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PAU Institute of Water and Energy Sciences
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Presented by

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TITLE: Techno Economic Assessment of Thermal Insulation Materials for Container House under Steppe Climate Conditions.

Defended on 10/09/2019 Before the Following Committee:

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ABSTRACT:

A building's energy consumption depends on the features of its envelope. In this research, comparative analyses were conducted to select the best insulation material for a residential building made of shipping containers. This building is called the JuaHouse, devoted to international competition named solar decathlon Africa. The analyses are based on literature review results from which three best materials were selected depending on specific criterions. Afterwards, based on Design Builder Software, different building thermal simulations had been generated for each insulation material in different thicknesses. Finally, economic analysis were carried out by analysing the investments costs, projected annual energy cost savings and payback.

RÉSUMÉ

La consommation d'énergie d'un bâtiment dépend des caractéristiques de son enveloppe. Dans cette recherche, des analyses comparatives ont été menées afin de sélectionner le meilleur matériau isolant pour une maison conteneurs. Ce bâtiment s'appelle JuaHouse, dédié à la compétition internationale « Solar Decathlon Africa ». Les analyses sont basées sur la revue de littérature à partir desquels trois meilleurs matériaux ont été sélectionnés sur la base des critères spécifiques. Par la suite, avec l'utilisation du le logiciel Design Builder, nous avons effectué des simulations thermiques pour chaque matériau isolant dans des différentes épaisseurs. Enfin, nous avons fait une analyse économique en prenant compte les coûts d'investissement, les économies annuelles de coûts prévues et le payback.

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.

Abbreviations:

WW2: World War 2.

HVAC: Heating Ventilation Air Conditioning

WCED: World Commission on Environment and Development

EEC: European Economic Community,

EU: European Union.

EPBD: Directive on the energy performance of buildings

RT: Reglementation Thermique.

AC: Air Conditioning.

NZEB: Nearly Zero Energy Building

EPC: Energy performance certificate

DWH: Domestic Hot Water

ADEREE: Agence Nationale pour le Développement des Energies Renouvelables et de l'Efficacité Energétique

EnEV: Energy Saving Ordinance

RES: Renewable Energy Sources

IPEE: Incentives Programme For Energy Efficiency

Bbio: Besoin Bioclimatique

Cpe: Le Coefficient d'Energie Primaire

KfW: Kreditanstalt für Wiederaufbau

IPEE: incentives programme for energy efficiency

EPS: Expanded polystyrene

BES: Building Energy Simulations

XPS: Extruded Polystyrene

PUR: Polyurethane

PF: Phenolic Foam

PAUWES: Pan African University Institute of Water and Energy Sciences.

MEMEE: Ministère Marocain de l'Energie, des Mines, de l'Eau et de l'Environnement

IRESEN: Institut de Recherche en Energie Solaire et Energies Nouvelles

UM6P: Université Mohammed VI Polytechnique

Introduction

1. Introduction:

Over the past centuries, attention has risen exponentially to energy and environmental issues, and many international and national policies have been established to ensure a more sustainable future for the planet.(S. Schiavoni et al 2016). Building and construction together accounts for 36% of worldwide final energy consumption and 39% of energy-related carbon dioxide (CO2) emissions when upstream power generation is included (UN 2017). The energy saving potential of this sector is substantial, with significant potential benefits at many levels. For individuals, energy-efficient homes mean improved comfort and more disposable income. For economic sectors, energy efficiency improves industrial competitiveness and increases asset values through rental and sales premiums. National governments can benefit from reduced energy- related expenditures and reduced energy dependency; while at the international level energy efficiency improvements equate to reduced GHG emissions, lower energy prices, improved natural resource management and other socioeconomic benefits. (European commission).

The building sector could lead to a reduction of its energy consumption by means of appropria te and effective insulation strategies. Effective insulation conserves energy and therefore requi res less energy for cooling room in summer and less heat to keep the home warm in winter.
The chain effect of the application of this energy efficiency method decreases the use of natural resources (oil and gas reserves) used for power generation and slows down their depletion rate. It therefore reduces the production of greenhouse gases. Building insulation is regarded as an easy yet extremely energy-efficient method that can be applied to residential, commercial and industrial buildings. The thermal insulator consists of mono or composite material that has the characteristic of high thermal resistance, showing the capacity to reduce the heat flow rate. Building insulation can therefore hold the heat / cool inside the house and stop heat flux with the surrounding area. The cost saving is another significant benefit of building insulation. This is possible as this technique contributes to favourable net energy balance by saving a bigger quantity of energy through the implementation of insulation than the energy needed to produce the insulation material itself (L. Aditya, 2017).

