INSULATION MATERIAL FOR A MODEL HOUSE IN ZAOUIAT SIDI ABDESSALAM

Spring 2017
Capstone Report

Student Statement:
I have applied ethics to the design process and in the selection of the final proposed design. And that, I have held the safety of the public to be paramount and have addressed this in the presented design wherever may be applicable.

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ABSTRACT

To make the lives of people living in Zaouiat Sidi Abdessalam better, my teammates and I will renovate and transform a model house to an ecofriendly one. It will help them go through the harsh weather that the Zaouiat faces in winter. To do so, I will be in charge of finding a suitable material for the renovation and the insulation of the house so that to limit the energy consumption on its heating.

My capstone project will be divided into three parts. The first one is about understanding the materials used in construction and insulation in Morocco, especially the region near Ifrane, by conducting a bibliographic study. It contains construction and insulation materials, their properties, advantages and disadvantages.

Then, the second part consists of conducting an experimental research on different combinations of construction and insulation materials to seek for the best heat properties. It is based on creating samples made of clay, cork, straw and mortar. Then, they are studied through many methods such as the flash method to find the thermal diffusivity, the asymmetrical hot plate to get the thermal conductivity, and others to find the specific heat capacity and thermal effusivity. This step shows that the mixture with cork and clay has the lowest thermal properties with a thermal conductivity of 0.15 W/(mK), a thermal diffusivity of 2.30 x 10^-7 m^2/s, a specific heat capacity of 969.29 J/(kg*K) and a thermal effusivity of 312.81 Ws^{0.5}m^{-2}K^{-1}. It presents the lowest capacity to exchange heat with its surroundings, and therefore, it promises to have the best thermal insulation. Whereas the mixture with 8% of straw and 96% clay has the greatest thermal conductivity with 0.63 W/(mK), the greatest specific heat capacity with 2233.14 Jkg^{-1}K^{-1} and the greatest thermal effusivity with 1304.19 Ws^{0.5}m^{-2}K^{-1}. Even if it doesn’t have the biggest thermal diffusivity, it is expected to have the worst thermal insulation.

Finally, the third part will involve implementing the combinations obtained in the previous part in the software Design Builder to compute the heat losses obtained from each mixture. The simulation confirmed that the mixture with clay and cork has the best thermal insulation as it gives the lowest heat losses in the walls either when it is implemented as a construction material with 1.38 kW or when it is implemented as an added layer of thermal insulation with 3.02 kW. It also confirmed the expectation that the mixture with the lowest thermal insulation is the one with 50% straw and clay. In fact, it shows that the mixture with the 50% straw and clay will give 3.92 kW if it is entered as construction material in the software and 5.16 kW if is entered as an interior layer of thermal insulation.
1. INTRODUCTION

Sustainable development deals with providing the basic needs of the present generation without compromising and affecting the future generations’ ability to provide their needs [1]. It has three pillars: social, environmental and economic pillar. The social pillar stands for the society’s and people’s ability to create a good and healthy social care and wellbeing for the citizens. The environmental pillar means that the people are living through the natural resources our earth is offering them and they need to consume them moderately. Finally, the economic pillar stands for the profit a country is making by using resources in an effective, efficient and sustainable manner. In order to have a perfect sustainable development, all the pillars should be balanced and should work together. Unfortunately, there is always a lack in one or more pillars, and the one that is in great danger and generally needs the greatest care is the environmental one.

![Figure 1: the three pillars of sustainable development](image)

Lately, Morocco has acknowledged the huge danger the environment is facing and is striving to improve environmental sustainability for the future generations by raising awareness of ongoing decrease on non-renewable energies and increase of electricity and water costs [1]. Moreover, the country is constantly encouraging research in renewable energies and finding solutions to improve the building sector. In fact, the biggest CO₂ emissions and energy consumption come from this sector.

So, one way to help the environment decrease the energy consumption related to the building sector is to increase the use and efficiency of the insulation, improve the construction material and increase the awareness of the importance of using an insulation. People tend to think that it is only a waste of money to install an insulation in their house when they are more wasting money on buying a huge load of heating means.
1.1 Project Description

Zaouiat Sidi Abdessalam is a small region in the outskirt of Ifrane, where the houses are in a deplorable condition. People living in that region are really poor and live from the vegetables, fruits and meats they produce. Since their houses are not suitable and adaptable for the harsh weather, the residents are obliged to use heating means such as wood, gas and coal which can be not only financially and physically burdensome, but also dangerous for their health. After visiting the region, the first thing that catches the eye is that most of the houses’ construction is not even finished. The habitants find finishing their house building really expensive while it can lessen their heating expenses.

This project has an objective of improving the lives the people by finding the adequate materials to renovate an empty building and adding an insulation system that will lessen the cost of heating. The building will be a workshop for the habitants of the Zaouiat to create handmade pieces and sell them. Moreover, it will also include a restaurant and an exhibit gallery for tourists. First, I will choose a house to renovate in the Zaouiat. It should be a small model house without any legal or architectural problems. Then, I will try to find the perfect materials that will suit the house via calculating their thermal properties (thermal conductivity, thermal diffusivity and many others) by conducting experiments, simulating the suitability of these materials on the house in Design Builder and finally choose the best one at the end.

1.2 STEEPLE Analysis

The STEEPLE analysis is a mean that allows companies, organizations and small businesses to assess the impacts and effects of their projects on their external environment. STEEPLE stands for social, economic, environmental, political, legal and ethical implications. It is better than the SWOT analysis, which is an acronym of strengths, weaknesses, opportunities and threats, since the SWOT analysis neglect the external environment. Moreover, it is an extension of the PEST, which deals only with political, environmental, social and technological implications. [2]

1.2.1 Social Implications:

The social factors analyzes the impact of the project on the population growth rate, the population’s safety, lifestyle and health. This capstone project will improve the living conditions of some citizens of the Zaouiat by creating a workshop where they can work and
help them go through the harsh and cold weather of Zaouiat Sidi Abdessalam. Construct buildings using natural resources can limit the risks of some health problems as well. Moreover, the renovated building will be a place where people can gather and share some moments together.

1.2.2 Technological Implications:

The technological factors deal with any new inventions and technologies related to the project. This project can improve the building sector as it will be about finding an innovative mixture of construction and insulation materials. Concerning the technologies used in the capstone, the simulation of many mixtures will be done thanks to Design Builder and the data obtained experimentally will be gathered thanks to BenchLink.

1.2.3 Environmental Implications:

The environmental factors study the positive and negative effects of the project on the environment. The main goal of the project is to design and build an ecofriendly model building. So, I will find solutions to limit the energy and heat consumption by increasing the efficiency and effectiveness of the building and insulation materials. Moreover, decreasing the energy consumption will lead to a decrease of the CO$_2$ emissions.

