CMU Cavity Wall)

The second scenario consists of this set of wall components, 2cm of plaster, 10 cm of concrete masonry unit, 5cm void, 10cm concrete masonry unit, 10 cm, and a 2cm layer of plaster (from outside to inside) (fig. D.1). The wall heat transfer coefficient is 1.57 w/m²k > 0.55 w/m²k, which is not acceptable in this climatic region according to the local studies.

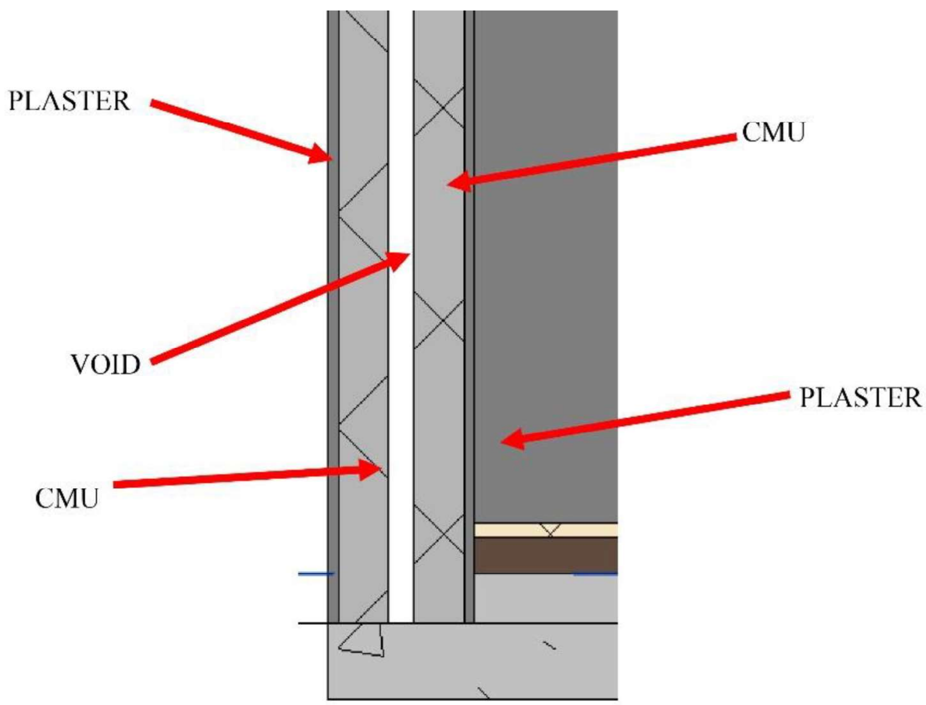


*Figure D.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing scenario number 2 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. the window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls was set at 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. The obtained result was 226 kwh/m²/yr (fig. D.2).

The second analysis of scenario number 2, coupled with a change in the percentage of the

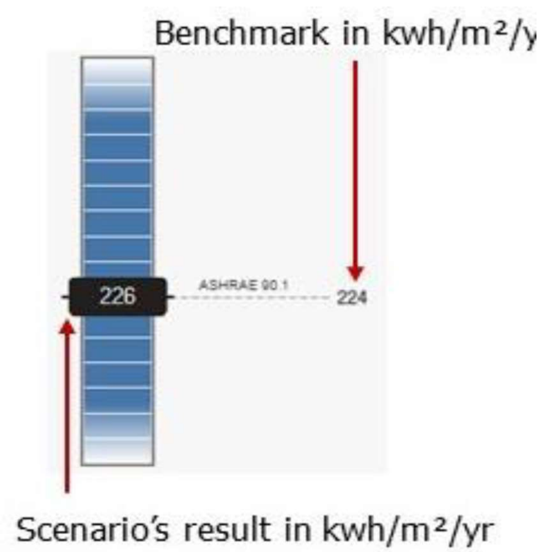


Figure D.2 Benchmark comparison of scenario 2. Source: https://insight360.autodesk.com/oneenergy/Model/201426. Accessed on: 13-03-2020

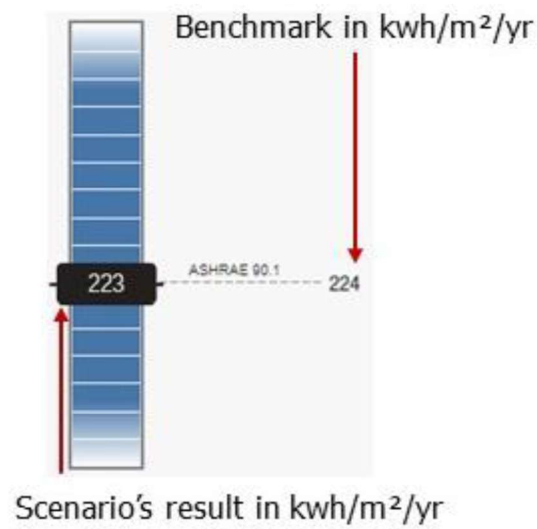


Figure D.3 Benchmark comparison of scenario 2. Source: https://insight360.autodesk.com/oneenergy/Model/201426. Accessed on: 13-03-2020

window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 223 kwh/m²/yr (fig. D.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is three kwh/m²/yr, showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 223 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of un-insulated walls. The consumption is higher than the minimum that should reach by two kwh/m²/yr.

## E. Appendix E: Scenario Number 3 (Insulated CMU Cavity Wall)

Scenario number three consists of this set of wall components, 2cm of plaster, 10 cm concrete masonry unit, 5cm void, insulation, vapor barrier, 10 cm of concrete masonry unit 10, and a 2cm layer of plaster (from outside to inside) (fig. E.1). The wall heat transfer coefficient is 0.3558 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

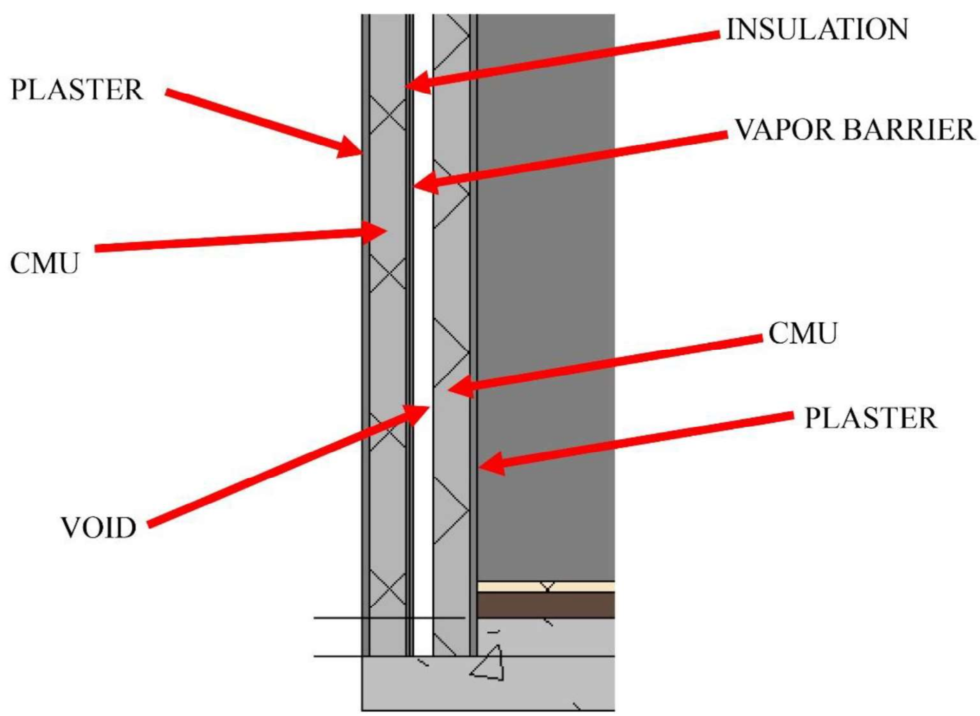


*Figure E.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing scenario number 3 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. The Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is at 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. The obtained result was 225 kwh/m²/yr (fig. E.2).

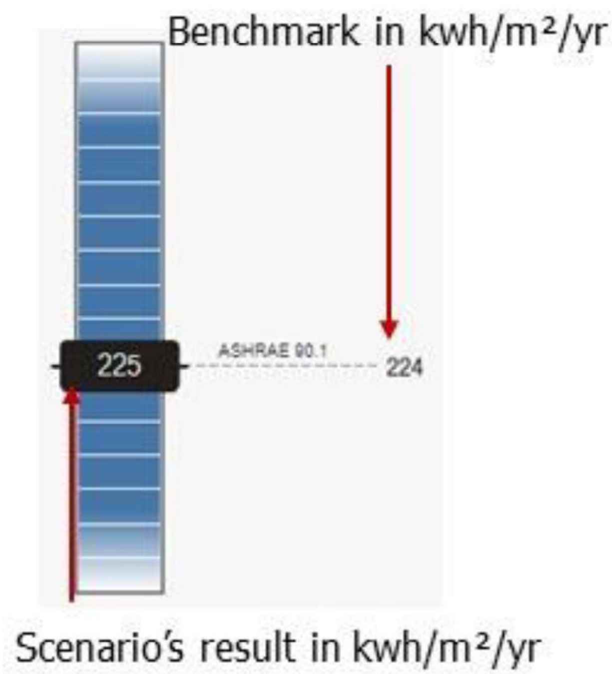


Figure E.2 Benchmark comparison of scenario 3. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

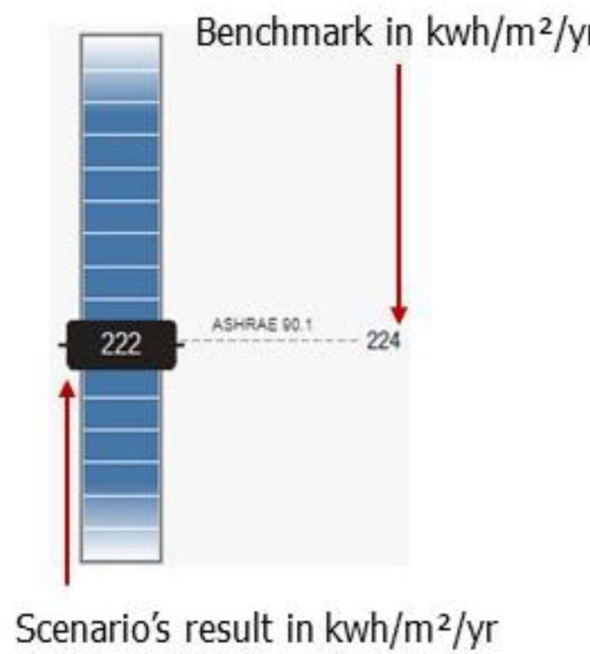


Figure E.3 Benchmark comparison of scenario 3. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

The second analysis of scenario number 3, coupled with a change in the percentage of the window to wall ratio showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 222 kwh/m²/yr (fig. E.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is three kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 222 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of insulated walls. The consumption is higher than the minimum that should be reached by one kwh/m²/yr.

## F. Appendix F: Scenario Number 4 (CMU Cavity Wall with Wet Stone Cladding)

The fourth scenario consists of this set of wall components, 2cm of plaster, 5cm cladding (wet cladding with mortar), 10 cm of concrete masonry unit, insulation; vapor barrier, 5cm void, 10 cm of concrete masonry unit, and a 2cm layer of plaster (from outside to inside) (fig.F.1). The wall heat transfer coefficient is 0.3558 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

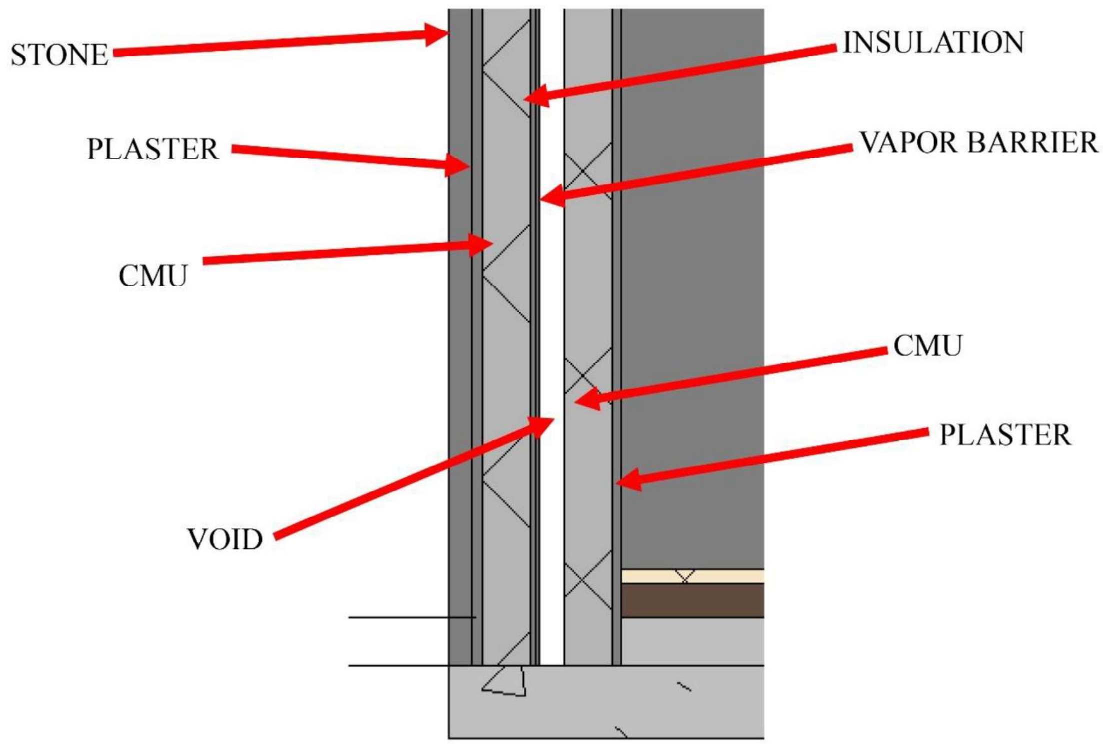


*Figure F.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 4 through insight 360, changing inputs to reach a unified analysis characteristic. The information was put as follows: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low e to have the lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. The result was 222 kwh/m²/yr (fig. F.2).

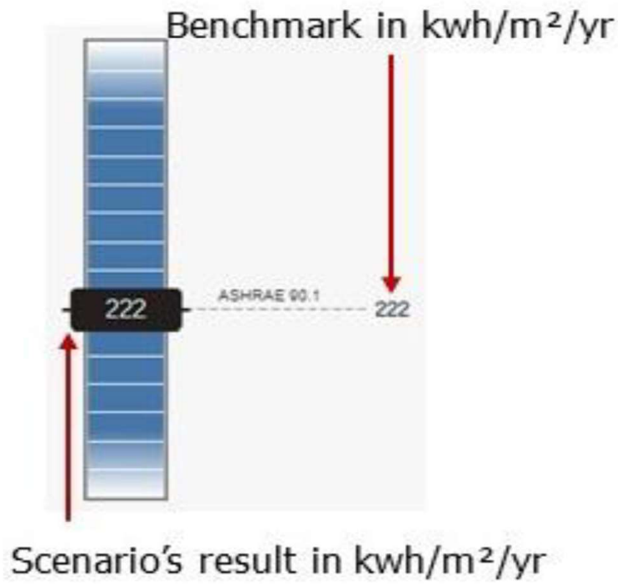


Figure F.2 Benchmark comparison of scenario 4.
Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

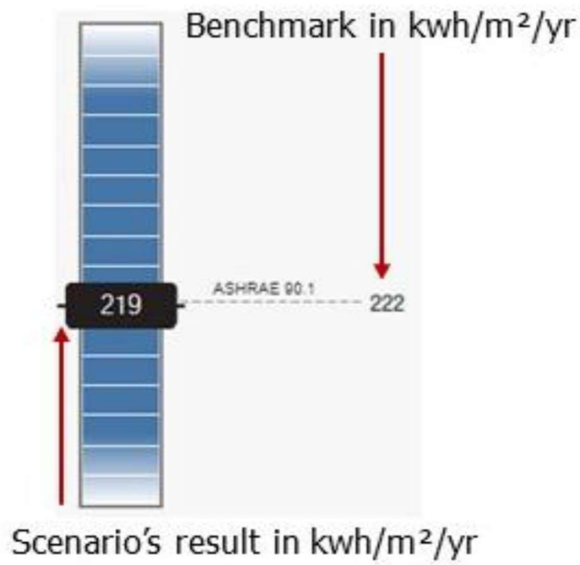


Figure F.3 Benchmark comparison of scenario 4.
Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

The second analysis of scenario number 4, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 219 kwh/m²/yr (fig. F.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only two kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 219 kwh/m²/yr under the benchmark. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the sufficient thermal properties combined with a low u-value of insulated walls. The consumption is equal to the benchmark.

## G. Appendix G: Scenario Number 5 (CMU Cavity Wall with Mechanical Stone Cladding)

The fifth scenario consists of this set of wall components, 5cm of stone cladding (mechanical cladding), 2cm of plaster, 10 cm of concrete masonry unit, insulation, vapor barrier, 5cm void, 10 cm of concrete masonry unit, and a 2cm layer of plaster (from outside to inside) (fig. G.1). The wall heat transfer coefficient is 0.3558 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

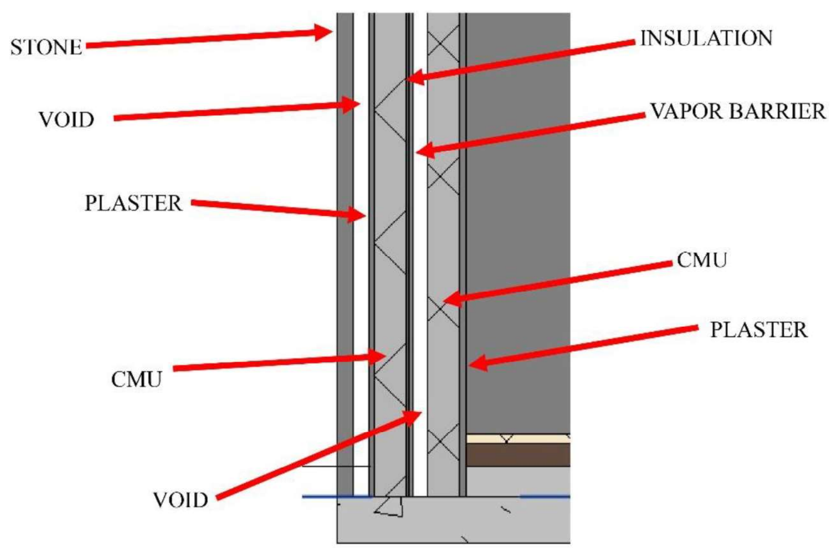


*Figure G.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 5 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. The obtained result was 222 kwh/m²/yr (fig. G.2).