2. Questions:

- How to select the appropriate material to be used when insulating fabric envelopes?
- What is the economic benefit of using building insulation materials?

- What are the actions that should be taken by the African countries governments in order to encourage the use of insulation materials?

3. Objectives:

This study aims to investigate the best insulation material for a container house called JuaHouse devoted to International Competition called Solar Decathlon Africa. While the specific objectives of this research are:

i. Determine materials with low impact on the environment basing on their availability, price and the U value.

ii. The use Design Builder software to do the thermal analysis of JuaHouse.

iii. Economic analysis of the findings.

Background

1. Introduction:

In this chapter we will describe the magnitude of greenhouse gases coming from the energy use and which contribute to climate change. Afterwards, we will highlight the energy transition as one of the solutions to reduce the negative impact of energy use and to ensure a sustainable development, this solution aim to transform the global energy sector from fossil-based to zero-carbon. Building as a sector that consumes energy, will also be described in the present chapter by highlighting the building energy status Morocco as a case study region, its energy activity evolution, different factors influencing energy consumption, environmental practices and examples of building energy codes.

2. Energy and Climate Change:

Nowadays, the world is at fastidious moment trying to eradicate global warming. The phenomenon is due to many factors such as greenhouse-gas (GHG) emissions. statistics have shown that those emissions increased by more than one quarter and the concentration of these gas has increased continuonsly to 435 parts per million carbon-dioxide equivalent (ppm CO2-eq) in 2012 (EEA, 2015. The international panel on climate change (IPCC) came to the assumption that the lack of serious measures taken , climate change will continue to have deep consequences on the safety of our world . It is high time all countries of the world unite together to maintain the growing regular climate degrees at two degree Celsius. This will be possible only if global emissions are cut down drastically. (International Energy Agency, 2015)

Greenhouse-gas emissions (GHG) only from the energy sector constitute about two-thirds of all anthropogenic greenhouse-gas emissions and carbon dioxide (CO2) from the field have increased drastically in the twentieth century. As a result, secure measures taken in the field of energy , are highly needed in order to eradicate the problem of climate change. (International Energy Agency, 2015)

Fossil fuel represent 80% of all energy need and more than 90% of emissions associated with energy are carbon dioxide from fossil-fuel combustion. From the year 2000, the interest in coal has risen from 3% to 44% of carbon dioxide ejection coming from energy alone; the amount of natural gas maintained a horizontal level at 20% while oil decreased from 42% to 35% in the year 2014. On the other hand (although it has less size and disappears from the air faster but affects global warming more than the other two) , Methane (CH_4) and nitrous oxide (N_2O) are other forceful green-house gases released by the energy sector .CH_4 represent 10% of energy -ejected gases and comes especially from oil and gas extraction, transformation and delivery .what remains is from (N_2O) ejections from energy transformation, industry, transport and buildings. (International Energy Agency, 2015)

3. Sectors of Final Energy Consumption and related CO2 Emissions:

Final energy consumptions represent what reach the client (people) for all energy operations. It is generally commingled into the final consumption by sectors: industry, transport, building , services (Figure 1) . The uses by each field have an impact on the carbon dioxide ejections with the exact rate. (United Nat ions Environment, 2017)