1.2.4 Economic Implications:

Concerning the economic factors, they deal with the impact of the project on the economic growth, inflation, interest rate, savings, investments and many business related themes. The workshop will be a smart building, i.e. it needs to generate the costs of electricity and heating so that almost all the profit gained from the tourist buying the art pieces and the restaurant will go to the citizens of the Zaouiat. Besides, this workshop will bring tourists and motivate people to invest in the Zaouiat to transform it a touristic village with hotels and many other activities and so generate a lot of profit for the poor people of the Zaouiat.

1.2.5 Political Implications:

The political factors of the project analyses the effects of the project on the governmental organization and the political stability. The goal of the Moroccan government lately is to improve the sustainable development of the country by encouraging researches on how to decrease the energy consumption. This project can be seen as helping the government achieving its goals as it is about transforming a model house into an eco-friendly one and limit
its energy consumption. Moreover, this project was funded by the region of Fes and Meknes as it was found to be interesting.

1.2.6 Legal Implications:

The legal implications see how the project may affect the tax policies, employment laws and environmental regulations. Before choosing a building to renovate for the capstone, it was made sure that it has no legal problems and that it follows all the construction laws. Moreover, the capstone will not break any safety regulation. All the decisions regarding the constructing and renovation of the house will follow the standards drawn by our country.

1.2.7 Ethical Implications:

The ethics are a set of morals and values that guide people essentially through their decision making. In order to work on this project ethically, I need to be honest with the citizens of the Zaouiat, keep them informed on the progress of the project and explain to them the role of each material used and its importance. Moreover, I need to keep in mind that I should follow the academic integrity and take it seriously. This project is an original work, and all references that helped build this project are cited.

2. METHODOLOGY

As mentioned before, the aim of this capstone project is to find a suitable and affordable material for the renovation and insulation of model house in Zaouiat Sidi Abdessalam in order to reduce the energy consumption. To do so, many steps need to be followed:

- The first step will be about getting a deep understanding of the materials used in the building sectors. It is necessary to go through a bibliographic study and literature review to first have a list of all materials used in building and insulation, know their composition, their properties, their advantages and their disadvantages. After that, the list of materials will be narrowed leaving only the materials that I can work with.
- The second step will be experimental. In other words, it will report all the trials of the experiments conducted with samples of mixed materials and present the result obtained from them. This step is primordial as it will help find the thermal properties of some combinations of materials. It will be conducted in L’Ecole Supérieure de Technologie as they have the machines needed to do the flash and the asymmetrical hot plate methods. In fact, Dr. Khebbazi, professor at the ESTS, and Fatima Zohra Elwardi, PhD
student, assisted me and guided me through the creation of the samples and extraction of their properties.

- The third steps will be a simulation in Design Builder. I will implement the mixtures of construction and insulation materials in a small model of the renovated house and test the efficiency and effectiveness of this materials to see if they will suit the conditions of Zaouiat Sidi Abdessalam and choose the best mixture according the software. All the results of the software will be enumerated in this step.

3. THEORITICAL STUDY

3.1 Properties

3.1.1 Density

The density, also known as the volumetric mass density, stands for the mass of a material over its volume. It is usually denoted by \( \rho \) and its SI unit is Kg/m\(^3\).

\[
\rho = \frac{m}{V}
\]

- \( m \): the mass of the material in Kg
- \( V \): the volume of the material in m\(^3\)
- \( \rho \): the density in Kg/m\(^3\)

3.1.2 Thermal conductivity

Thermal conductivity is a material’s aptitude to conduct heat. It is denoted by \( k \), \( \lambda \) or \( \kappa \). This property is retrieved from Fourier’s law of heat conduction. Fourier thinks that the rate of heat transfer with respect to time through a substance is positively related to the temperature difference in the cross area and negatively related to the thickness. In SI units, its unit is W/(mK). If we have a model as shown in figure 12, the equation to calculate the thermal conductivity is:

\[
k = \frac{Qd}{tA\Delta T}
\]

*Figure 2: Fourier's law of heat conduction*
There is an experimental way to determine the thermal conductivity of a material or mixture which is called the asymmetrical hot plate. This method, shown in figure 13, uses three thermocouples which are linked to the lower surface of the heating element, the upper and the lower surface of the sample as shown in figure 13. These thermocouples will measure temperatures T0, T1, and T2 of the sample and heating element that will appear on the software BenchLink. Then, the thermal conductivity can be calculated using the equation below:

$$\lambda_1 = \left( \frac{U^2}{RA} - \frac{\lambda_2}{t_2} \right) \frac{t_1}{T_0 - T_1}$$

λ₁ : The thermal conductivity of the mixture in W/(mK)
U: The voltage induced in the sample in V
A: The area of the sample’s surface in m²
R: The resistance of the insulation foam in Ω
t₁: The sample’s thickness in m
t₂: The insulation foam’s thickness in m

3.1.3 Thermal diffusivity

Thermal diffusivity expresses the rate of heat transfer at a constant pressure. Its unit, in SI units, is m²/s. It is usually seen as the velocity of heat transfer. Here is the process to find the thermal diffusivity:
First, there is the flash method which is done experimentally. In fact, a surface of the sample receives a strong laminar flow in a closed box each 10-15 seconds. After that, a thermocouple links the sample’s face that doesn’t receive the radiation to the computer, and more precisely the software Benchlink. The software creates a graph from the data collected via the thermocouple of the temperature with respect to time. The experiments is done when the temperature starts decreasing. Using the graph, two methods can be used to find the sample’s thermal diffusivity.

![Graph](image)

**Figure 5:** graph obtained from the data given by Benchlink

- The first method is called the Parker method. It can retrieve the diffusivity using this equation:

\[
D = 0.139 \frac{d^2}{t_{1/2}^{1/2}}
\]

Where \(d\) is the thickness of the sample in m and \(t_{1/2}\) is the time where \(T_2\) will be half \(T_m\) in s.

- The second method is called the DE Giovanni method. It uses these equations to get the thermal diffusivity:

\[
D_1 = \frac{d^2}{t_{5/6}^{5/6}} (0.15t_{5/6} - 1.25t_{2/3})
\]

\[
D_2 = \frac{d^2}{t_{5/6}^{5/6}} (0.76t_{5/6} - 0.926t_{2/3})
\]

\[
D_3 = \frac{d^2}{t_{5/6}^{5/6}} (0.618t_{5/6} - 0.862t_{2/3})
\]

And so:

\[
D = \frac{D_1 + D_2 + D_3}{3}
\]

### 3.1.4 Specific Heat Capacity
The specific heat capacity is the amount of heat needed to increase the temperature of 1 kg of the material by 1 K. Its unit is joule per kelvin times kilogrammes. It can be computed using this equation:

\[ C_p = \frac{k}{D\rho} \]

Where \( k \) is the thermal conductivity in W/(mK), \( D \) is the thermal diffusivity in m\(^2\)/s and \( \rho \) is the density of the material in kg/m\(^3\).