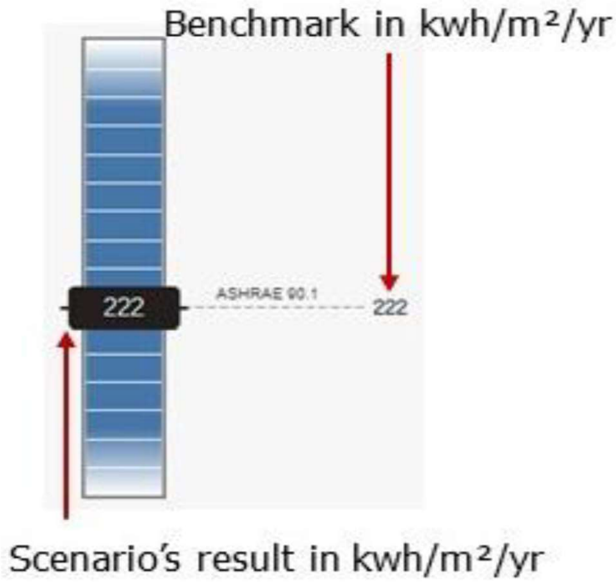


Figure G.3 Benchmark comparison of scenario 5. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

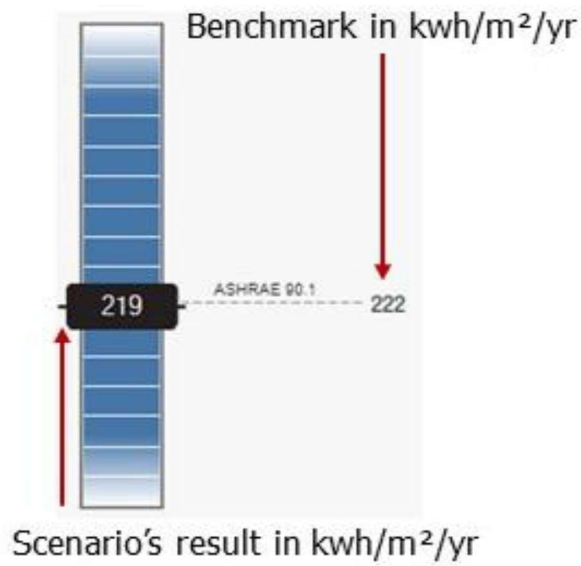


Figure G.2 Benchmark comparison of scenario 5. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

The second analysis of scenario number 5, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 219 kwh/m²/yr (fig. G.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only three kwh/m²/yr showing a minor lower consumption between the two simulations.

Scenarios full year simulation, but still, the energy does fluctuate a low of 219 kwh/m²/yr. More so, with no openings available to ensure no infiltration rates, the energy consumption shows relatively lower peaks (when compared to the first simulation run). Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the sufficient thermal properties combined with a low u-value of insulated walls. The consumption is equal to the benchmark.

## H. Appendix H: Scenario Number 6 (Reinforced Concrete)

The sixth scenario consists of this set of wall components, 2cm of plaster, 20 cm reinforced concrete 20, and a 2cm layer of plaster (from outside to inside) (fig. H.1). The wall heat transfer coefficient is 4.0525 w/m²k > 0.55 w/m²k, which is not acceptable in this climatic region according to the local studies.

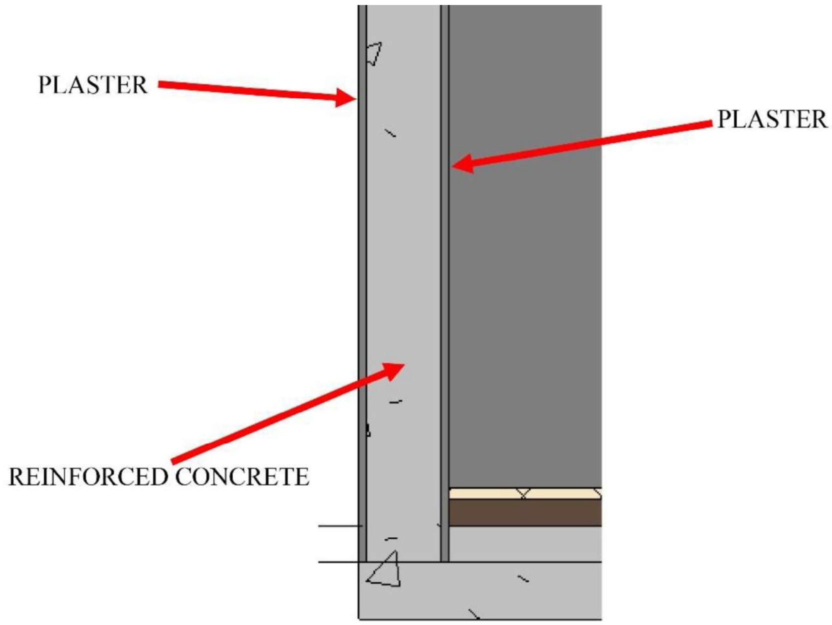


*Figure H.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 6 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the

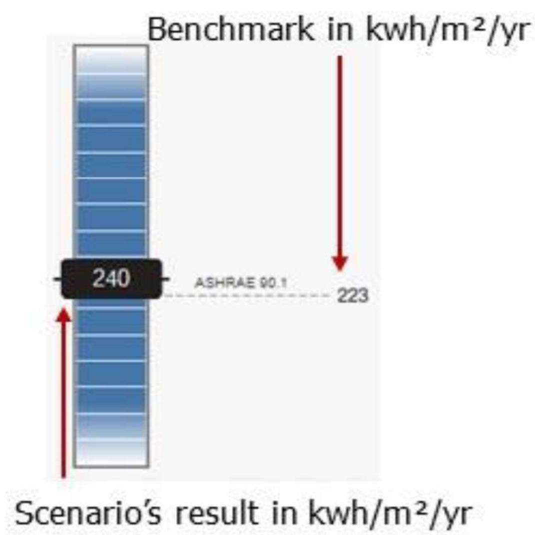


Figure H.2 Benchmark comparison of scenario 6. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

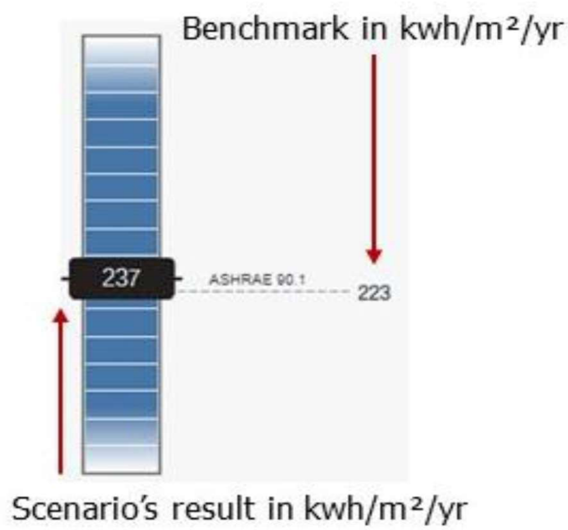


Figure H.3 Benchmark comparison of scenario 6. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020 lowest heat transfer through windows and glass. The roof is made of reinforced concrete 25 cm and covered with roof tiles. The obtained result was 240 kwh/m²/yr (fig. H.2).

The second analysis of scenario number 6, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The result is 237 kwh/m²/yr (fig. H.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only three kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 237 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Scenarios. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of un-insulated walls. The consumption is higher than the minimum that should be reached by 17 kwh/m²/yr.

## I. Appendix I: Scenario Number 7 (Timber Wood and CMU)

The seventh scenario consists of this set of wall components, 5cm of timber wood, insulation; vapor barrier; 5cm void, 10 cm of concrete masonry unit, and a 2cm layer of plaster (from outside to inside) (fig. I.1). The wall heat transfer coefficient is 0.2125 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

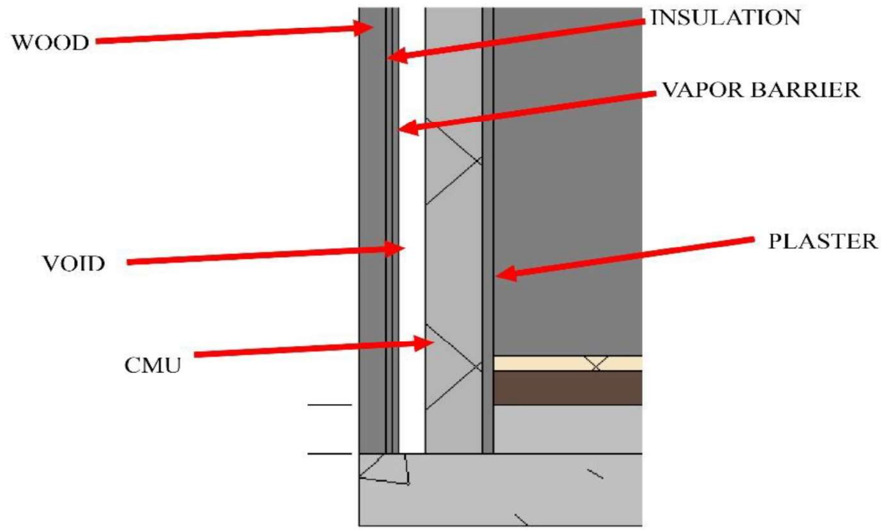


*Figure I.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 7 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the

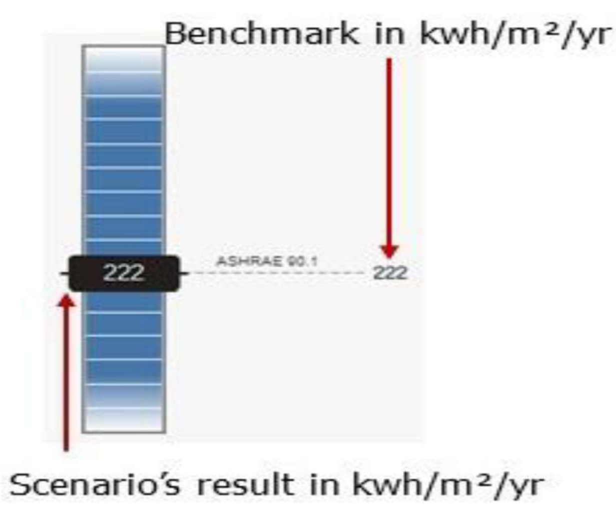


Figure I.3 Benchmark comparison of scenario 7. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020

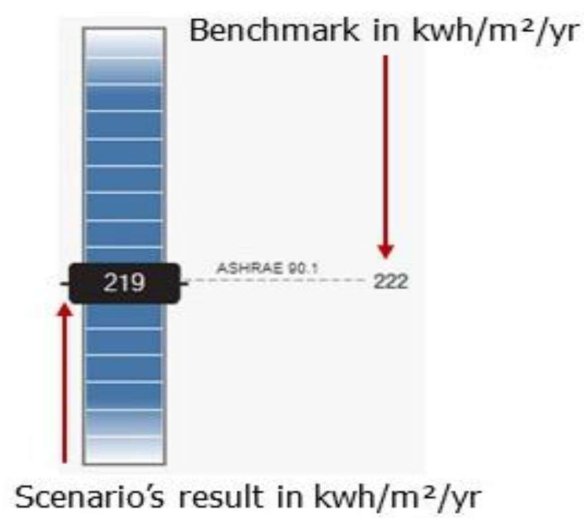


Figure I.2 Benchmark comparison of scenario 7. Source: https://insight360.autodesk.com/oneenergy Model/201426. Accessed on: 13-03-2020 lowest heat transfer through windows and glass. The roof is made of wood 15 cm and covered with roof tiles. The obtained result was 222 kwh/m²/yr. (fig. I.2).

The second analysis of scenario number 7, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 219 kwh/m²/yr. (fig. I.3). Besides, having a house with no opening will cause ventilation and daylight problems, while the difference is only three kwh/m²/yr. showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 219 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of insulated walls. The consumption is equal to the benchmark.

## J. Appendix J: Scenario Number 8 (Timber Wood and Reinforced Concrete)

The eighth scenario consists of this set of wall components, 5 cm of timber wood, insulation, vapor barrier, 5cm void, 20 cm reinforced concrete, and a 2cm layer of plaster (from outside to inside) (fig. J.1). The wall heat transfer coefficient is 0.2075 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies.

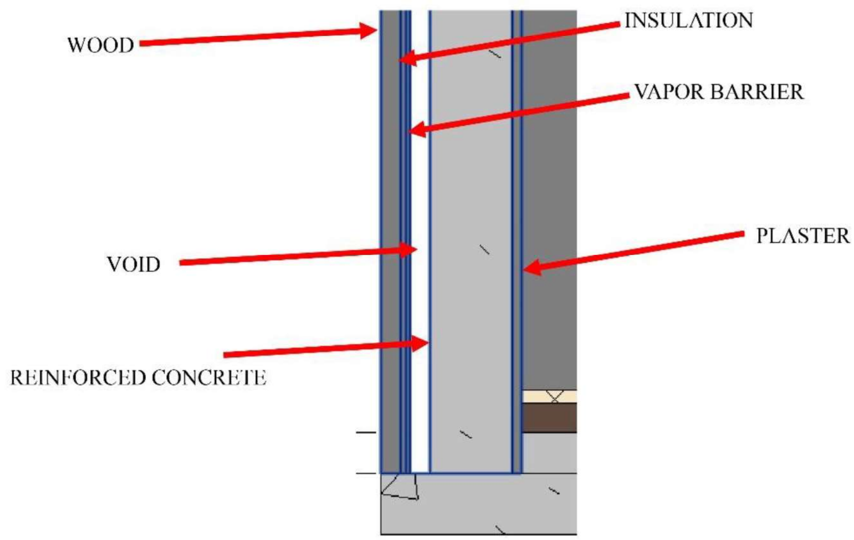


*Figure J.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 8 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of wood 15 cm and

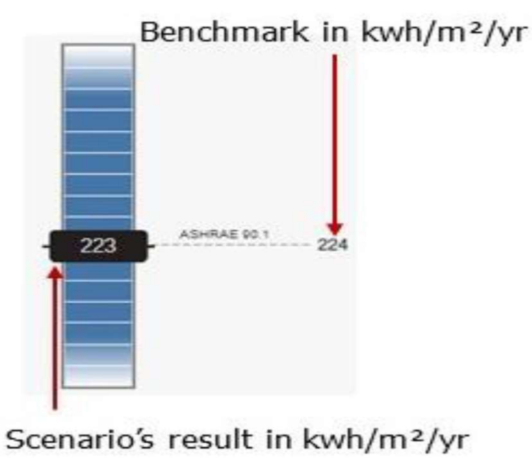


Figure J.2 Benchmark comparison of scenario 8. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

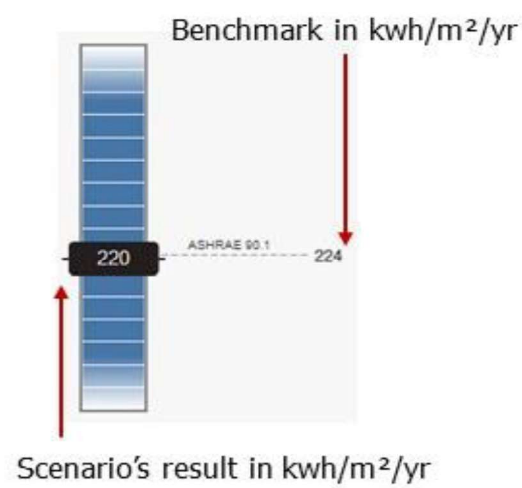


Figure J.3 Benchmark comparison of scenario 8. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020 covered with roof tiles. The obtained result was 223 kwh/m²/yr (fig. J.2).

The second analysis of scenario number 8, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 220 kwh/m²/yr (fig. J.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only three kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 220 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the sufficient thermal properties combined with a low u-value of insulated walls. The consumption is lower than the minimum that should be reached by one kwh/m²/yr.

## K. Appendix K: Scenario Number 9 (Timber Wood Cavity Wall)

The ninth scenario consists of this set of wall components, 5cm of timber wood, insulation, vapor barrier, 5cm void, and another 5 cm of timber wood (from outside to inside) (fig. K.1). The wall heat transfer coefficient is 0.1515 $w/m^2k < 0.55\ w/m^2k$, which is acceptable in this climatic region according to the local studies.

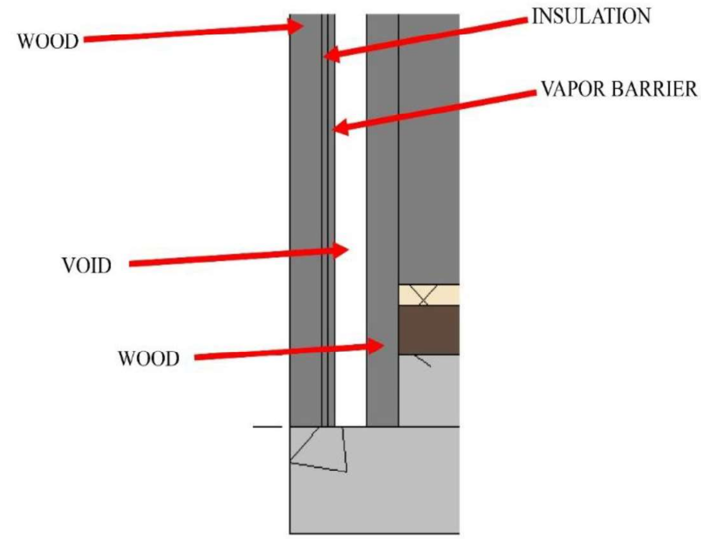


*Figure K.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 9 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio

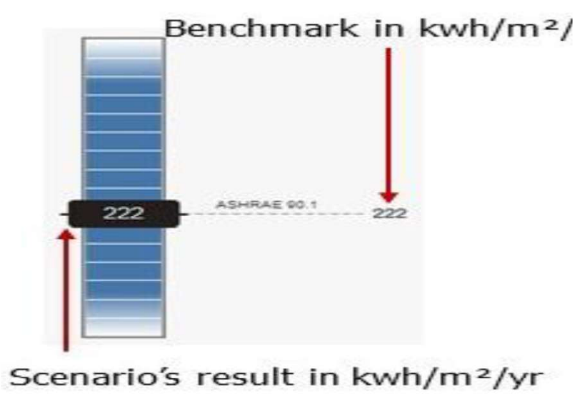


Figure K.3 Benchmark comparison of scenario 9. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-

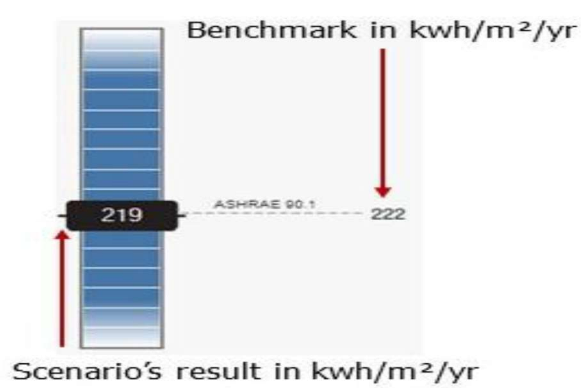


Figure K.2 Benchmark comparison of scenario 9. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020 of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of wood 15 cm and covered with roof tiles. The obtained result was 222 kwh/m²/yr (fig. K.2).

The second analysis of scenario number 9, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 219 kwh/m²/yr (fig. K.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only three kwh/m²/yr showing a minor lower consumption between the two simulations.
The Scenarios full year simulation shows that energy fluctuates with 219 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the sufficient thermal properties combined with a low u-value of insulated walls. The consumption is equal to the benchmark.

## L. Appendix L: Scenario Number 10 (Single CMU Wall)

The tenth scenario consists of this set of wall components, 2cm of plaster, 20 cm of concrete masonry unit, and a 2cm layer (from outside to inside) (fig. L.1). The wall heat transfer coefficient is 2.76 w/m²k > 0.55 w/m²k, which is not acceptable in this climatic region according to the local studies.