### 3.1.5 Thermal Effusivity

Thermal effusivity is a material’s ability to conduct and exchange thermal energy with its surrounding. It can be either extracted experimentally using a thermal effusivity sensor (which is unfortunately unavailable in almost all laboratories in Morocco) or theoretically using an equation that regroups all the properties seen before:

\[ e = \sqrt{k\rho c_p} \]

Where \( k \) is the thermal conductivity in W/(mK), \( c_p \) is the material’s heat capacity in J K\(^{-1}\)Kg\(^{-1}\) and \( \rho \) is the density of the material in kg/m\(^3\).

### 3.2 Construction Materials

#### 3.2.1 Clay

Clay is one the most ancient materials used in building shelters. It is obtained naturally from the rocks’ decomposition and it combines clay minerals, organic matter and metal oxides. Moreover, the clay is classified as inorganic material that has many properties. First of all, it is easy to procure as it is a natural source and so is really an economic material. Then, it is

![Figure 6: Clay in form of blocks](image)
ecofriendly since it is recyclable and its carbon emissions are relatively small compared to other construction materials. Moreover, it purifies the air by absorbing humidity and moisture. The clay has a crystalline composition made of sheet-like structure which is known as the phyllosilicate \([3]\). It contains a mixture of two types of sheets: Tetrahedral (which is made of silicate of \((\text{SiO}_4)^4^-\)) and octahedral (which is made of aluminate of \((\text{AlO}_4)^5^-\)). Moreover, there is three types of clay: Illite, Kaolinite and Montmorillonite-Smectite. The Illite is a clay with two layers of tetrahedral and one layer of octahedral (T-O-T or 2/1). The Kaolinite has a structure composed of one tetrahedral layer and one octahedral one (T-O or 1/1). Then, the Montmorillonite-Smectite is composed of two layers of tetrahedral sheets and one layer of octahedral sheet. It differs from the Illite by the distance that separates the sheets. Finally, the clay has a density varying between 1000 and 2200 Kg/m\(^3\) and a coefficient of thermal conductivity between 0.2 and 1.1 W/(mK) depending on the type of the clay.

### 3.2.2 Stone

The stone is one of the most robust construction materials. It is not only strongly durable, but also the oldest the stone is, the better are its properties and its aesthetic. Moreover, it is a material extracted from earth, so it doesn’t need any further energy or power to produce it. The natural stone is also known by its wide range of shades and structure. Unlike other materials, stones can be kept in any shape and glued together by either clay or mortar (which is a mixture of sand and cement). It is a material that highly resist wind, snow, rain and all harsh weather factors. Besides, stone is recyclable and requires little to no maintenance over time. It is divided in three categories: Igneous, sedimentary and metamorphic. The igneous stones (as seen in figure 8) come from the cooling and transforming of lava or magma from a liquid phase to a solid phase. The sedimentary rocks (as seen in figure 7) come from the accumulation of small fragment of rocks on the surface of the earth. And, the metamorphic stones can be either igneous or sedimentary rocks whose properties have been changed due to the temperature or
the pressure they were created in [4]. Finally, stone has a density between 2300 and 2800 kg/m$^3$ and a thermal conductivity of about 1.7 W/(mK).

### 3.2.3 Cob

Cob is a material composed of clay, sand, straw and sometimes soil, as shown in figure 10. These ingredients are mixed together with specific amounts to get a dough that is left to dry after the house is built. Each ingredient is important and has a unique job. For example, the clay (and sometimes with soil) plays the role of the glue that holds all the other ingredients together and the straw gives the walls made of cob its tensile strength. The cob is a good material for building construction as it is very inexpensive and hence affordable to many. It has an excellent thermal mass and so it will keep the houses warm in winter and cold in summer. Moreover, the cob is very easy to use, doesn’t require any special equipment or training and can last very long. Finally, even if it depends on the amount of each ingredient, the cob’s average density is 1685 kg/m$^3$ and its average thermal conductivity is 1.1 W/mK [5].

### 3.2.4 Concrete

The concrete is one of the most used materials in construction. It is cheap and easily found in most places. Moreover, it can be shaped in any way possible, but it is usually used as bricks as shown in figure 11. The durability of concrete is very high and it helps prevent fires as it is a
non-combustible material. This material is mainly made of aggregate, which is a mixture of gravel and rocks. There are two types of concrete depending on the type of aggregate it contains: lightweight and heavyweight concrete. The lightweight concrete contains aggregate with a density less than 2080 kg/m$^3$ due to its porous nature. Which means that it has a high water absorber. The heavyweight concrete contains aggregate that have a density greater than 2080 kg/m$^3$. So, unlike lightweight concrete, it is really less porous and have a greater mass-to-volume ratio [6].

3.3 Insulation Materials

3.3.1 Industrial Materials

3.3.1.1 Fiberglass

The Fiberglass, also known as glass wool, is an insulation made from glass fibers and sand. It is either sold in rolls or in slabs. The process of making this material is complex as it requires a high temperature. It starts with creating the glass fibers by mixing sand and glass at approximatively 1500 °C. The spinning that comes after creates the shape and feel of wool that is shown in figure 12. The fiberglass provides safety for the habitants as it is non-combustible. But, people should be careful and meticulous about the exact components of the fiberglass as it may contain formaldehyde which is dangerous for the health [7]. Its thermal conductivity is between 0.037 and 0.04 W/mK but it can increase to 0.037 and 0.055 W/mK according to the level of humidity and density.

Figure 12: Fiberglass
3.3.1.2 Rock Wool:

![Figure 13: Rock Wool](image)

The rock wool, also known as mineral wool, is an insulation material which is similar to fiberglass but using molten rock to produce fibers. In fact, the manufacture process starts with melting rocks at a temperature of about 1600°C. Just like the fiberglass, the spinning procedure after creates the wool texture of the insulation material, as shown in figure 13. The rock wool is not a great resistant of fire as it can burst into flames, but it remains a resistant to moisture and continues to do its insulation work even when humid. Moreover, the insulation material can regulate not only the exchange of heat, but also the exchange of sounds with the surroundings. However, it can create a feeling of irritation which can worsen to become lung cancer. The mineral wool’s thermal conductivity is slightly bigger than the fiberglass’ thermal conductivity. [8]

3.3.1.3 Cellulose

![Figure 14: Cellulose](image)

Cellulose insulation is a material made from paper or wood fibers. It is made by crashing the newspaper waste to small pieces thanks to a hammer mill as seen in figure 14. The cellulose
insulation is the most resistant insulation material to fire and provides also a good sound insulation. Moreover, it is made of about 80% recycled matter. Its density is 56 kg/m$^3$ and its thermal conductivity is 0.040 and 0.066 W/mK. [9]

### 3.3.2 Natural Materials

#### 3.3.2.1 Cork

![Cork](image)

Figure 15: Cork

Cork is a natural material found usually in Maâmora forest, as seen in figure 15. It is recommended to use it as an insulation material as not only its durability is unlimited, but also can be recycled over and over again. Moreover, it is considered as a renewable material that needs approximatively nine years to grow again after being cut. Health related, it is a natural material that don’t cause any physical harm to people and doesn’t release any harmful gas after being burned.

It is composed of 45% of Suberin, which makes it compressible and elastic and limits the passage of any liquid or gas. Its density is between 45 and 150 in Kg/m$^3$, its thermal conductivity is between thermal conductivity 0.038 and 0.058 W/(mK), its water absorption is 0.5 Kg/m$^2$ and its resistance to compression is between 100 and 120 KPa. [10]
3.3.2.2 Sheep’s wool

Sheep’s wool, as shown in figure 16, is a natural insulation material. It is eco-friendly since it is renewable and can be re-used as well. Moreover, it is believed to purify the air in the buildings as it absorbs gases that can be harmful to people’s health such as Sulphur Dioxide and Nitrogen Dioxide. Another advantage of using sheep’s wool is that it can prevent fire. In fact, containing a big amount of nitrogen allows it to just heat up instead of bursting into flames. Finally, not only it gives a heat insulation but also a good sound insulation compared to other systems. Its density is between 13 and 25 in Kg/m³, its thermal conductivity is between 0.035 and 0.058 W/(mK), its moisture absorption in w/w is 35% and its flame resistance in euro class is E. [11]

3.3.2.3 Straw

Straw, as show in figure 17, is a natural insulation material coming from waste. In fact, after the grain are harvested, the farmers retrieve the edible part and sell the bale which later becomes a great insulation material. Moreover, it can prevent fire by not letting the oxygen go through it. However, it remains a weak fire preventer compared to sheep’s wool and cork. Straw is
usually used as it gives thick walls that, using other materials, can be really expensive and that helps in the aesthetic of the house. Finally, straw bale, as an insulation material, is affordable and easy to find. Its density is between 90 and 180 in Kg/m$^3$, its thermal conductivity is between thermal conductivity 0.044 and 0.063 W/(mK). [12]

### 3.3.2.4 Sawdust

Sawdust is the waste that results from transforming wood. It is not usually used as an insulation material, especially in Morocco. Its role is mainly to prevent stains on the floor. It is composed from 56.2% carbon and 0.1% Nitrogen. The sawdust is the most cost effective and efficient insulation material. Moreover, since it is usually in the form of small pieces, hydrated lime is added to the mixture. The lime can be beneficial as it can repel insects. Its density is between 1000 and 1200 in Kg/m$^3$, its thermal conductivity is between thermal conductivity 0.06 and 0.07 W/(mK). [13]

### 4. STATE OF THE ART

Construction and insulation materials have been a subject of interest of many researchers. In fact, they always sought to optimize their thermal properties in a way or another. Here are some of the works of those skilled scientists:

Dr. Budaiwi and Adel A. Abdou, in their study “Comparison of Thermal Conductivity Measurements of Building Insulation Materials under Various Operating Temperatures”, investigated the impact of temperature over the thermal insulation of certain materials. They noticed that almost all the research done on the insulation materials was conducted in air temperature, which is considered to be 24°C. So, they tried to find the effect of different temperatures on thermal insulation by finding the relationship between these temperatures and the thermal conductivity of some materials. The result they obtained was that the sensitivity $\lambda$-
value of the materials to different temperatures is related to the density of the material. To be more precise, they found that the lower the density of a material, the bigger are the impacts of temperature on the thermal conductivity of the material. Dr. Budaiwi and Adel A. Abdou focused their work on industrial insulation materials such as fiberglass, wood wool, polyethylene and others, while I’m more interested by natural materials as they are healthier, cheaper and recyclable.

Another talented researcher was interested by the thermal insulation. Bjørn Petter Jelle in his research project “Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities”, started by finding the advantages and disadvantages of many industrial and natural insulation materials. Then, he Int deeper by retrieving some thermal properties such as thermal conductivity, perforation, robustness, emission during fire and fire resistivity and climate aging of some industrial materials such as expanded and extruded polystyrene, polyurethane, mineral wools and many others. He noticed that, from the materials stated before, there is almost no one that achieve all the requirements of a good thermal insulation. So, he turned toward future thermal building insulation materials such as vacuum insulation and Nano insulation materials, tried to find their strengths and weaknesses and compared them to the previous insulation materials. Once again, this research is more focused on industrial and futuristic insulation materials even if it mentioned a little bit natural insulation systems. The main goal of this capstone is to build an ecofriendly building, and the most ecofriendly materials are the natural ones.

Finally, there is the work of Dr. Soumia Mounir which is a little bit close to my capstone. In her research project “Experimental approach of measuring thermal properties for ecological materials based on additives cork or wool and Illite”, she worked on extracting the thermal properties (thermal conductivity, thermal effusivity and thermal diffusivity) of the clay when it is mixed with the cork, the sheep’s wool or plastic waste experimentally. Then, she studied thermal inertia of some materials to calculate the delay temperature and heat flow densities of the mixtures. Finally, she conducted a simulation in a software called TRNSYS to determine the effect of those mixtures on the energy efficiency of a model house. She found, from the simulation, that the mixture requiring the least amount of heating in winter is the mixture of clay and sheep’s wool. The difference between my capstone project and Dr. Soumia’s research project is that I focused on the cork and straw while she was interested in the cork, the sheep’s wool and the waste plastic.

5. EXPERIMENTAL STUDY
5.1 Experimental procedures

5.1.1 Materials used

5.1.1.1 Clay

In order to reach the smallest amount of errors, I chose to work with a clay from the Zaouiat Sidi Abdessalam so that it matches the house I work on. Thanks to the X-ray diffraction technique and fluorescence X, I could find the chemical composition of the clay:

![Clay's X-rays results](image)

Figure 19: Clay's X-rays results

<table>
<thead>
<tr>
<th>Chemical component</th>
<th>Percentage contained in clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>59.6%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>22.4%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>6.69%</td>
</tr>
<tr>
<td>Cao</td>
<td>0.0777%</td>
</tr>
<tr>
<td>MgO</td>
<td>0.97%</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.53%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.832%</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.458%</td>
</tr>
</tbody>
</table>

From the results shown below in figure 19 and table 1, I see that the clay is composed of a mineral mixture, Quartz, Mica and Alumna. So, the clay I am going to work with is an Illite clay with a crystalline structure of 2:1 layer (T-O-T).
I chose clay as it is abundant in the area, and so it would be easy and cheap to procure. Moreover, since it is an Illite clay, it has many advantages such as low water absorption, low shrinkage, chemical stability, thermal and electrical insulation and many others.