After analyzing the scenario number 10 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of concrete 250 cm and covered with roof tiles. The obtained result was 222 kwh/m²/yr (fig. L.1).

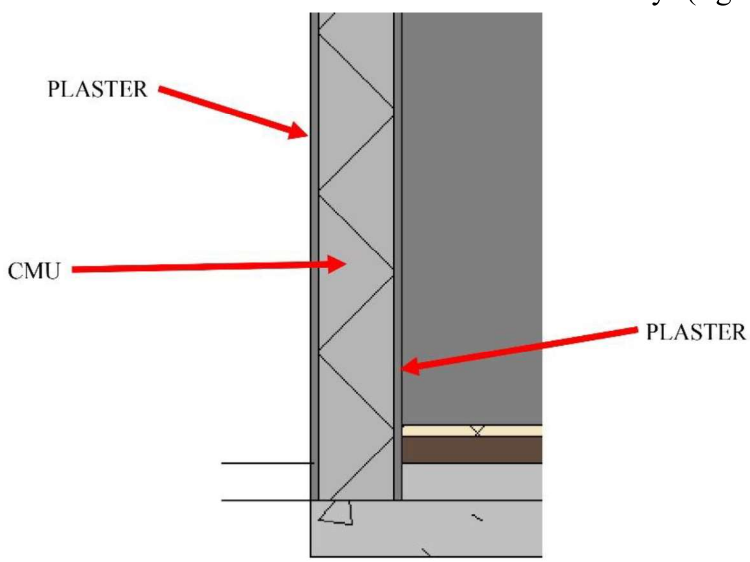


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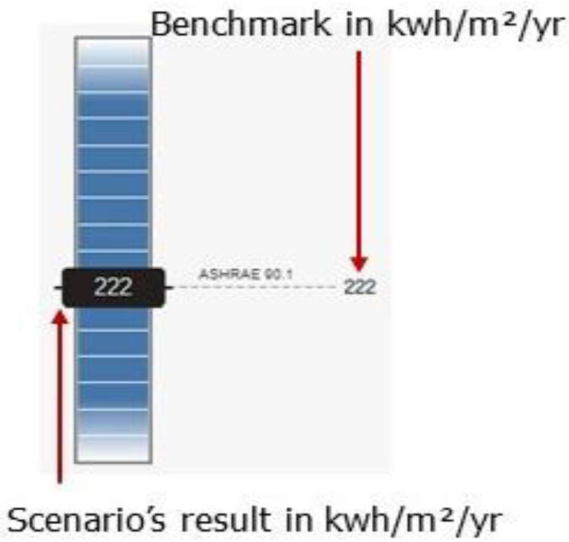
*Figure L.1 Wall section showing consatruction materials. Source: Revit Autodesk 2020 by Author*

The second analysis of scenario number 10, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 219 kwh/m²/yr (fig. L.2). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only four kwh/m²/yr showing a minor lower consumption between the two simulations.



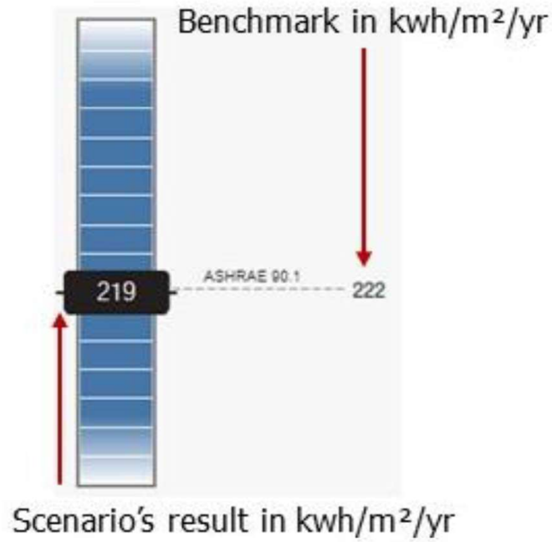




Figure L.2 Benchmark comparison of scenario 10. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

Figure L.3 Benchmark comparison of scenario 10. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

The Scenarios full year simulation

shows that energy fluctuates with 219 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of insulated walls. The consumption is equal to the benchmark.

## M. Appendix M: Scenario Number 11 (Limestone)

Scenario number 11 consists of this combination of two wall components, 35 cm limestones, and a 2cm layer of plaster (from outside to inside) (fig. M.1). The wall heat transfer coefficient is 1.26 w/m²k > 0.55 w/m²k, which is not acceptable in this climatic region according to the local studies.

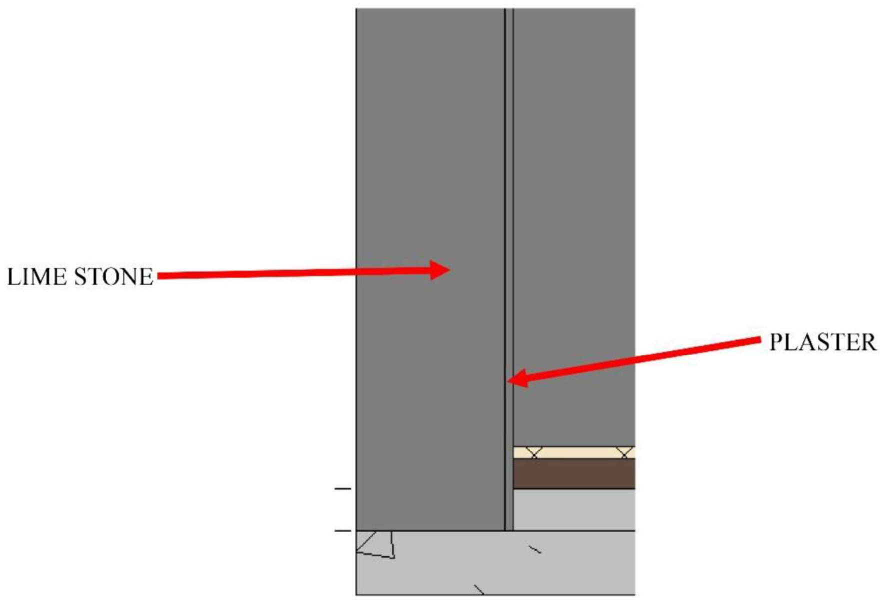



*Figure M.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author*

After analyzing the scenario number 11 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the lowest heat transfer through windows and glass. The roof is made of concrete 250 cm and covered with roof tiles. The obtained result was 235 kwh/m²/yr (fig. M.1).

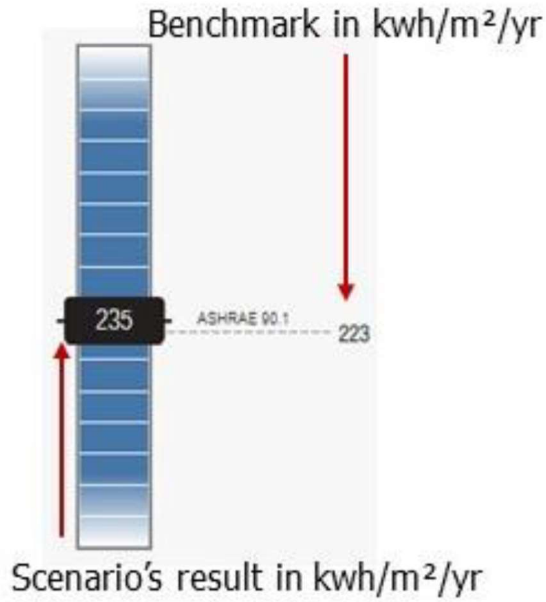



Figure M.2 Benchmark comparison of scenario 11. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

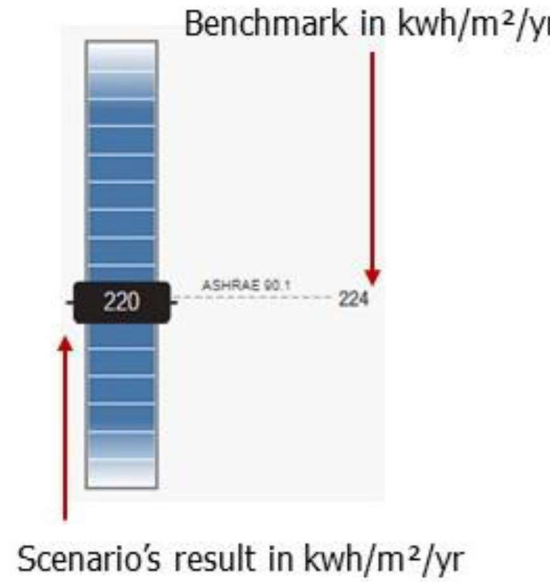



Figure M.3 Benchmark comparison of scenario 11. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

The second analysis of scenario number 11,

coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 231 kwh/m²/yr (fig. M.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only four kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 231 kwh/m²/yr under the benchmark. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls inside the benchmark of ASHRAE 140, resulting from the sufficient thermal properties combined with a low u-value of insulated walls. The consumption is higher than the benchmark by 12 kwh/m²/yr.

## N. Appendix N: Scenario Number 12 (Timber Wood and Limestone)

Scenario number 12 consists of this set of wall components, 5 cm of timber wood, insulation, vapor barrier, 5cm void 5, 35 cm of limestone, and a 2cm layer of plaster (from outside to inside) (fig. N.1). The wall heat transfer coefficient is 0.216 w/m²k < 0.55 w/m²k, which is acceptable in this climatic region according to the local studies. After analyzing the scenario number 12 through insight 360, changes of inputs were made to reach a unified analysis characteristic. The following information was adopted: building orientation East-West towards the south. Window to wall ratio of the southern walls is at 20 %. Window to wall ratio of the northern walls is 15%. Window to wall ratio of the western and eastern walls is 20%. All window glass is triple low-e to have the

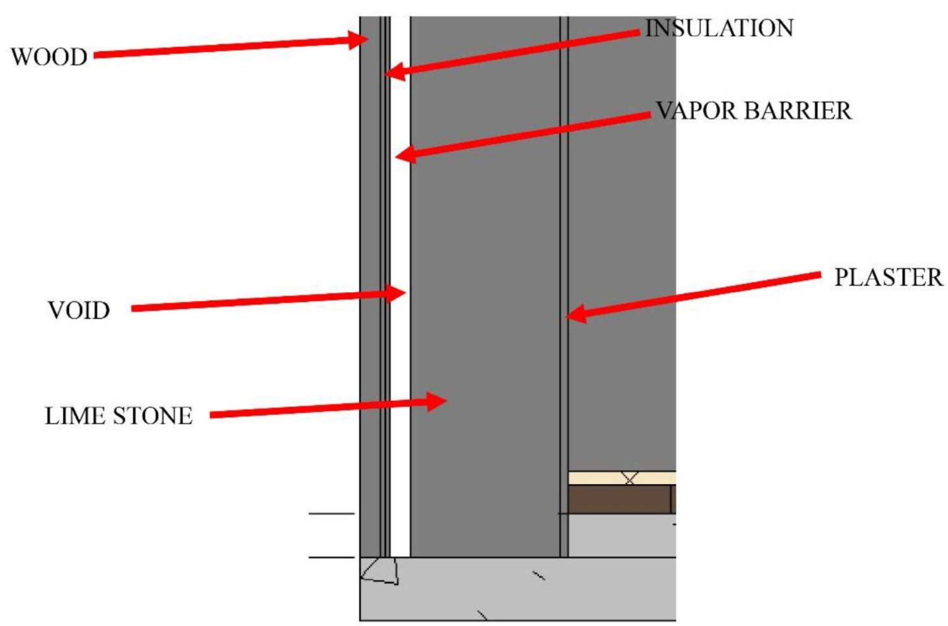



*Figure N.1 Wall section showing construction materials. Source: Revit Autodesk 2020 by Author* lowest heat transfer through windows and glass. The roof is made of wood 15 cm and covered with roof tiles. The obtained result was 219 kwh/m²/yr (fig. N.2).

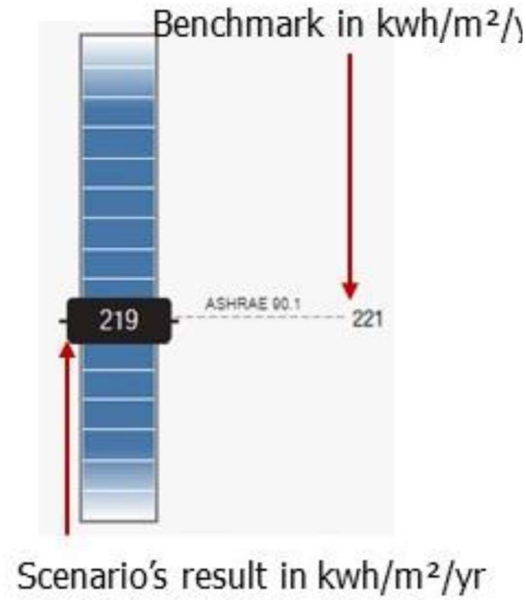



Figure N.2 Benchmark comparison of scenario 12. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

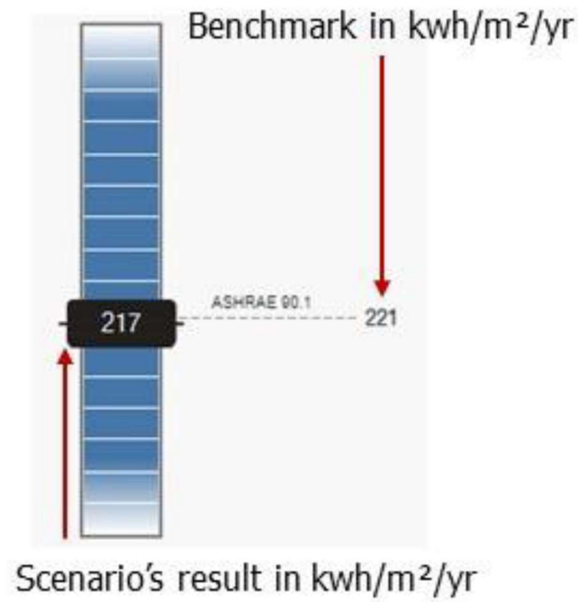



Figure N.3 Benchmark comparison of scenario 12. Source: hhttps://insight360.autodesk.com/ oneenergyModel/201453. Accessed on: 13-03-2020

The second analysis of scenario number 12, coupled with a change in the percentage of the window to wall ratio, showed a different outcome. The window to wall ratio in all orientations was changed to 0 while keeping other characteristics. The second simulation that suggests having no openings at all showed minor lower consumption. The obtained result is 217 kwh/m²/yr (fig. N.3). Also, having a house with no opening will cause ventilation and daylight problems, while the difference is only four kwh/m²/yr showing a minor lower consumption between the two simulations.

The Scenarios full year simulation shows that energy fluctuates with 217 kwh/m²/yr. More so, although having no openings to ensure no infiltration rates, the energy consumption shows relatively lower peaks when compared to the first simulation run. Furthermore, while looking at the entire set of results, it is clear that the overall envelope falls outside the benchmark of ASHRAE 140, resulting from the insufficient thermal properties combined with a low u-value of insulated walls. The consumption is more than the minimum that should be reached by two kwh/m²/yr.

## O. Appendix O: January Energy Consumption

During each month, every scenario had different fuel consumption percentages per month. First, the winter season reported the highest number of fuel consumption, where the temperature drops to reach the lowest records between all seasons. Scenario number 1 and 2 simulated 9003 MJ, scenario number 3 9285 MJ, Scenario number 4 9081 MJ, scenario number 5 9508 MJ, scenario number 6 9366 MJ, scenario number 7 9185 MJ, scenario number 8 9002 MJ, scenario number 9 9269 MJ, scenario number 10 9366 MJ, scenario number 11 8623 MJ, and finally, scenario number 12 simulated 8808 MJ. As shown in Table 13, the scenario that had the lowest fuel consumption was scenario number 11, followed by scenario number 12. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table O.1).

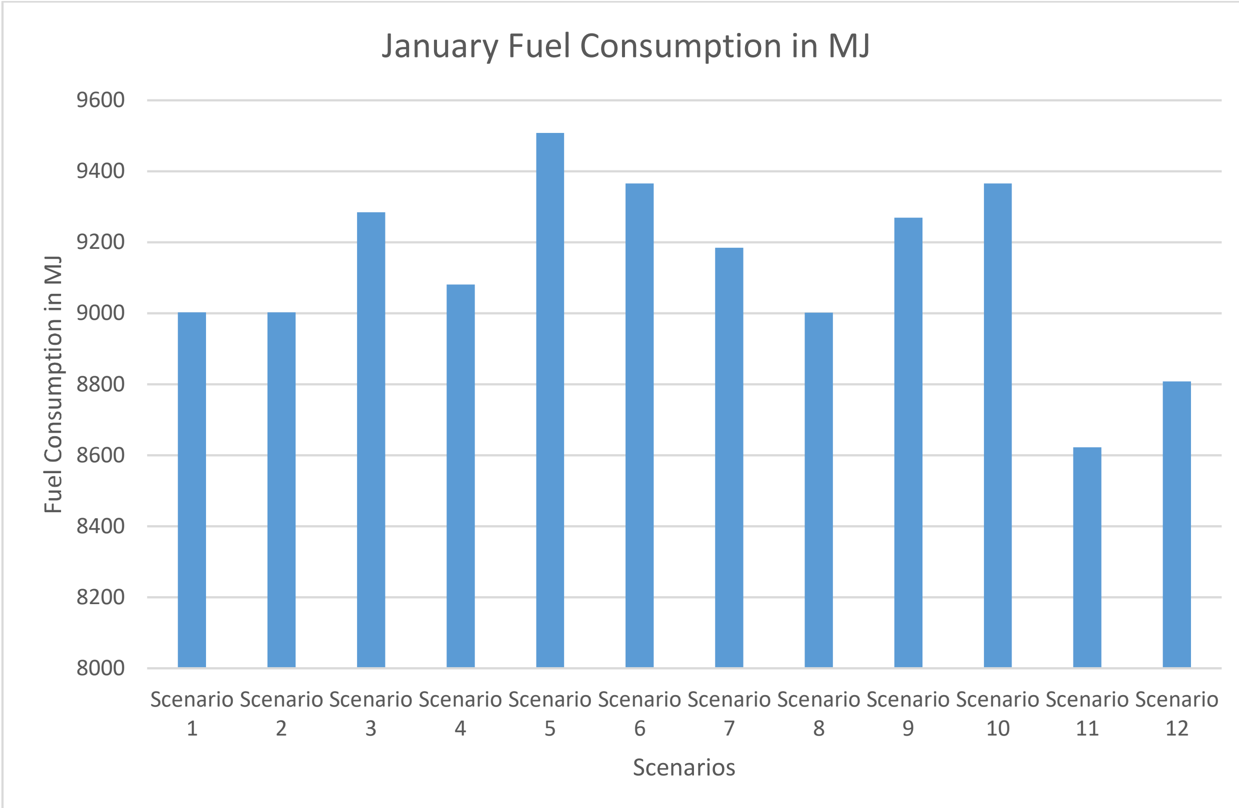



*Table O.1 January fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, Table 14 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest consumption and simulated 107 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 99 KWH. Then comes scenario number 1, 8, and 11, which simulated 101 KWH. Scenario number 2, 6, 9, and 10 simulated 105 KWH, scenario number 3 simulated 104 KWH, scenario number 4 and 7 simulated 103 KWH, and finally, scenario number 5 simulated 107 KWH (table O.2).