5.1.1.2 Cork

I decided to work with the cork as a substitute of rock used to build the house. It is a material in form of aggregate retrieved from Mâamora forest. Even if it is not really accessible to the villagers of Zaouiat Sidi Abdessalam, I chose this material for its good thermal properties. It is really light and can be compressed easily. Moreover, according to Khabbazi [14], the cork, when mixed to cement, contribute to increase the energy efficiency of the house.

5.1.1.3 Straw

The straw, as seen in the theoretical study, has many advantages. The main important advantage for our research is its good thermal insulation. I chose straw over many other insulation materials as it is cheap and easy to afford. Moreover, it would not need any other transportation costs as it is found everywhere, especially in small villages where they raise sheep. Moreover, for this project, it would be beneficial to have two components to compare to and to choose from at the end.

5.1.1.4 Mortar

Mortar is the combination of sand, cement and water. It has many uses, either serve as a binder and so links the construction materials together, or serve as a protection layer for the construction materials. Since I want to use clay as a binder in the mixtures, I will mainly add mortar to the mixture as a protection layer.

5.1.2 Samples’ creation

The samples I created thanks to a wooden mold of approximately 11.5x11.5x3.5 cm. I created 8 samples with different mixtures in each samples. Then, I left the samples to dry in the air for a long period of time first. After that, I put them in an oven with a temperature of 40° C to get rid of any humidity remaining in them. Before mixing the materials together, I measured the amount needed to have the ingredient filling the whole mold three times and calculated their average. After that, I calculated the volume of the wooden mold which is:

\[ V_{\text{mold}} = \text{height} \times \text{width} \times \text{length} \]
\[ = 3.5 \times 11.5 \times 11.5 \]
\[ = 462.875 \text{ cm}^3 \]
\[ = 462.875 \times 10^{-6} \text{ m}^3 \]
Then, I calculated the density of using the average mass over the volume of the mold to get the density of the sample. The masses and densities obtained are shown in table 2.

**Table 2: Masses and densities of the materials used**

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass to fill the mold</th>
<th>Volume of the mold</th>
<th>Density of material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay (dry)</td>
<td>520.5 g</td>
<td>462.875 cm³</td>
<td>1124.49 kg/m³</td>
</tr>
<tr>
<td>Cork</td>
<td>35.7 g</td>
<td>462.875 cm³</td>
<td>77.13 kg/m³</td>
</tr>
<tr>
<td>Straw</td>
<td>18.95 g</td>
<td>462.875 cm³</td>
<td>40.94 kg/m³</td>
</tr>
<tr>
<td>Mortar</td>
<td>815.59 g</td>
<td>462.875 cm³</td>
<td>1762 kg/m³</td>
</tr>
</tbody>
</table>

This step was done so that I can see if the results obtained from the mixtures are correct or not as their densities need to be between the smallest and greatest densities of their ingredients. After that, I came up with the mixtures, each different in the choice of materials, thickness or both.

**Mixture 1:**

![Mixture 1](image)

*Figure 20: Mixture 1 (15% cork + 85% clay)*

For the first mixture, I chose the cork, as shown in figure 20. In order to find the best fit of cork with the clay, I tried many ratios. So, for this mixture, I decided to have the full amount of cork to fill the mold (which means an amount of 35.7 g) and half the amount of clay needed to fill the mold (which gave us approximately 208 g) with a water ratio of 0.5 W/g (which is 104 ml of water). I mixed very well the clay with the cork until I was sure that each piece of cork will stick with the other, I added the mixture in the mold and left it to dry in the air. It contains 15% of cork and 85% of clay.
**Mixture 2:**

![Image of Mixture 2](image)

*Figure 21: Mixture 2 (7%cork+43%clay+50%mortar)*

In the second mixture, I wanted first to change the ratio of cork and clay. But, after second thoughts, I preferred to keep the same mixture but change the thickness instead. So, I prepared the same mixture but with smaller amount. In other words, I divided both the amount of clay and cork used in mixture 2 in half, i.e. I worked with 104.4g of clay with a ratio of 0.4 W/g (I reduced the water to clay ratio as I noticed that in mixture 2 the clay was too liquid and watery). With this amount, I filled 2 cm of thickness from the mold which originally have a thickness of 3.5 cm. After that, I decided to add a protection layer of mortar. After trying many ratios, the one that gave a mortar which is viscous is one amount of sand, one amount of cement and 0.25 amount of water. After mixing 60g of sand, 60g of cement and 30ml of water, I added it on top of the clay-cork mixture which gave a thickness of 0.5cm, as shown in figure 18. This mixtures contains 7% of cork, 43% of clay and 50% of mortar

**Mixture 3:**

![Image of Mixture 3](image)

*Figure 22: Mixture 3(5%cork+29%clay+66%mortar)*

In the third mixture, I kept the same amounts for clay and cork as the mixture 2 and the same thickness, but I changed the amount of the sand and cement used in mortar to get a bigger layer. To do so, as specified before, I worked with an amount of 104.4g of clay with 0.4 W/g (which is 41.72ml of water) and an amount of 17.85g of cork. Then, I doubled the amount of mortar
used in mixture 3 using another ratio. As I wanted a mixture of mortar that is mushier, I used one amount of sand, one amount of cement and 0.2 amount of water instead of 0.25. So I worked with 120g of sand, 120g of cement and 48 ml of water. It gave approximatively 2cm of clay-cork mixture and 1cm of mortar as seen in figure 19. It has 5% of cork, 29% of clay and 66% of mortar.

Mixtue 4:

![Figure 23: Mixture 4 (4%cork+22%clay+75%mortar)](image)

This mixture is also about playing with the thickness of the mortar. In fact, I want to test if the protection layer of mortar and its thickness has an impact on the thermal properties of the cork and clay. So, I kept the same amount of clay and cork as mixture 2 and 3, but I changed the amount of mortar so that I can have a thickness of 1.5 cm of mortar and 2 cm of clay and cork as shown in figure 23. I kept the same ratio of the mortar and so used 180g of sand, 180g of cement with 24ml of water (0.2 W/g). It combines 4% of cork, 21% of clay and 75% of mortar.

Mixtue 5:

![Figure 24: mixture 5 (4%cork+50%clay)+(4%cork+42%mortar)](image)

After testing many thicknesses of mortar, another idea came to my mind. In fact, I wondered what would happen if I added cork with both the clay and mortar. So, I used half the amount
needed to fill the mold of cork (which is 17.85g) with half the amount used to fill the mold of clay (which gives 208g) with 90g of sand, 90g of cement and 36ml of water (0.2 W/g) mixed with the same amount of cork used before. It has 4% of cork with 50% of clay and 4% of cork with 42% of mortar.

**Mixture 6:**

![Image of mixture 6](image)

*Figure 25: mixture 6 (8% straw+92% clay)*

After using the cork as first substitute to the stones used in the model house, I replaced it again with straw. For this mixture, I choose to have the straw predominant over the clay. Hence, I used the full amount of straw to fill the mold (which gives 18.95g) and half the amount of clay used to fill the mold (which is 208g). Then, I mixed all the ingredient together and pushed the clay and straw into the mold until I got a surface which is neat and horizontal. I noticed that the amount of straw was really bigger than the clay and that it might not hold very well (as shows figure 25), but I decided to leave it that way. It contains 8% of straw and 92% of clay.

**Mixture 7**

![Image of mixture 7](image)

*Figure 26: mixture 7 (4% straw+96% clay)*
As mentioned before, using the full amount of straw to fill the mold was not very efficient. So, I added this mixture to use another straw to clay ratio. For this mixture, I used the same amount of clay as mixture 6 (which is 208g) with 0.3 W/g (which gives 62.4ml of water), and I added half the amount of straw used in mixture 6 (which is 9.475g). Then I pushed the mixture into the mold as done before to give it a well-ordered surface. This mixture is better than the previous one as there was enough clay to hold the straw together, as shown in figure 26. It has 4% of straw and 96% of clay

**Mixture 8:**

![Figure 27: Mixture 8 (3%straw+62%clay+35%mortar)](image)

For this last mixture, I added a layer protection made by mortar on top of the clay and straw. I worked with the same amount of straw and clay for mixture 7 (which are 9.475g for straw, 208g for clay and 62.4ml of water with a ratio of 0.3 W/g). Then I mixed 60g of sand with 60g of cement and 24ml of water and added it on the clay/straw mixture. Which gave us a 1.5cm thickness for straw/clay and 0.5cm thickness for mortar as seen in figure 27. It consists of 3% of straw, 62% of clay and 35% of mortar

### 5.1.3 Results and Discussions

#### 5.1.3.1 Density:

When the mixtures dried after putting them in an oven to remove any extra humidity, I weighted each one carefully and calculated their dimensions so that I can compute their densities. The table 3 summarizes my findings:

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Densities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>673 Kg/m³</td>
</tr>
</tbody>
</table>
As I can see the densities of all the mixtures are between 600 and 1700 Kg/m$^3$, and so between the values of table 2. The densities of mixtures with the cork and clay are the smallest ones. In fact, it even diminishes the density of the clay itself. The smallest density is the one of mixture 1 (mixture of clay and cork only) with 673 Kg/m$^3$ and it gets bigger when I added mortar. What is strange however, is that the density mortar, when mixed with the cork, decreased a lot making the difference between the density of mixture 1 (mixture clay and cork only) and density of mixture 5 (mixture of clay and cork with mortar and cork) really small. Finally, the density of clay and straw gets quite big and when the mortar was added in mixture 8, it reached the biggest density among the mixtures.

5.1.3.2 Thermal conductivity:

After calculating the density, I went on calculating the thermal conductivity. Thanks to the asymmetrical hot plate method, I was able to get some temperatures that enabled me to obtain the mixtures’ thermal conductivity. I worked with an insulation foam made of polystyrene. It has a thermal conductivity $\lambda_2$ equal to 0.04, a thickness $t_2$ equal to 0.0102m and a surface $S$ of 0.01m$^2$. Moreover, the voltage source I worked with was set to 6V and 0.15A. Then I waited till the temperatures (T0, T1 and T2) shown in Benchlink became stagnant and I used them to calculate the thermal conductivity. The table 4 summarizes the results obtained.

\begin{table}
<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
</tr>
</thead>
<tbody>
<tr>
<td>t$_1$ in m</td>
<td>0.03</td>
<td>0.025</td>
<td>0.03</td>
<td>0.035</td>
<td>0.038</td>
<td>0.02</td>
<td>0.015</td>
<td>0.02</td>
</tr>
<tr>
<td>T0 average</td>
<td>30.07</td>
<td>27.54</td>
<td>28.35</td>
<td>26.76</td>
<td>29.62</td>
<td>26.59</td>
<td>28.83</td>
<td>26.59</td>
</tr>
<tr>
<td>T1 average</td>
<td>23.27</td>
<td>22.24</td>
<td>23.89</td>
<td>21.81</td>
<td>22.54</td>
<td>23.51</td>
<td>22.89</td>
<td>23.21</td>
</tr>
<tr>
<td>T2 average</td>
<td>21.43</td>
<td>20.86</td>
<td>22.05</td>
<td>21.27</td>
<td>22.04</td>
<td>21.28</td>
<td>22.18</td>
<td>21.24</td>
</tr>
</tbody>
</table>
\end{table}
\[ \lambda_1 \text{ in } W/(mK) \begin{array}{cccccccc} & 0.15 & 0.22 & 0.34 & 0.39 & 0.24 & 0.20 & 0.63 & 0.38 \\ \hline \end{array} \]

It is known that the smallest the thermal conductivity is, the better is the thermal insulation. From the results obtained in the table 4, I can see that the mixture that can be considered as the best insulation for the house is the cork mixed with clay (mixture 1) with a thermal conductivity of 0.15 W/(mK). After comes the mixture with 8% of straw and 92% of clay with a thermal conductivity of 0.2 W/(mK) (mixture 6). The mixture with the worst thermal insulation is mixture 7, which is with 4% of straw and 96% of clay, with a thermal conductivity of 0.63 W/(mK). It can be concluded that having bigger amount of straw decreases the thermal conductivity and so increases the thermal insulation.

### 5.1.3.3 Thermal diffusivity:

While waiting for the temperatures to stabilize to get the thermal conductivity of the mixtures, I ran the flash method to save time as these methods need a lot of time and patience. First, I put the samples in the closed box and waited for the temperatures displayed in Benchlink to stabilize. Then, I extracted all the temperatures saved each 5 seconds and I plotted them with respect to time.

After that, using the parker method, I obtained the thermal diffusivity of each mixture, as shown in the table 5.