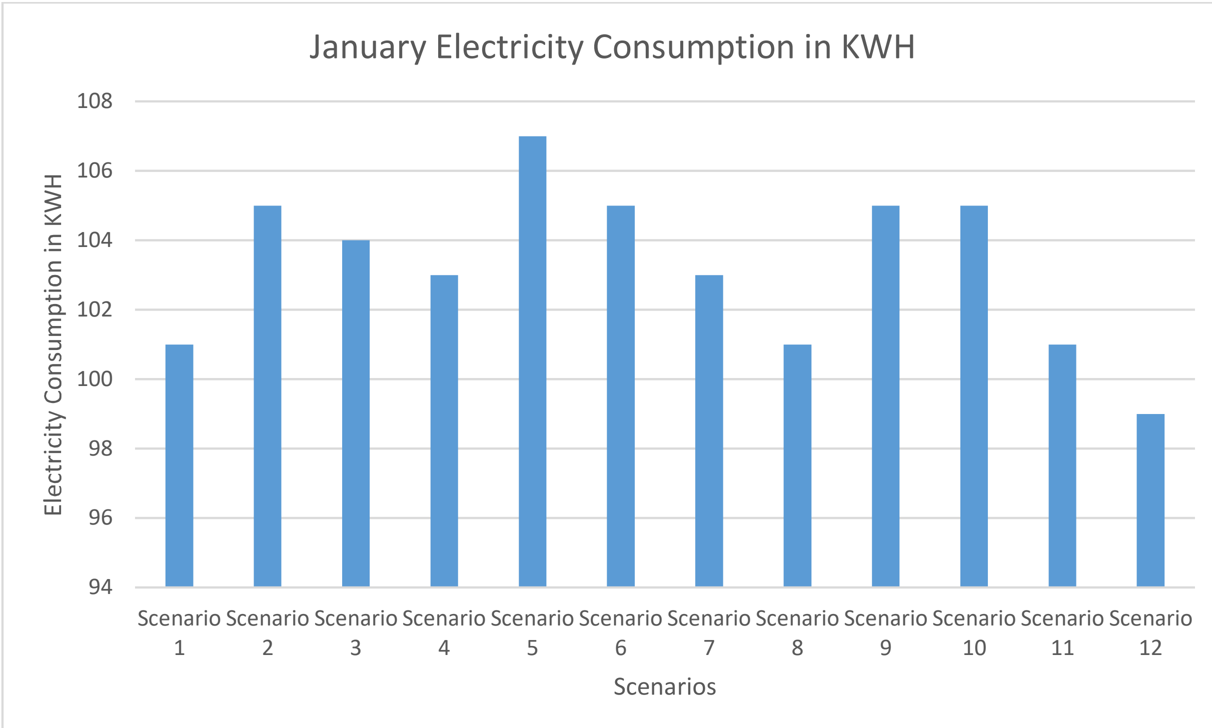



*Table O.2 January electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in January in scenarios number 1, 4, 6, 7, 8, 9,10, 11, and 12 is 67 %. Whereas Scenario number 2, 3, and 5 simulated 68 % (table O.3).

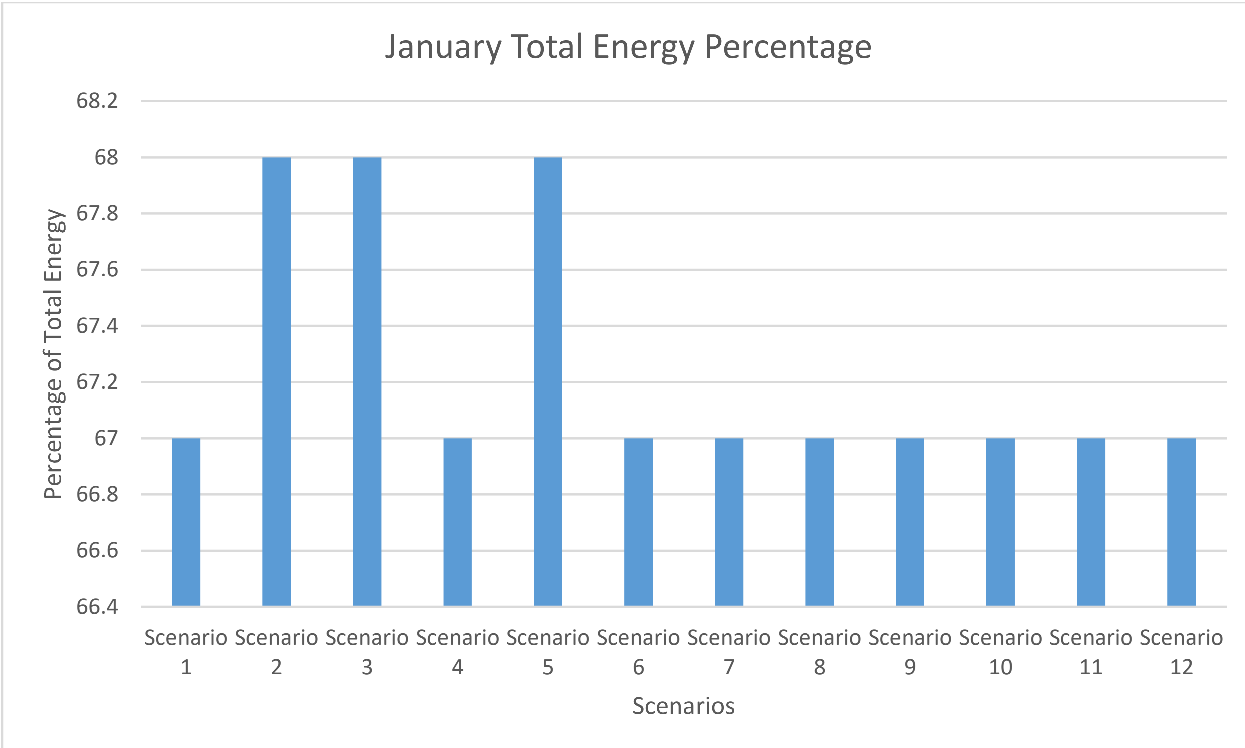



*Table O.3 January total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## P. Appendix P: February Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 7182 MJ, scenario number 2 7437 MJ, scenario number 3 7423 MJ, Scenario number 4 7247 MJ, scenario number 5 7577 MJ, scenario number 6 7484 MJ, scenario number 7 7326 MJ, scenario number 8 7184 MJ, scenario number 9 7395 MJ, scenario number 10 7484 MJ, scenario number 11 7152 MJ, and finally, scenario number 12 marked 7028 MJ. As shown in Table 16, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table P.1).

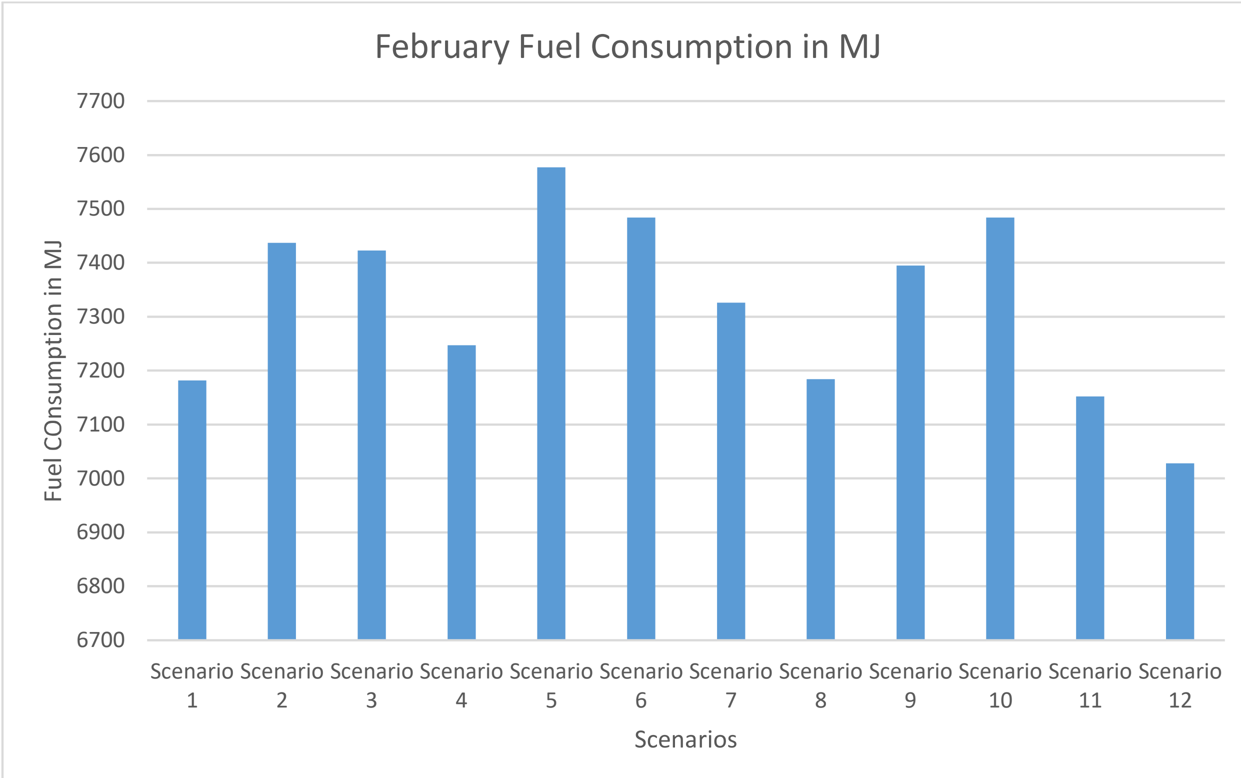



*Table P.1 February fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for the electricity consumption, observation of Table 17 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest and simulated 107 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 79 KWH. Then comes scenario number 1, 8, and 11, which simulated 81 KWH. Scenario number 2, 3, 6, and 10 simulated 84 KWH. Scenarios number 4 simulated 82 KWH, number 7, and 9 simulated 83 KWH, and finally, scenario number 5 simulated 85 KWH (table P.2).

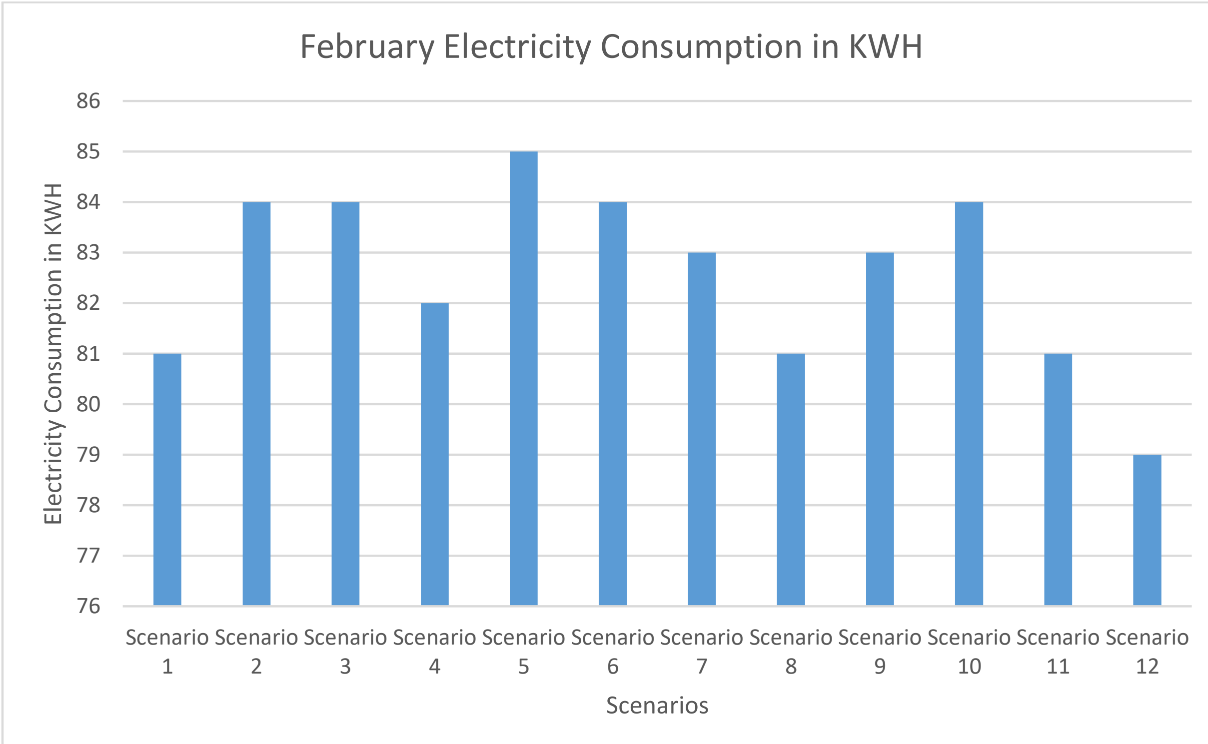



*Table P.2 February electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in February was equal in all scenarios where they simulated 65 % (table P3).

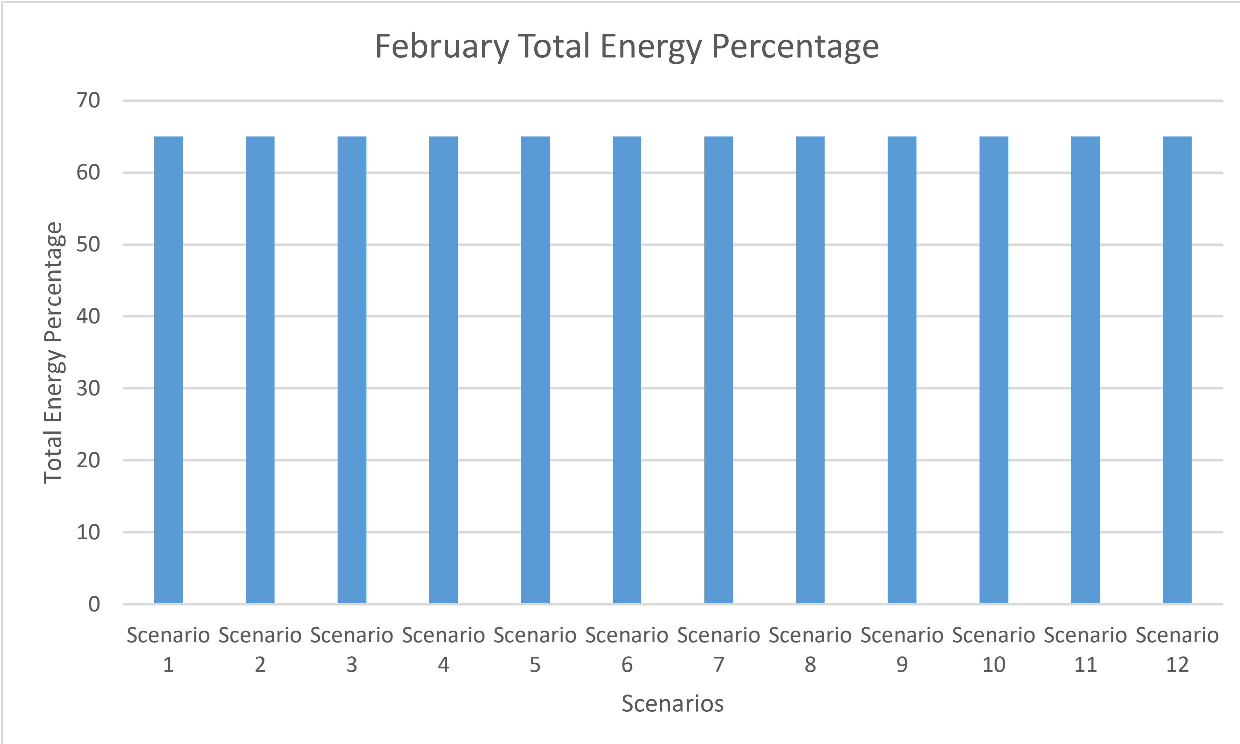



*Table P.3 February total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## Q. Appendix Q: March Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 6470 MJ, scenario number 2 6699 MJ, scenario number 3 6685 MJ, Scenario number 4 6459 MJ, scenario number 5 6832 MJ, scenario number 6 6740 MJ, scenario number 7 6552 MJ, scenario number 8 6423 MJ, scenario number 9 6613 MJ, scenario number 10 6740 MJ, scenario number 11 6396 MJ, and finally, scenario number 12 simulated 6310 MJ. As shown in Table 19, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts

the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table Q.1).

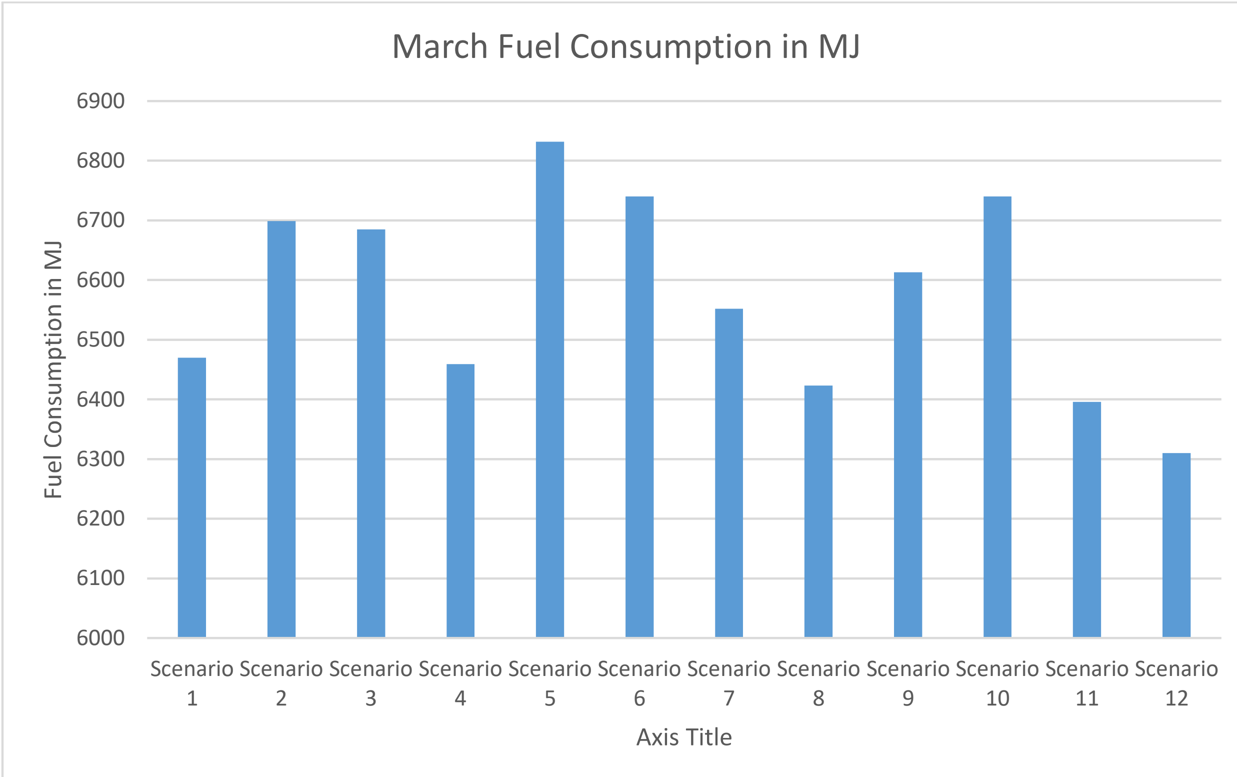



*Table Q.1 March fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for the electricity consumption, observation of Table 20 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest and simulated 78 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 72 KWH. Then comes scenarios number 1 and 7, which marked 74 KWH. Scenario number 2, 3, simulated 76 KWH, scenarios number 4 and 7 simulated 74 KWH, scenario number 8 and 11 simulated 73 KWH, scenario number 6 and 10 registered 77 KWH, scenario number 5 simulated 78 KWH, and finally, scenario number 9 simulated 75 KWH (table Q.2).