<table>
<thead>
<tr>
<th>Table 5: Mixture’s thermal diffusivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time ( t_{1/2} ) in s</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Mixture 1</td>
</tr>
<tr>
<td>Mixture 2</td>
</tr>
<tr>
<td>Mixture 3</td>
</tr>
<tr>
<td>Mixture 4</td>
</tr>
<tr>
<td>Mixture 5</td>
</tr>
<tr>
<td>Mixture 6</td>
</tr>
<tr>
<td>Mixture 7</td>
</tr>
<tr>
<td>Mixture 8</td>
</tr>
</tbody>
</table>

Just like the thermal conductivity, lower thermal diffusivity means that the exchange of heat between the surroundings and the interior of the building is low, and so the thermal insulation is good. From our results, I can see that the mixture with the lowest thermal diffusivity is the
first mixture, and so the cork and clay can be seen as having the best thermal insulation. Whereas the mixture with the greatest thermal diffusivity is none other than the fourth mixture with 4% of cork, 21% of clay and 75% of mortar. The results obtained from thermal diffusivity match the results found from the mixtures’ thermal conductivity in the mixture with the best insulation, but differ in the mixture with the worst thermal insulation.

5.1.3.4 Specific Heat Capacity
Using the equation that is mentioned before and which links the thermal diffusivity, the thermal conductivity and the density of the mixtures, I was able to compute the specific heat capacity of each mixture, as shown in the table 6:

<table>
<thead>
<tr>
<th>Mixture 1</th>
<th>969.29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture 2</td>
<td>1287.23</td>
</tr>
<tr>
<td>Mixture 3</td>
<td>1285.87</td>
</tr>
<tr>
<td>Mixture 4</td>
<td>1030.53</td>
</tr>
<tr>
<td>Mixture 5</td>
<td>1220.09</td>
</tr>
<tr>
<td>Mixture 6</td>
<td>913.08</td>
</tr>
<tr>
<td>Mixture 7</td>
<td>2233.14</td>
</tr>
<tr>
<td>Mixture 8</td>
<td>956.19</td>
</tr>
</tbody>
</table>

The specific heat capacity provides the quantity of heat required to raise the temperature of a material or a combination of materials by 1K. For our mixtures, the mixture that require the greatest amount of heat to change its temperate is mixture 7 which contains 4% of straw and 96% of clay. In fact, compared to the other mixtures, it needs approximatively double amount of heat. The mixture that needs the lowest amount of heat is mixture 6 which is clay with 8% of straw and 92% of clay.

5.1.3.5 Thermal Effusivity
The final factor that can affect the thermal insulation of a material is its thermal effusivity. This factor is calculated from previous properties that are thermal conductivity, density and specific heat capacity. The results obtained are recorded in table 7.
Table 7: The mixtures' thermal effusivity

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Thermal effusivity in $Ws^{0.5}\text{m}^{-2}\text{K}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture 1</td>
<td>312.81</td>
</tr>
<tr>
<td>Mixture 2</td>
<td>451.55</td>
</tr>
<tr>
<td>Mixture 3</td>
<td>693.48</td>
</tr>
<tr>
<td>Mixture 4</td>
<td>694.47</td>
</tr>
<tr>
<td>Mixture 5</td>
<td>446.23</td>
</tr>
<tr>
<td>Mixture 6</td>
<td>411.96</td>
</tr>
<tr>
<td>Mixture 7</td>
<td>1304.19</td>
</tr>
<tr>
<td>Mixture 8</td>
<td>767.22</td>
</tr>
</tbody>
</table>

Low thermal effusivities mean that the material has a good thermal insulation. This can be explained by the fact that a material with low thermal effusivity means that it doesn’t absorb heat from its surrounding, and so the material has a weak ability to adjust its temperature with its external surrounding. Once again, mixture 1 with 15% of cork and 85% of clay has the lowest thermal effusivity with 312.81 $Ws^{0.5}\text{m}^{-2}\text{K}^{-1}$ and so present the best insulation properties. The mixture with the highest thermal effusivity is mixture 7 with an effusivity of 1304.19 $Ws^{0.5}\text{m}^{-2}\text{K}^{-1}$.

6. SIMULATION

6.1 Building Chosen
The building chosen to be our workshop is an abandoned building in ruins, left from the colonial era. It is in front of the river, which gives it an aesthetic touch. Moreover, the building is vacant so renovating it will be easy as it will not have to be evacuated first.
One of my teammate, Salma Boujmiraz, working on the architecture of the building shaped the building and created a model in design builder. Design builder is a software that enables us to simulate and model houses, which has many functions such as 3D and realistic modeling of buildings (as shown in figure 29), calculating heat losses and gains of a building and many others.

Figure 28: Building chosen to renovate

Our vision for the building is that its basement will contain an atelier where people will create tapestries and carpets, a living room where people can rest and a small Hamman and a kitchen for the local people. Then, its first floor will contain an art gallery where the tapestries and carpets will be exposed, a restaurant/ café for the visitors and a veranda and an office. Figure 23 and 24 show the blueprint of the building drawn in design builder.

Figure 29: Realistic model done in Design Builder
6.2 Simulation Procedures

Since many factors enter into consideration and that don’t give the same results, a simulation of the building is primordial. As stated before, one of the characteristics of design builder is that it gives you heat losses in a regular winter day, which will help define the best thermal insulation. The first step that needs to be done is to search for a reference to which I will compare our mixtures. Since the building is made of stones, I will consider the limestone provided by design builder as our reference. Then, I will create new model data for our mixtures where I will enter the mixtures’ properties obtained experimentally. On one hand, I will start
first by considering the material as our construction material. It will have the same thickness as the actual existing wall (which is 0.4m). Then I will conduct our heating design simulation. On the other hand, I will consider our mixture as an insulation interior layer added to the limestone, with a thickness of 0.1m and redo the heating design simulation.

6.3 Results and discussion

The heating design simulation of design builder provides a graph of the heat losses that happen to the building. In the graph, many factors are presents such as gazing, ceiling, external ventilation. Those factors were set to standard so that the impact of the most important factor for this capstone, which is walls heat losses, can be noticed. The zone sensible heating is the amount of heating energy that a plant should procure if it wants to overcome the heat losses obtained (see appendix). It will also be changing as it is the addition of the heat losses of all the factors.

**Limestone:** the heat losses obtained from the walls are 6.77 KW/ per winter day. This value will be considered as the reference that needs to be optimized.

**Mixture1:** When the clay and cork are used as the construction material of the building, the heat losses of the walls are about 1.38 kW. The first thing that can be noticed is that it is really small compared to the limestone. In fact, the heat losses of the mixture with 15% of cork and 85% of clay are approximatively one sixth of the heath losses of the reference material. Since smaller heat losses mean good insulation, the clay and cork have a six times better thermal insulation than the limestone. When mixture 1 is used as an exterior layer of thermal insulation, the heat losses obtained from walls are approximatively 3.02 kW. Although they increased from 1.38 to 3.02 kW, they remain better than limestone itself.