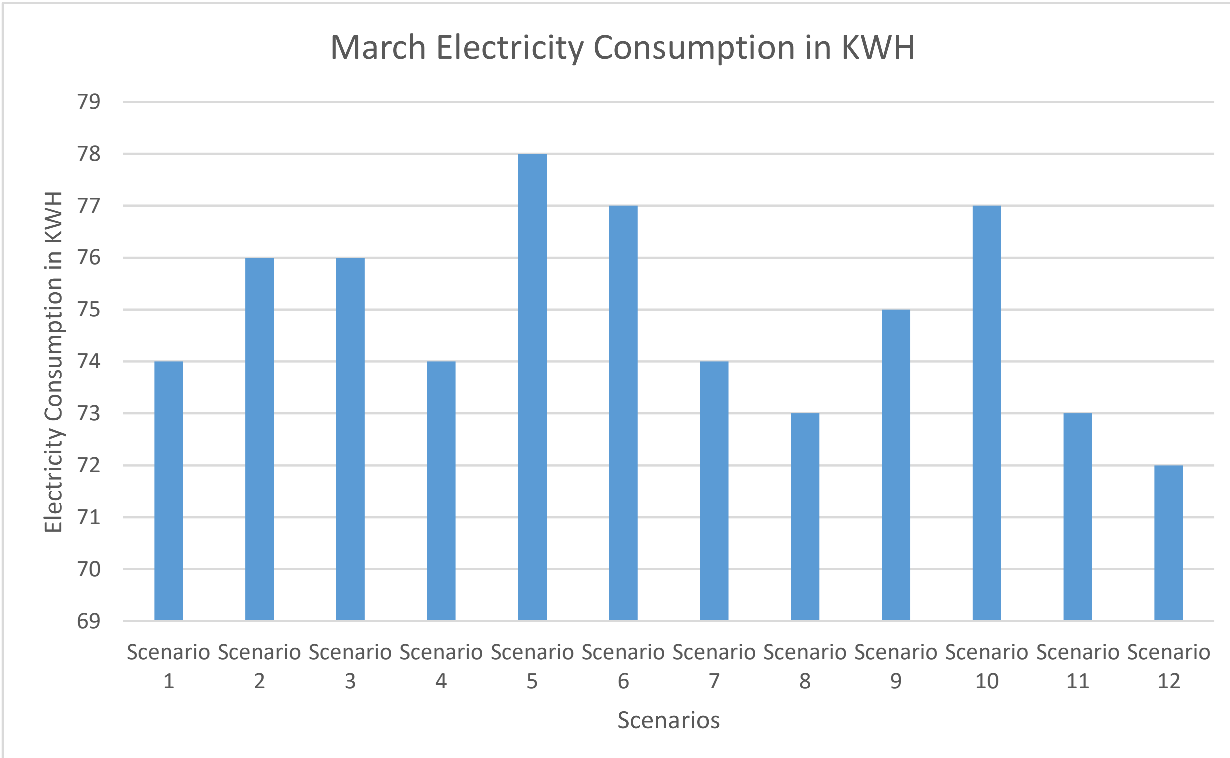



*Table Q.2 March electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in March in scenarios number 1, 4, 7, 8, 9, 11, and 12 is 60 %. Whereas, Scenarios number 2, 3, 5, 6, and 10 simulated 61 % (table Q.3).

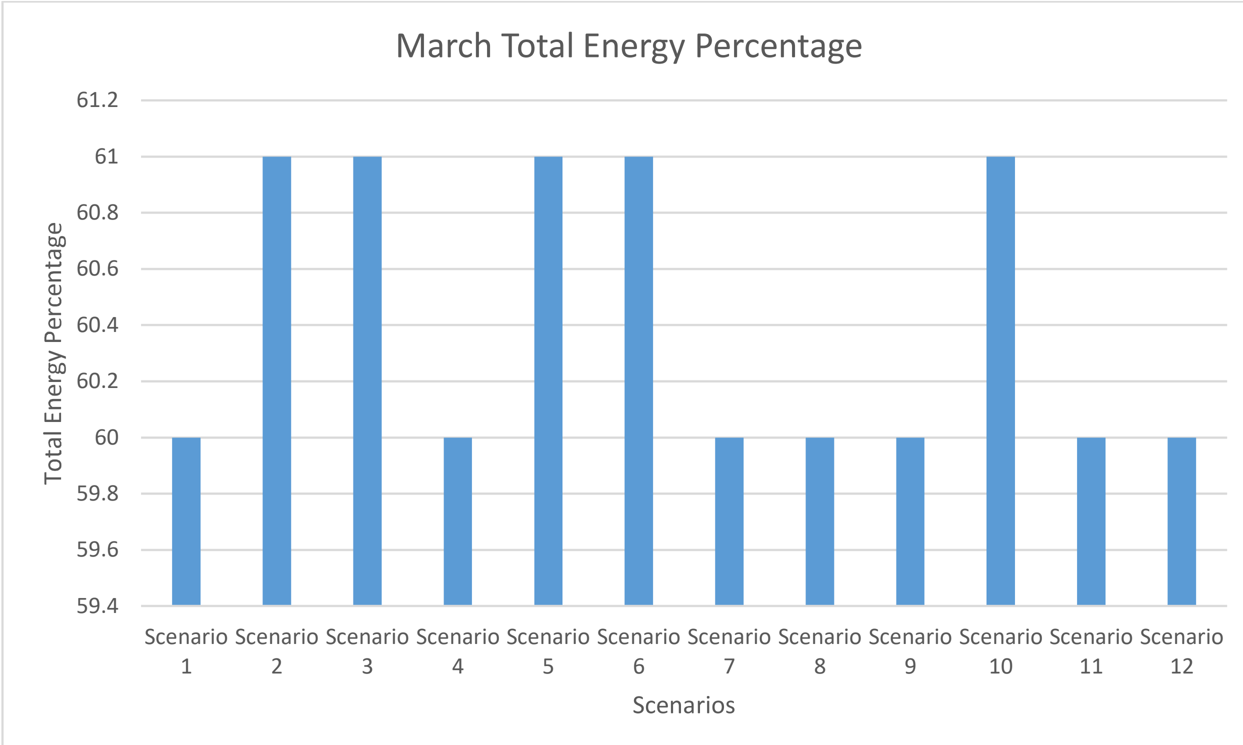



*Table Q.3 March total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## R. Appendix R: April Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 3846 MJ, scenario number 2 3984 MJ, scenario number 3 3976 MJ, Scenario number 4 3818 MJ, scenario number 5 4070 MJ, scenario number 6 4005 MJ, scenario number 7 3903 MJ, scenario number 8 3831 MJ, scenario number 9 3939 MJ, scenario number 10 4005 MJ, scenario number 11 3814 MJ, and finally, scenario number 12 simulated 3748 MJ. As shown in Table 22, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts

the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table R.1).

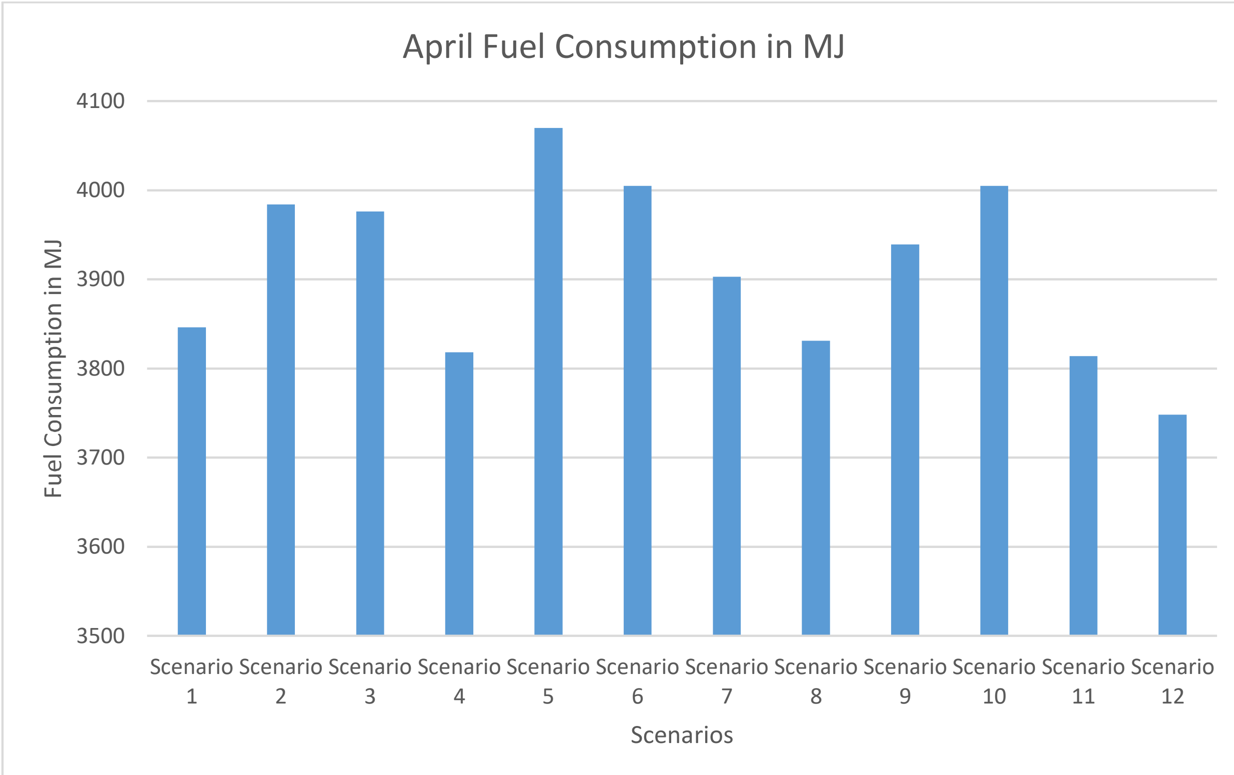



*Table R.1 April fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for the electricity consumption, observation of Table 23 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario numbers 5, 6, and 10 simulated the highest value, which is 46 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 43 KWH. Scenario number 2, 3, 7, and 9 simulated 45 KWH. Scenario number 1, 4, 8, and 11 simulated 44 KWH (table R.2).

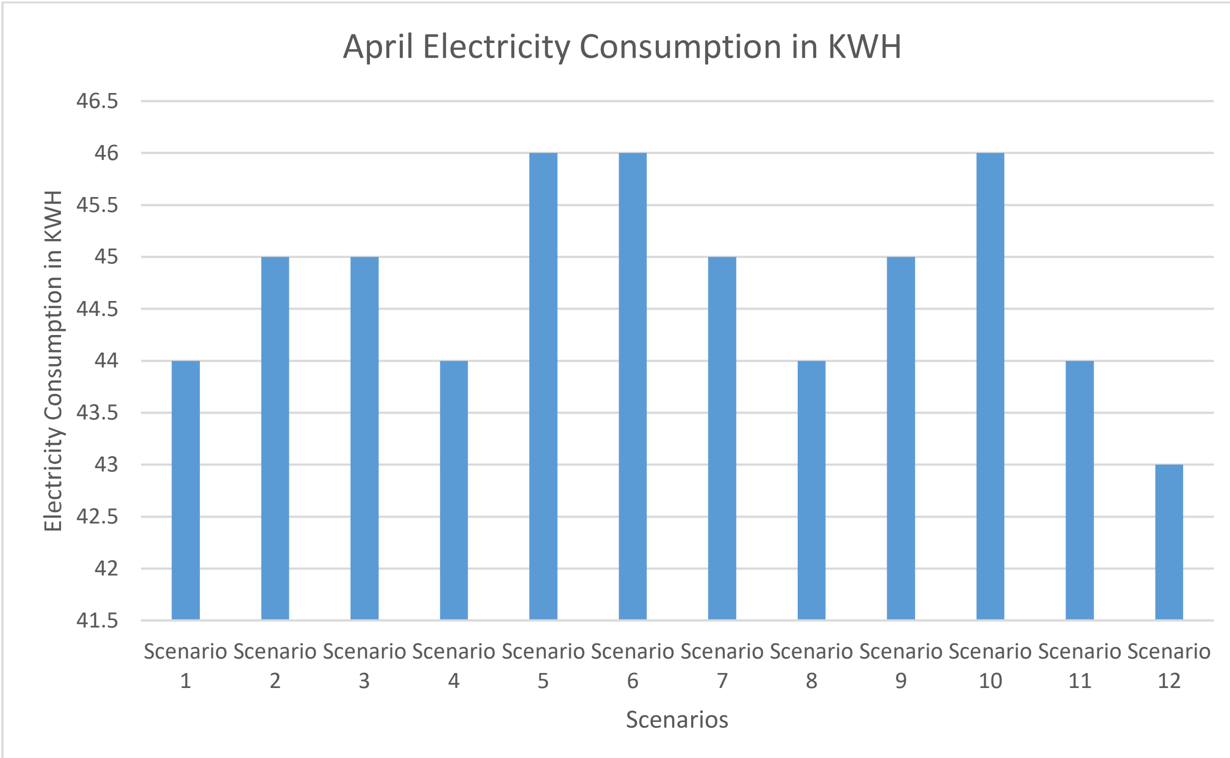



*Table R.2 April electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in April in scenarios number 1, 4, 7, 8, 9, 11, and 12 is 48 %. Whereas Scenario number 2, 5, 6, and 10 simulated 49 %, and finally, scenario number 3 simulated 79 % (table R.3).

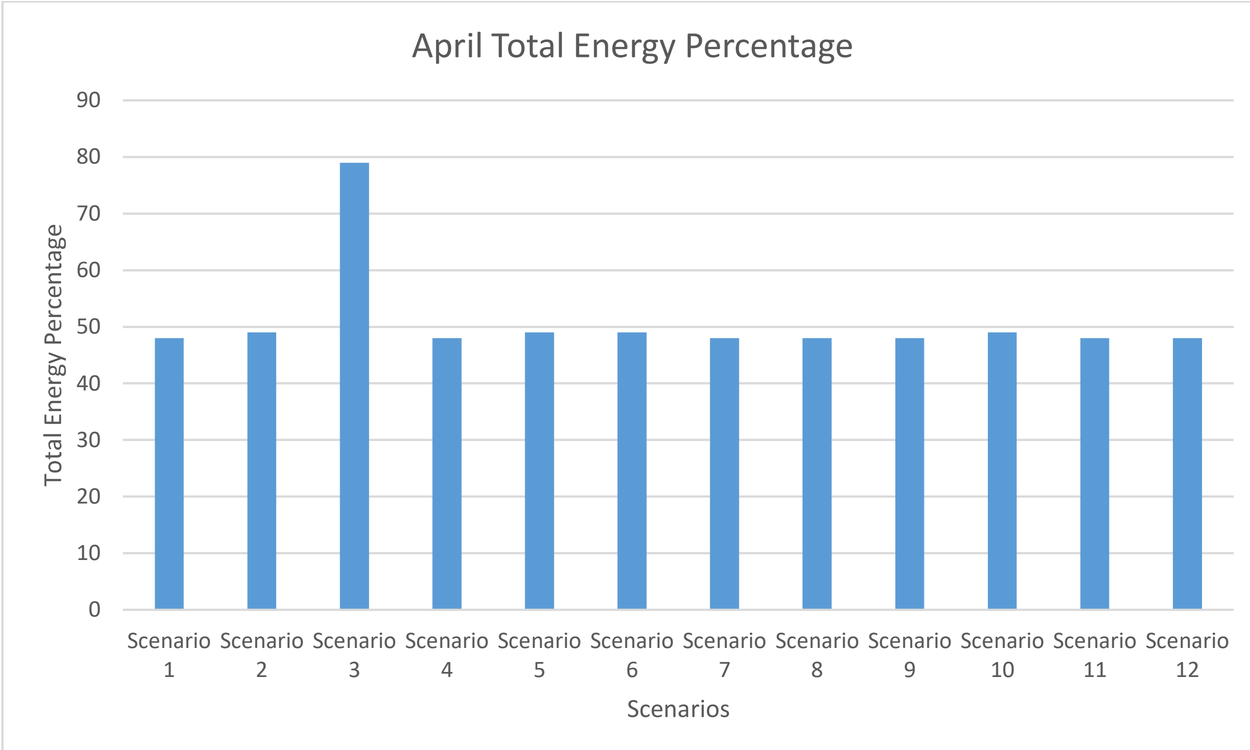



*Table R.3 April total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## S. Appendix S: May Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 2091 MJ, scenario number 2 2160 MJ, scenario number 3 2154 MJ, Scenario number 4 2037 MJ, scenario number 5 2205 MJ, scenario number 6 2173 MJ, scenario number 7 2086 MJ, scenario number 8 2057 MJ, scenario number 9 2104 MJ, scenario number 10 2173 MJ, scenario number 11 2049 MJ, and finally, scenario number simulated 12 2020 MJ. As shown in Table 25, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 4. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table S.1).

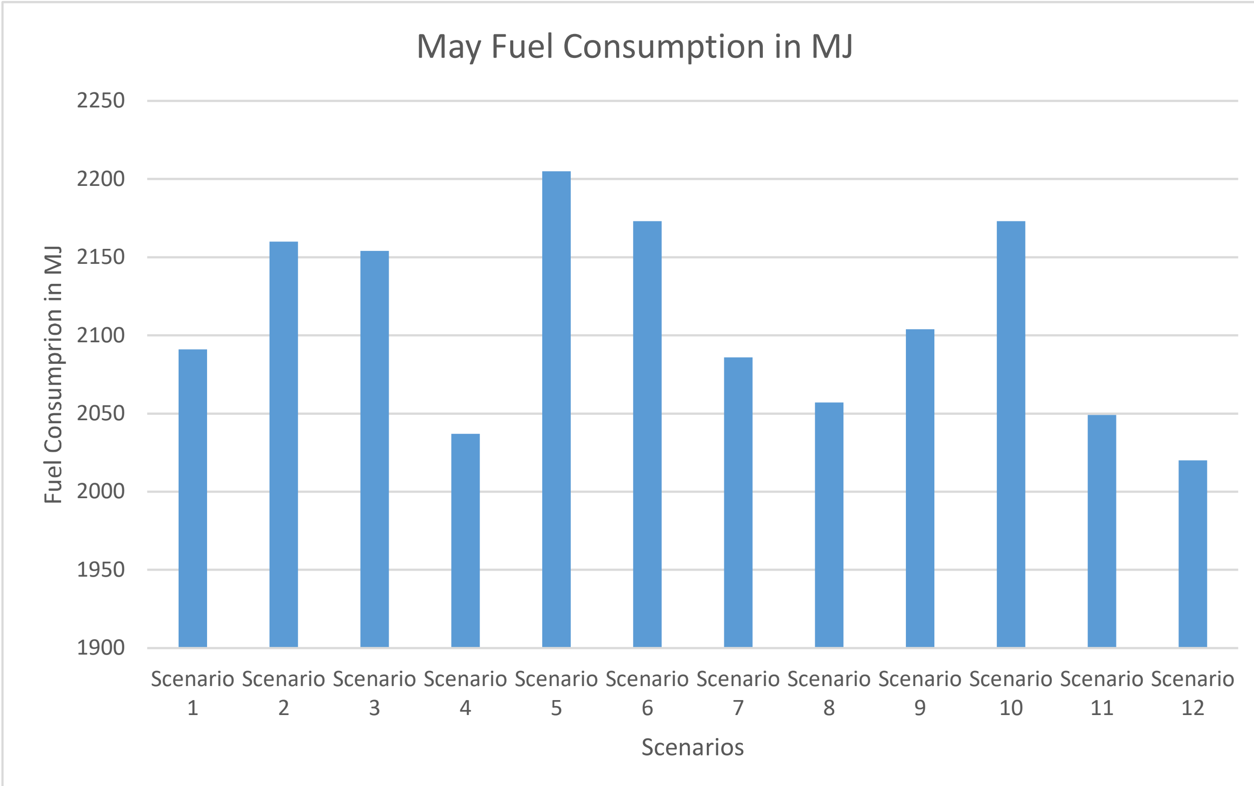



*Table S.1 May fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in May in scenarios number 1, 7, 8, 9, 11, and 12 is 31 %. Whereas, Scenario number 2, 3, 5, 6, and 10 simulated 32 %, and scenario number 4 simulated 30 % (table S.2).

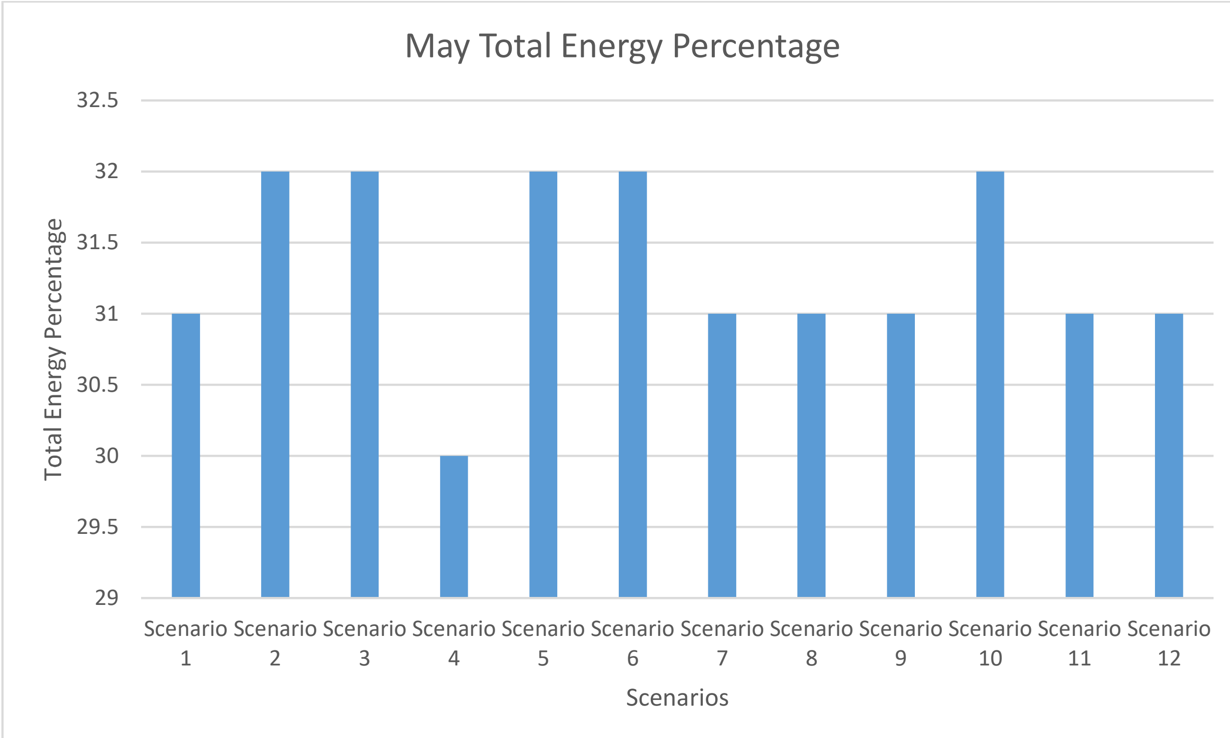



*Table S.2 May total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## T. Appendix T: June Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 728 MJ, scenario number 2 746 MJ, scenario number 3 744 MJ, Scenario number 4 695 MJ, scenario number 5 761 MJ, scenario number 6 750 MJ, scenario number 7 724 MJ, scenario number 8 713 MJ, scenario number 9 732 MJ, scenario number 10 750 MJ, scenario number 11 713 MJ, and finally, scenario number 12 simulated 702 MJ. As shown in Table 27, the scenario that had the lowest fuel consumption was scenario number 4, followed by scenario number 12. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table T.1).

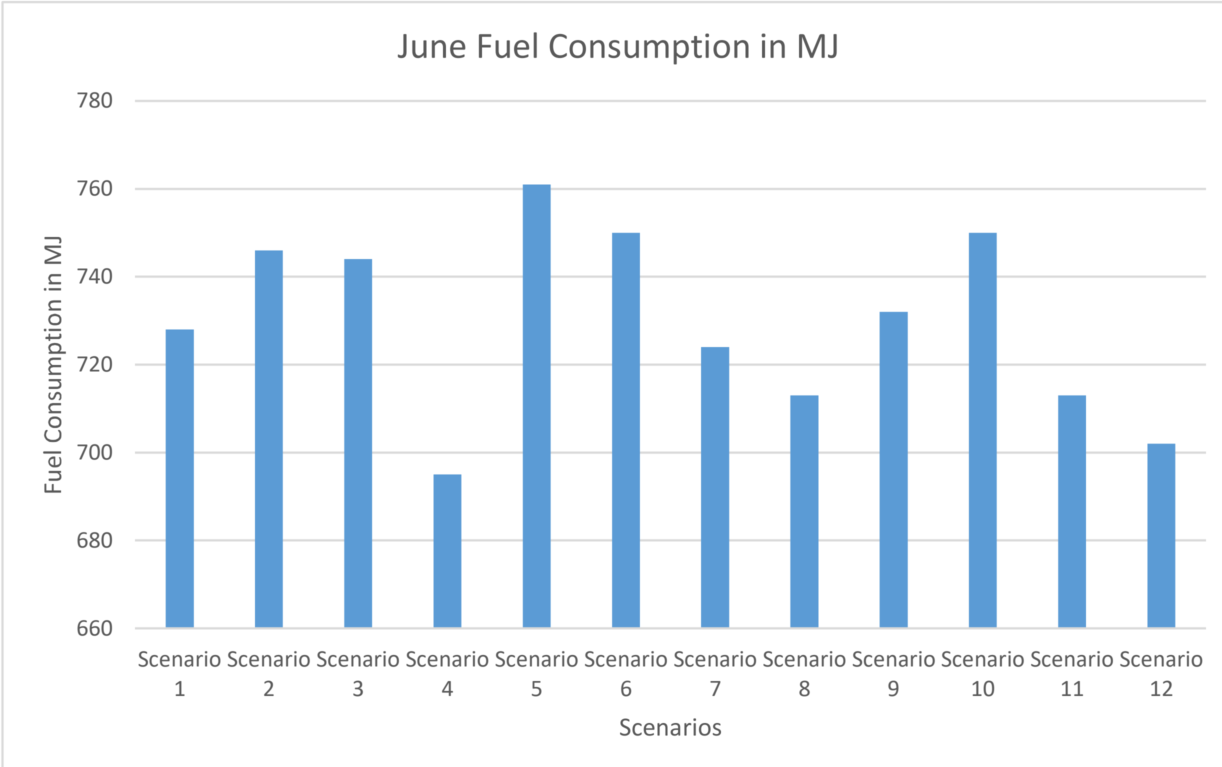



*Table T.1 June fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in June in scenario number 1 7, 8, 9, 11, and 12 is 31 %. Whereas, Scenario number 2, 3, 5, 6, and 10 simulated 32 %, and finally, scenario number 4 simulated 30 % (table T.2).

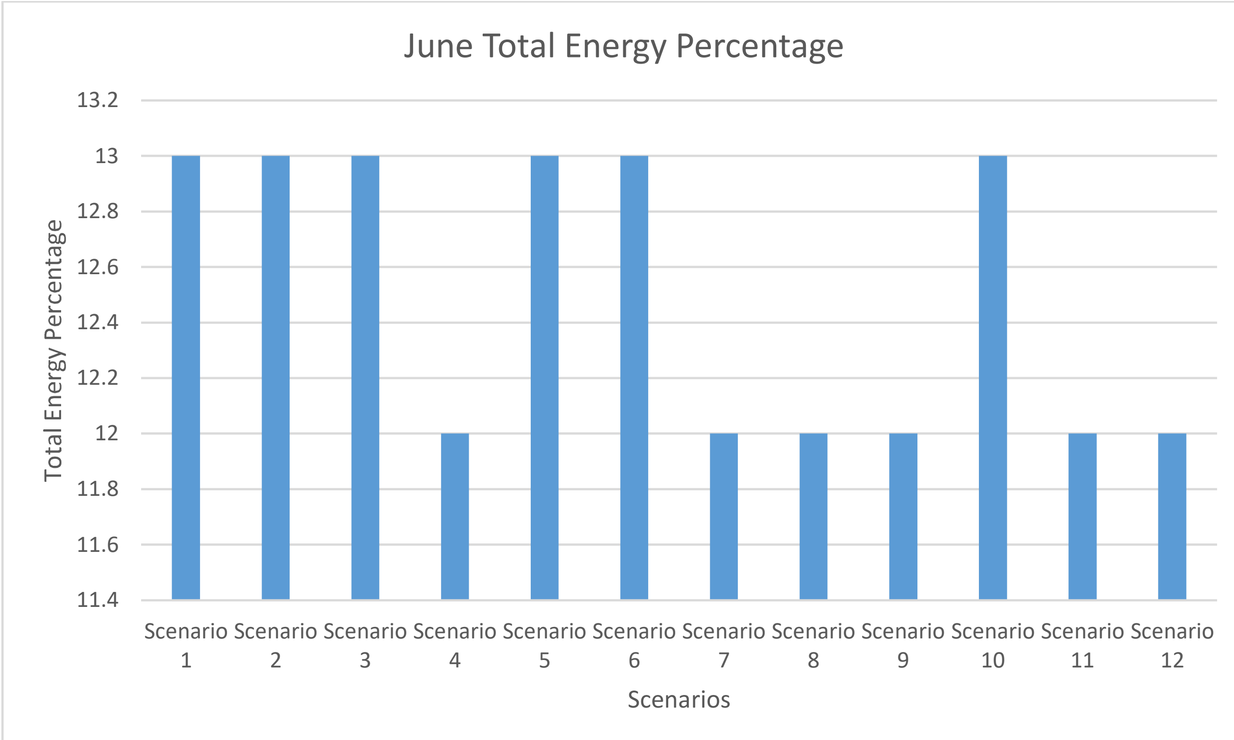



*Table T.2 June total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## U. Appendix U: July Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 598 MJ, scenario number 2 614 MJ, scenario number 3 613 MJ, Scenario number 4 573 MJ, scenario number 5 626 MJ, scenario number 6 619 MJ, scenario number 7 599 MJ, scenario number 8 589 MJ, scenario number 9 605 MJ, scenario number 10 619 MJ, scenario number 11 587 MJ, and finally, scenario number 12 simulated 583 MJ. As shown in Table 29, the scenario that had the lowest fuel consumption was scenario number 4, followed by scenario number 12. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table U.1).

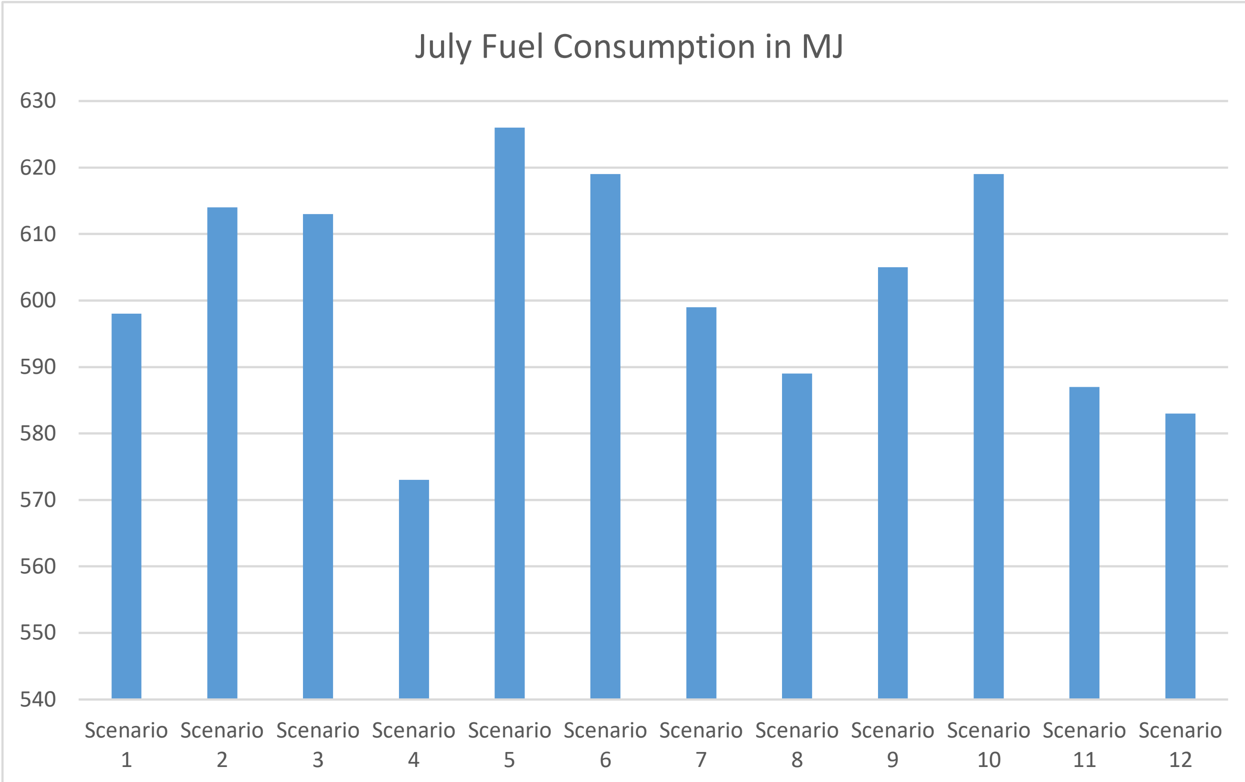



*Table U.1 July fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in July in all scenarios is 10 % (table U.2).

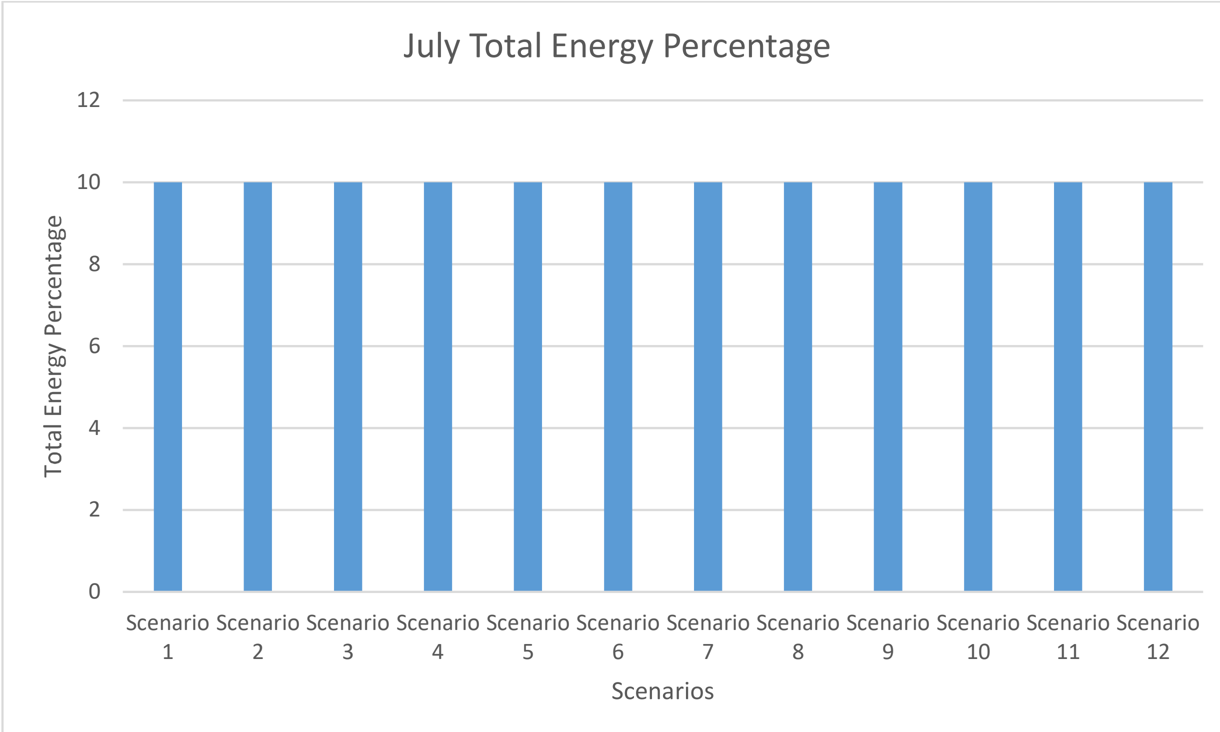



*Table U.2 July total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## V. Appendix V: August Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 496 MJ, scenario number 2 513 MJ, scenario number 3 512 MJ, Scenario number 4 486 MJ, scenario number 5 523 MJ, scenario number 6 511 MJ, scenario number 7 498 MJ, scenario number 8 490 MJ, scenario number 9 502 MJ, scenario number 10 511 MJ, scenario number 11 488 MJ, and finally, scenario number 12 simulated 480 MJ. As shown in Table 31, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table V.1).