**Mixture2:** This mixture is composed 7% of cork, 43% of clay and 50% of mortar. The simulation showed that the heat losses obtained when putting mixture 2 as construction material of the building are about 1.84 kW. The mortar added diminished the thermal insulation of the clay and cork. Still, it is almost three times better than limestone. The same observation can be done when the mixture is used as thermal insulation material instead of construction material. The heat loss obtained than are 3.63 kW, which is two times better than the reference material.

**Mixture 3:** This simulation confirmed the previous observation. In fact, the heat losses increased from 1.84 to 2.54 kW when 5% of cork, 29% of clay and 66% of mortar were used as a construction material. Moreover, the heat losses increased from 3.63 to 4.31 kW when the mixture is entered in the software as a thermal insulation layer. It can be concluded from these two previous mixtures that the more mortar is added, the bigger are the heat losses and the
smaller is the thermal insulation. However, both the results obtained with this mixture remain better than using limestone.

**Mixture 4:** As expected, when I increased mortar in this mixture, the heat losses increased as well. The results obtained in this simulation are 2.82 kW when the mixture is used to build the house and 4.52 kW when the cork, clay and mortar are used only as an interior insulation layer. Just like with the three previous mixtures, the results obtained with mixture 4 are better than what was obtained when limestone was used to build the house.

**Mixture 5:** When adding the cork to the mortar, it diminished the heat losses obtained in mixture 4 almost by half. In fact, the simulation showed that the heat losses of the building’s walls in a regular winter day will be 1.97 kW if the mixture is to be used in building the house and 3.47 kW if it is to be used as a thermal insulation layer. It is still less efficient then having only the cork and clay. However, it is more effective than almost all the mixtures where the principal ingredients are cork, clay and mortar, and more efficient than the limestone.

**Mixture 6:** When I replaced the cork with straw in this mixture, the simulation gave the second best results right after mixture 2. It showed that if I use this 8% of straw with 92% of clay to hold it, the heat losses will be 1.71 kW if it is used to build the house and 3.47 kW if it is used as interior thermal insulation.

**Mixture 7:** After thinking that the previous mixture might not hold, I added this one where the clay is predominant over the straw. The heat losses obtained almost doubled from the previous mixture and so its thermal insulation seriously diminished. Even if its thermal properties are better than limestone, it gives the worst insulation from the eight mixtures with 3.92 kW if it is used in constructing the building and 5.16 kW if it is used as a thermal insulation layer. It can be concluded that the greater the amount of straw, the greater the thermal insulation will be.

**Mixture 8:** After running the simulation of the final mixture, I noticed that it contradicted one of the previous observations. This mixture contains approximatively the same amount of clay and straw than the previous mixture, and a small layer of mortar was added. What was noticed earlier is that when the mortar is added to the mixture, it diminishes its thermal insulation. However, this mixture gave smaller heat losses than mixture 7 with 4% of straw and 96% of clay. The simulation showed that the heat losses will be 2.75 kW and 4.48 kW if this mixture was used as a construction material and as an added insulation system respectively. So, I can conclude that the mortar decreases only the cork’s ability of thermal insulation.

From this simulation, it can be concluded that if I choose any one of this mixture as either a construction material or as an added interior insulation system, its thermal properties will be better than those of the existent wall’s limestone. The simulation showed that the best mixture
to use is the one with 15% of cork and 85% of clay (mixture 1) followed by the one with the one with 8% of straw and 92% of clay (mixture 6). It also presented mixture 7 (which is made of 4% of straw and 96% of clay) as having the worst thermal properties among all the mixtures. It also showed that the mortar diminishes the thermal insulation of cork, however, it helps increase the thermal insulation of straw. It can be explained by the thermal insulation of mortar being between the thermal insulation of cork and straw. Therefore, it decreases the insulation of cork when added to it as it has lower insulation ability and increases the insulation of straw since it has a greater insulation system.

For the Zaouiat, the best fit would be using the first mixture with 8% of straw and 92% of clay as a construction material, but it would be better to use it as an exterior insulation material since the limestone wall is already built and seems strong. Moreover, using it as an insulation can be more affordable for the Zaouiat’s habitants.
7. CONCLUSION

This Capstone’s aim is to find a suitable and reasonable construction and isolation material for a model house in Zaouiat Sidi Abdessalam. To achieve this goal, many parts were completed. First, the capstone’s first part deals with a theoretical study that gives information for a better understanding of the construction and insulation materials, their thermal properties, their advantages and even their disadvantages. Then, its second part will be an experimental part where mixtures from cork, clay, straw and mortar were created, and their thermal properties retrieved through the flash method and the asymmetrical hot plate. From this part, the mixture with cork and clay distinguished itself with its outstanding thermal properties and so promised a good thermal insulation. Then, the third contained a simulation done in design builder. Each mixture was either entered as construction material of the house or as a layer of insulation materials and after a heating simulation was conducted. The simulation affirmed that the mixture with the best insulation is 15% of cork with 85% of clay, followed by the mixture with 8% of straw and 92% of clay. Finally, I choose the mixture with cork and clay as an interior insulation of the building to renovate as it would be more accessible for the habitant of the Zaouiat.
8. REFERENCES


[13] TREATMENT OF SAWDUST INSULATION FOR PROTECTION AGAINST, MOLD, DECAY, INSECTS, RODENTS AND FIRE. Retrieved from

9. APPENDIX

1. Flash method graphs

![Graph 1]

![Graph 2]
2. Design Builder graphs

Limestone:
Mixture 1:
a) **Used as a construction material:**

![Graph showing heat balance for Mixture 1 as a construction material]

b) **Used as added thermal insulation:**

![Graph showing heat balance for Mixture 1 as added thermal insulation]

Mixture 2:
a) **Used as a construction material:**

![Graph showing heat balance for Mixture 2 as a construction material]
b) **Used as added thermal insulation:**

![Diagram showing heat balance for added thermal insulation](image)

**Mixture 3:**

a) **Used as a construction material:**

![Diagram showing heat balance for construction material](image)

b) **Used as added thermal insulation:**

![Diagram showing heat balance for added thermal insulation](image)
Mixture 4:

a) **Used as a construction material**

![Graph showing heat balance for Mixture 4](image)

b) **Used as added thermal insulation:**

![Graph showing heat balance for Mixture 4](image)

Mixture 5:

a) **Used as a construction material**

![Graph showing heat balance for Mixture 5](image)

b) **Used as added thermal insulation:**

![Graph showing heat balance for Mixture 5](image)
Mixture 6:

a) Used as a construction material

b) Used as added thermal insulation:
Mixture 7:

a) **Used as a construction material**

b) **Used as added thermal insulation:**

Mixture 8:

a) **Used as a construction material**

b) **Used as added thermal insulation:**