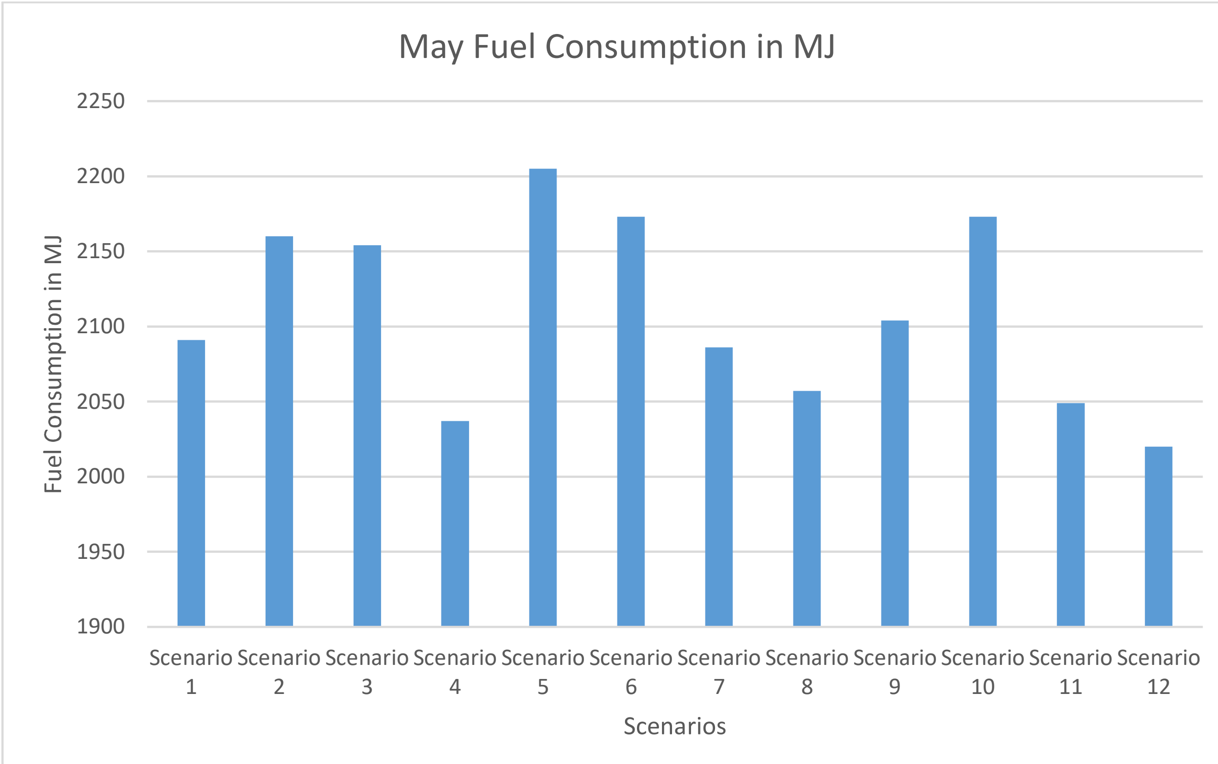



*Table V.1 August fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in August in all scenarios is 8 % (table V.2).

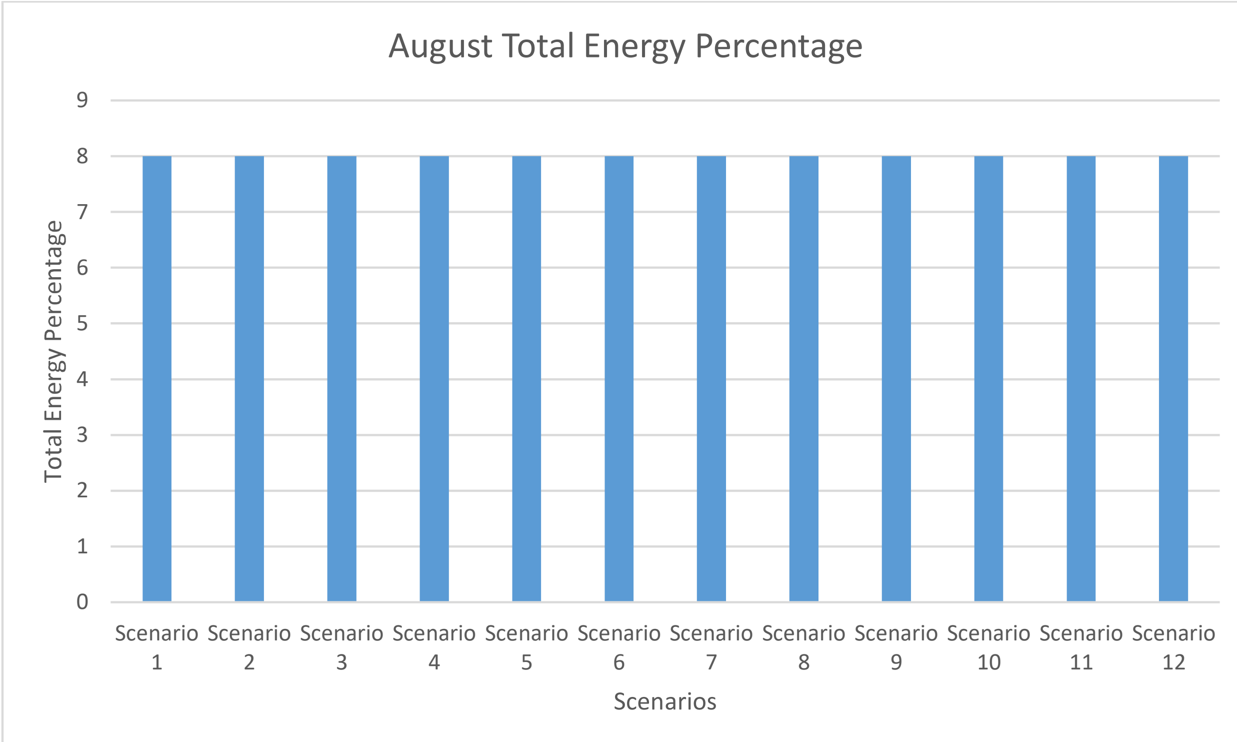



*Table V.2 August total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## W. Appendix W: September Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 690 MJ, scenario number 2 709 MJ, scenario number 3 707 MJ, Scenario number 4 673 MJ, scenario number 5 722 MJ, scenario number 6 712 MJ, scenario number 7 695 MJ, scenario number 8 684 MJ, scenario number 9 701 MJ, scenario number 10 712 MJ, scenario number 11 682 MJ, and finally, scenario number simulated 12 670 MJ. As shown in Table 33, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 4. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table W.1).

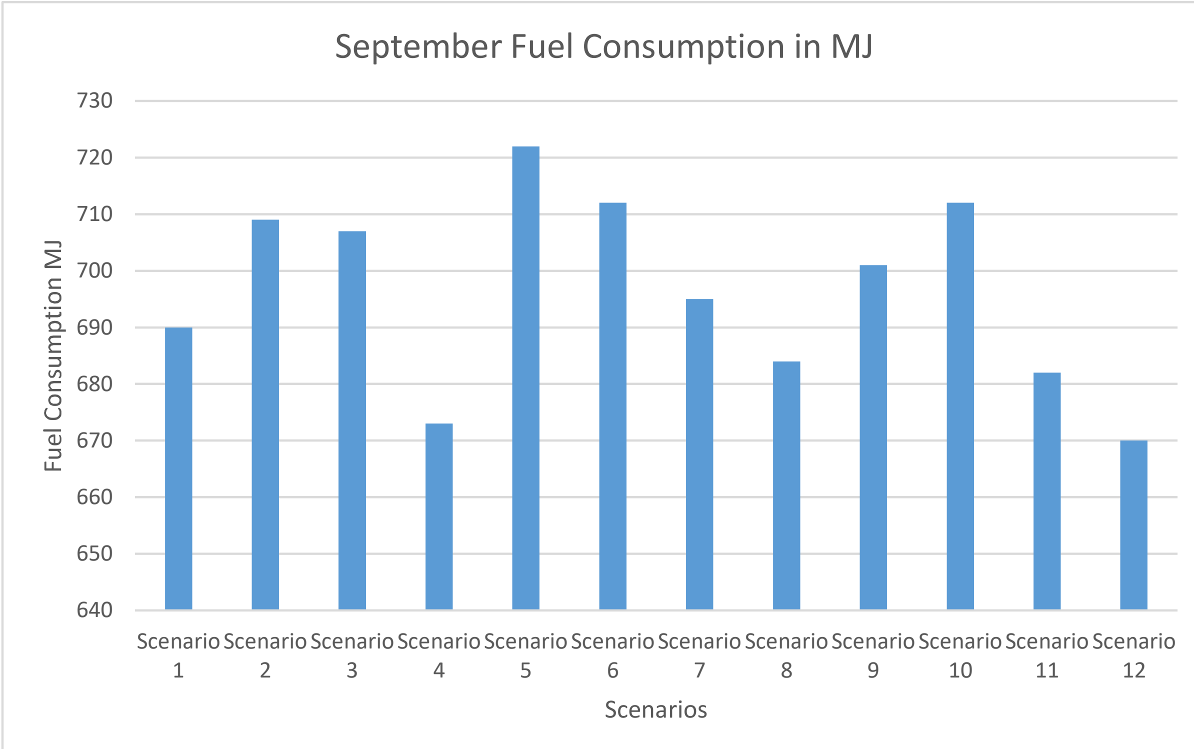



*Table W.1 September fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in September for scenario number 1, 2, 3, 5, 6, 10, 11, and 12 is 13 %, while scenario number 4, 7, 8, and 9 simulated 12 % (table W.2).

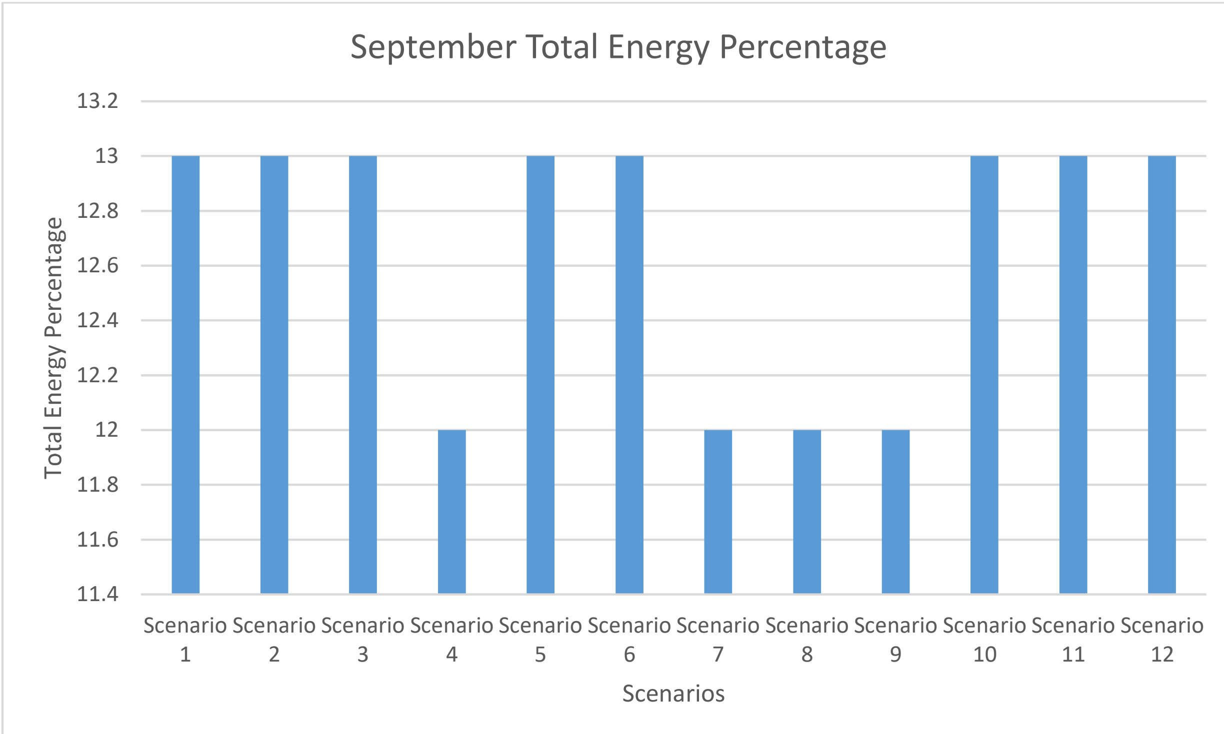



*Table W.2 September total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## X. Appendix X: October Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 2282 MJ, scenario number 2 2355 MJ, scenario number 3 2349 MJ, Scenario number 4 2213 MJ, scenario number 5 2400 MJ, scenario number 6 2362 MJ, scenario number 7 2266 MJ, scenario number 8 2233 MJ, scenario number 9 2285 MJ, scenario number 10 2362 MJ, scenario number 11 2224 MJ, and finally, scenario number 12 simulated 2196 MJ. As shown in Table 35, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 4. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts

the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table X.1).

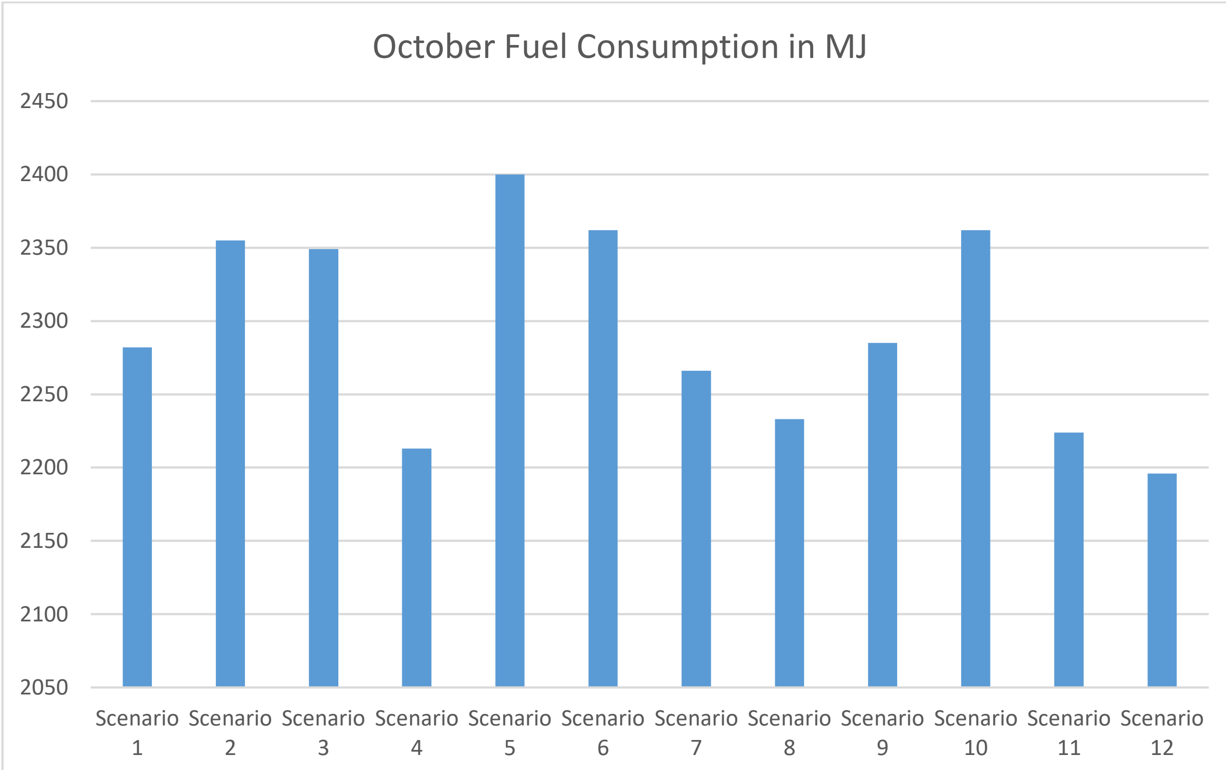



*Table X.1 October fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for electricity consumption, no electricity spent on heating in all scenarios.

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in October for the scenarios number 2, 3, 5, 6, and 10 is 35 %, scenario number 4, 7, 8, 9, 11, and 12 marked 34 %, and scenario number 4 marked 33 % (table X.2).

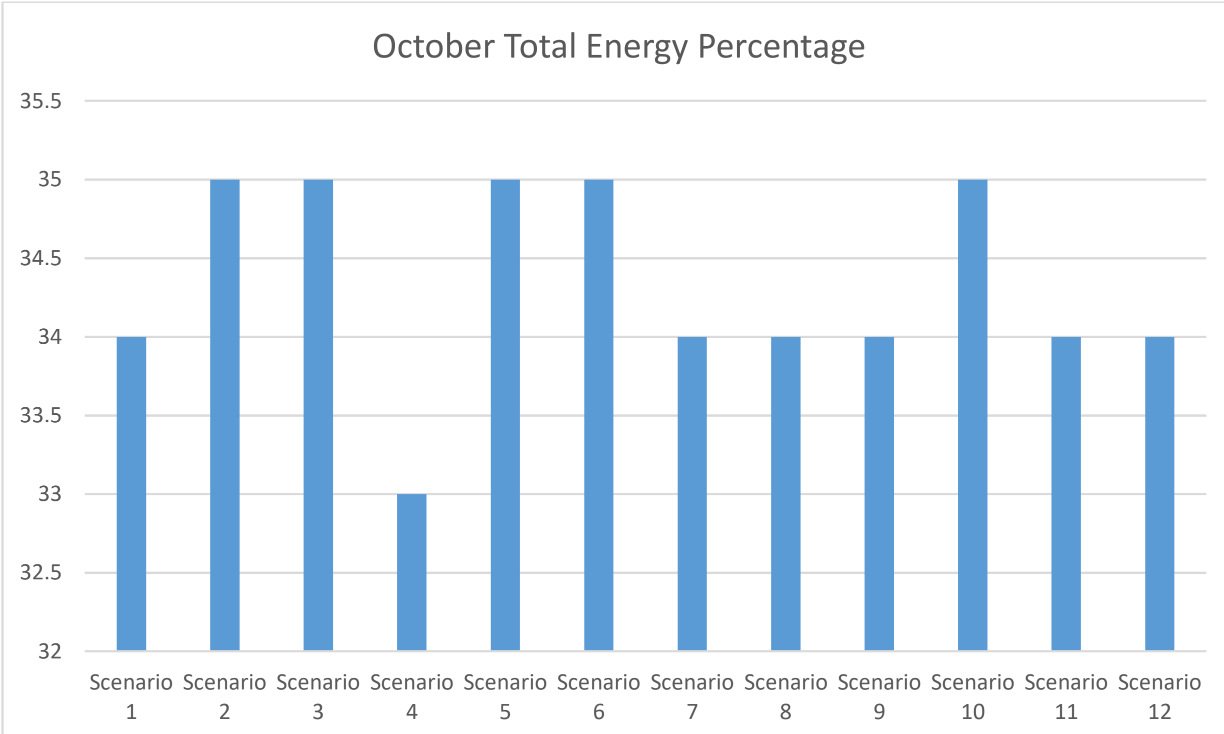



*Table X.2 October total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## Y. Appendix Y: November Energy Consumption

Further figures and chart observations show that scenario number 1 simulated 5249 MJ, scenario number 2 5445 MJ, scenario number 3 5421 MJ, Scenario number 4 5260 MJ, scenario number 5 5530 MJ, scenario number 6 5468 MJ, scenario number 7 5315 MJ, scenario number 8 5194 MJ, scenario number 9 5360 MJ, scenario number 10 5468 MJ, scenario number 11 simulated 5177 MJ, and finally, scenario number 12 simulated 5091 MJ. As shown in Table 37, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table Y.1).

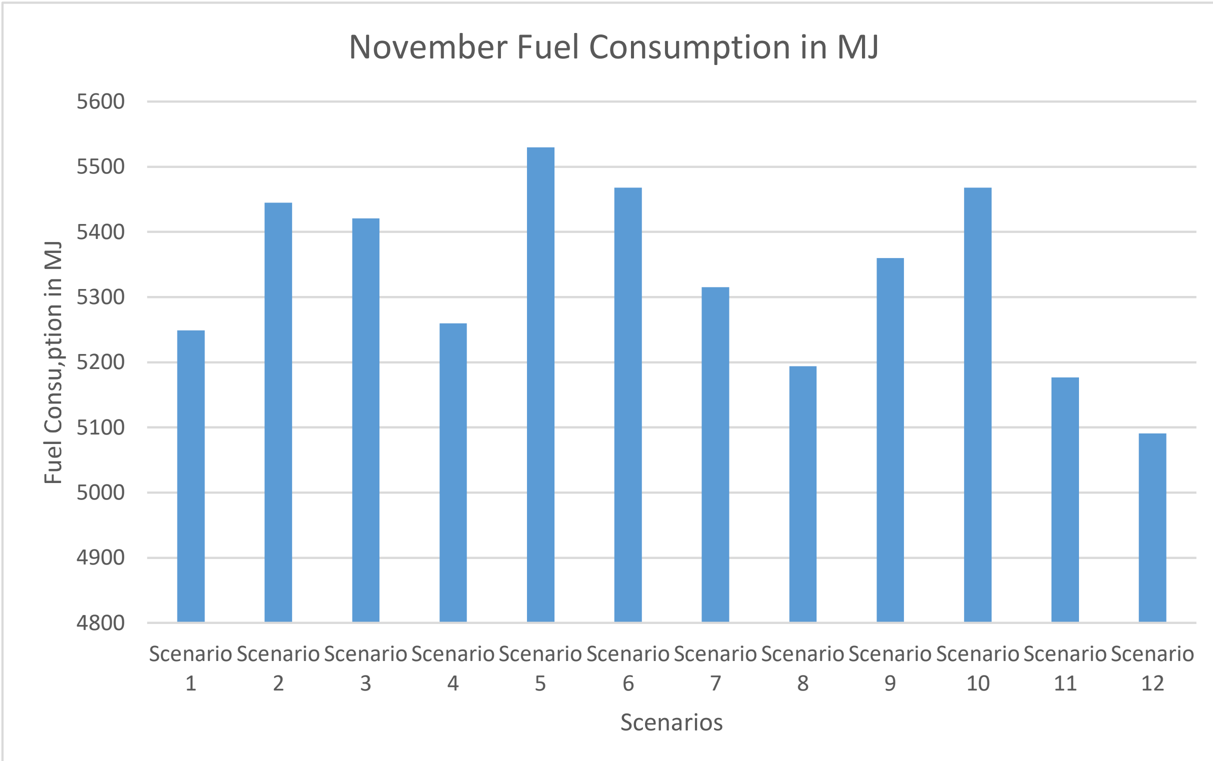



*Table Y.1 November fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for the electricity consumption, observation of Table 38 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest and simulated 63 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 58 KWH. Scenarios number 6 and 10 simulated 62 KWH. Scenario number 7 and 9 simulated 61 KWH, scenario number 1 and

4 simulated 60 KWH. Scenario number 2,3, 6, and 10 simulated 62 KWH. Finally, Scenario number 8 and 11 simulated 59 KWH (table Y.2).

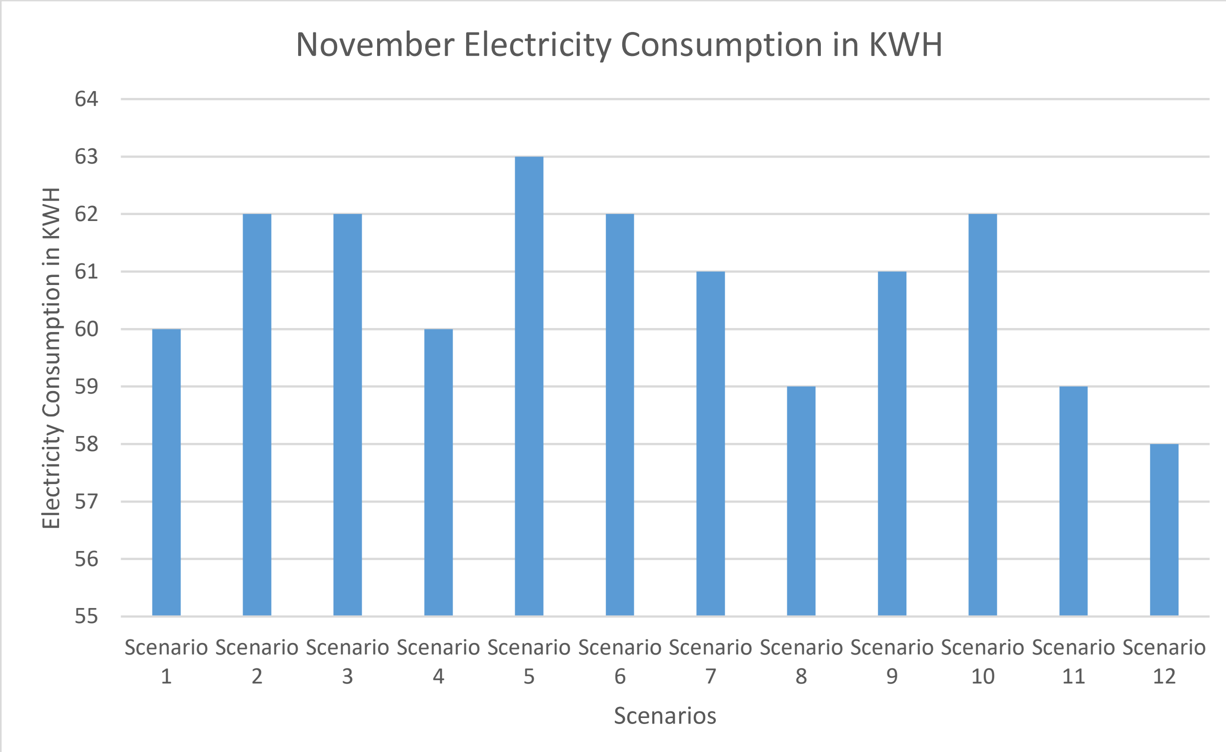



*Table Y.2 November Electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in November for scenario number 1, 2, 3, 5, 6, 7, 9, and 10 is 57 %, and scenarios 4, 8, 11, and 12 is 56 % (table Y.3).

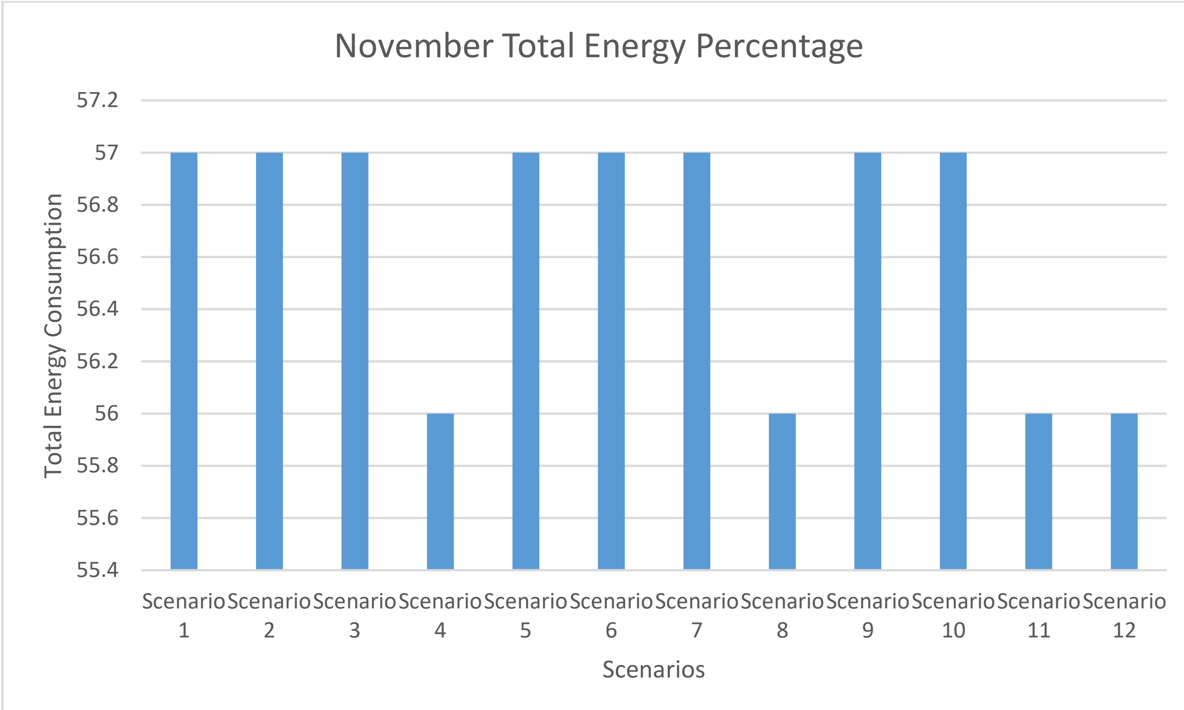



*Table Y.3 November total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

## Z. **Appendix Z: December Energy Consumption**

Further figures and chart observations show that scenario number 1 simulated 8611 MJ, scenario number 2 8939 MJ, scenario number 3 8912 MJ, Scenario number 4 8734 MJ, scenario number 5 9110 MJ, scenario number 6 8977 MJ, scenario number 7 8796 MJ, scenario number 8 8640 MJ, scenario number 9 8876 MJ, scenario number 10 8977 MJ, scenario number 11 8603 MJ, and finally, scenario number 12 simulated 8443 MJ. As shown in Table 40, the scenario that had the lowest fuel consumption was scenario number 12, followed by scenario number 11. These numbers differ from month to the other because of the degree day mentioned in the previous section, where it impacts the heating to reach a comfortable and suitable indoor temperature. Accordingly, the scenario that marked the highest fuel consumption is number 5 (table Z.1).

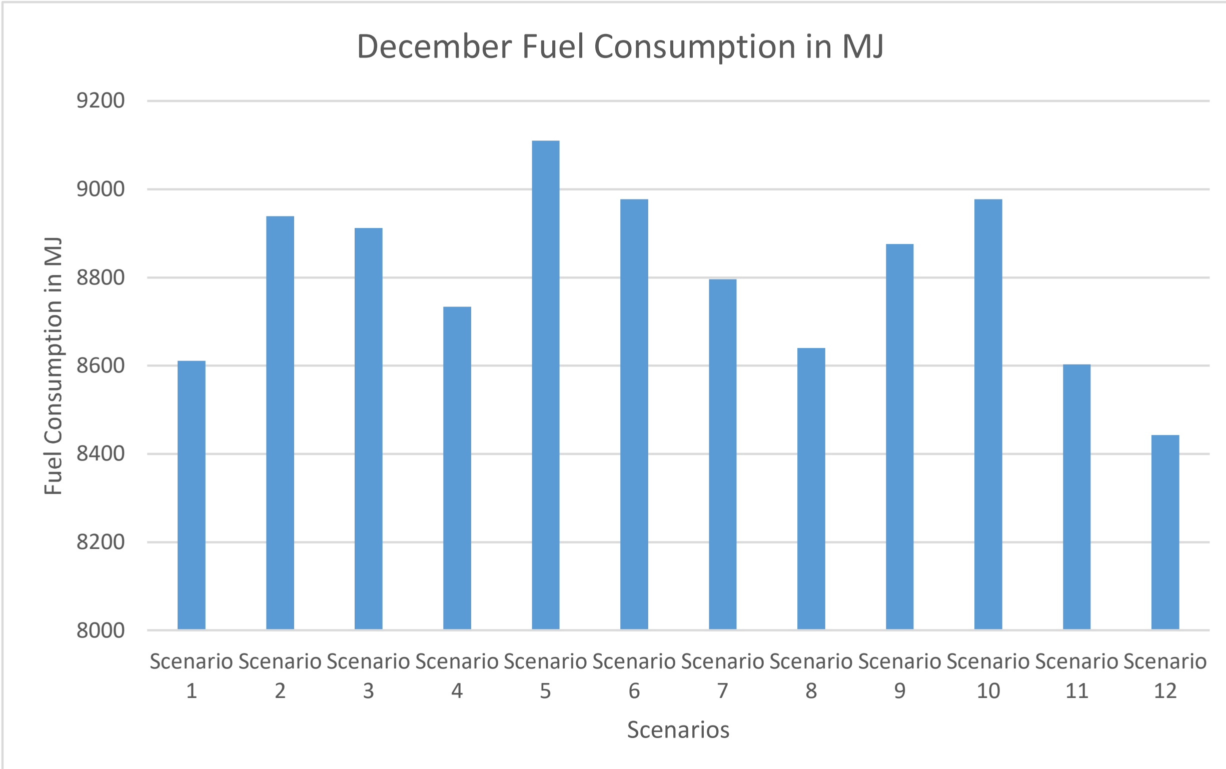



*Table Z.1 December fuel consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As for the electricity consumption, observation of Table 41 shows that the electricity spent on heating registered the lowest value in scenario number 12. It is also remarkable that there is a slight difference in consumption between the months that showed the highest fuel consumption. Besides, electricity consumption changes between seasons according to the degree day and variation between indoor and outdoor temperatures. The electricity consumption in scenario number 5 was the highest and simulated 101 KWH. In comparison, scenario number 12 had the lowest usage between all scenarios where electricity consumption on space heating is equal to 94 KWH. Then comes scenario number 1 and 11, which simulated 95 KWH. Scenario number 2, 3, and 9 simulated 99 KWH, scenario number 4 simulated 97 KWH. Scenario number 6 and 10 simulated 100

KWH. Scenario number 7 simulated 98 KWH, and finally, scenario number 8 simulated 96 KWH (table Z.2).

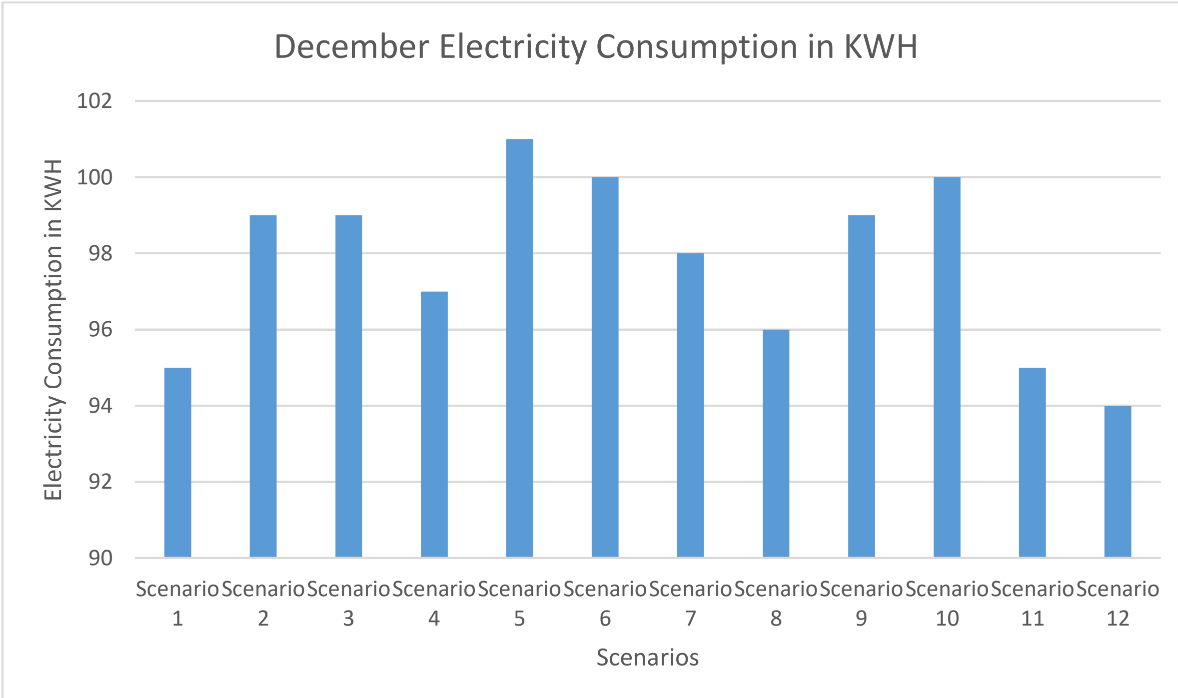



*Table Z.2 December Electricity consumption. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*

As mentioned before, the study aims to assess the impact of the external building's envelope on energy consumption and demand in the high mountains of Lebanon. For this reason, the percentages of total energy consumption were simulated. So far, the total energy spent on space heating, according to the simulation software (insight 360), simulated the highest percentages during winter and fall seasons in comparison with lighting, space cooling, pumps, and hot water. The percentage of energy spent on space heating in December for scenario number 1, 4, 8, 11, and 12 is 66 %, while the percentage for scenarios 2, 3, 5, 6, 7, 9, and 10 is 67 % (table Z.3).

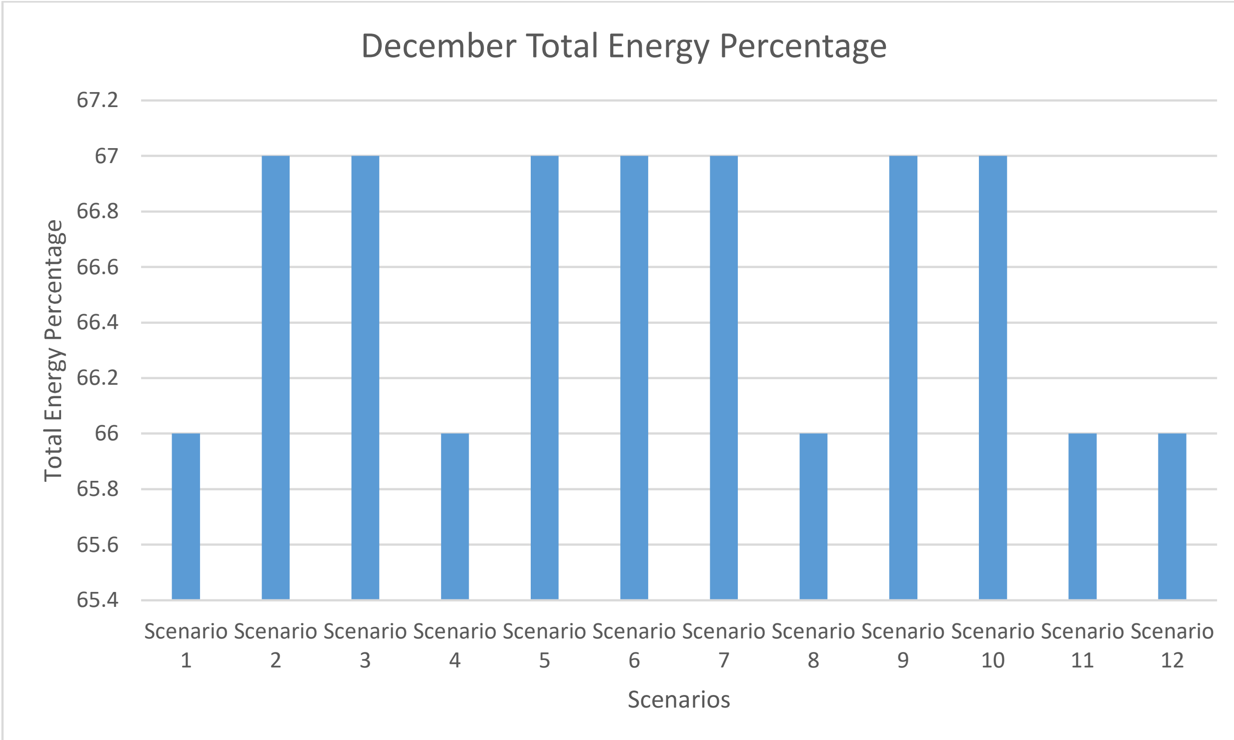



*Table Z.3 December total energy Percentage. Source: https://gbs.autodesk.com/GBS/Run/Chart?ProjectID=s9T9ZZn5vAQ%3d. Accessed on: 15-03-2020*