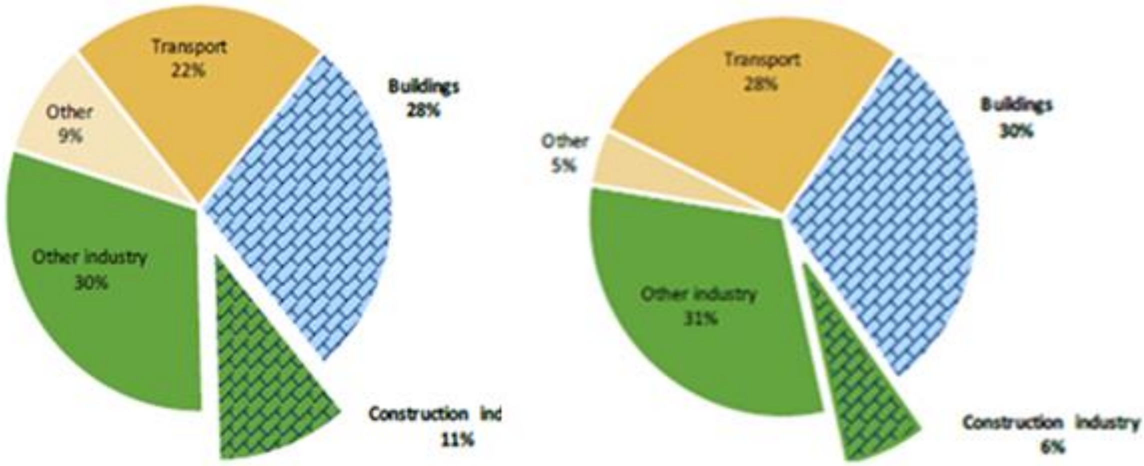


Figure 1: Global Energy consumption and CO2 Emissions per sector in 2015
Reference: United Nations Environment, 2017

4. Energy Transition:

Continual advancement aims carried by the UN or the agenda of 2063 of the African union are all at once continental and global initiatives to eradicate .famine, preserve the planet and make sure that its inhabitants live in security and prosperity (United Nations, 2019) .Among those fields is that of energy in which they advocate energy transition as a way to words their perception.

The idea of energy transition is the change of global energy field from fossils to zero-carbon by the end of the twenty-first century (International Renewable Energy Agency. 2017).

4.1. Main pillars of Energy transition:

Renewable energy, energy efficiency and conservation are the major components of energy transition and they are explained as (National Energy Education Development Project,2014) :

- Renewable energy: consumes energy sources which are continually replenished by nature like the sun, the wind, water, the heat of the earth , and plants . Sustainable energy technologies transform these fuels into accessible types of energy and they are not harmful to the environment.
- Energy efficiency includes the usage of technology that needs less energy to do the similar operations.
- Energy conservation involves any actions resulting in less energy use.

Renewable Energy, Energy Efficiency and Conservation are having several advantages as presented in the following scheme:

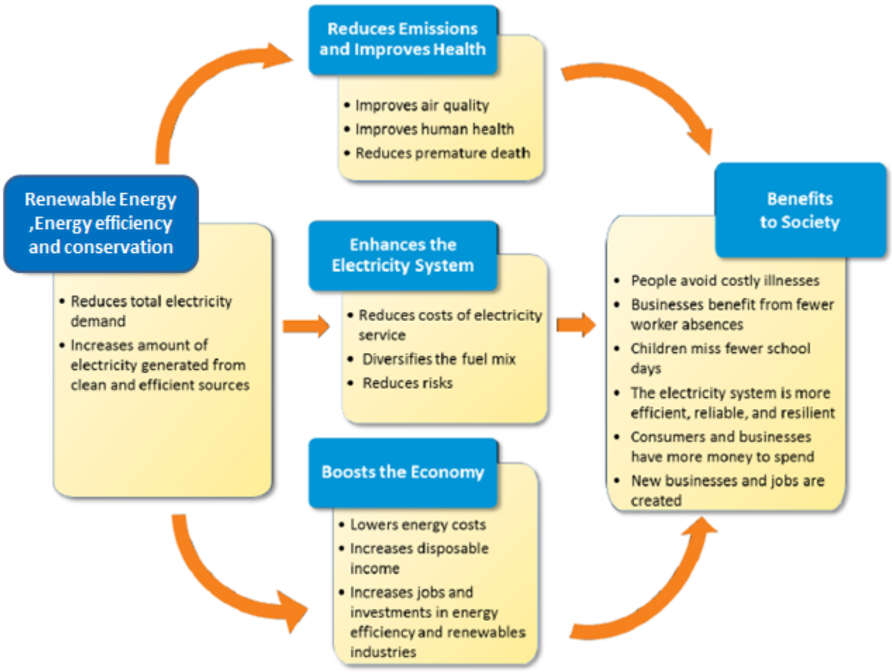


Figure 2 : The Multiple Benefits of Energy Efficiency and Renewable Energy
Reference: U.S. Environmental Protection Agency (EPA), 2011

5. Renewable energy, energy efficiency and conservation need to expand in all sectors:

Increasing the deployment of renewable energy , energy efficiency and conservation measures in all sectors will have to spread their advantages in order to attain their targets (example: climate targets) in this respect and according to IRENA , the deployment of renewable energy should rise from 15% of the total primary energy supply in the year 2015 to nearly two-thirds by the year 2050. Besides, the energy intensity of the global economy will have to decrease by almost two-thirds in the year 2050, decreasing the sum of the total primary energy supply

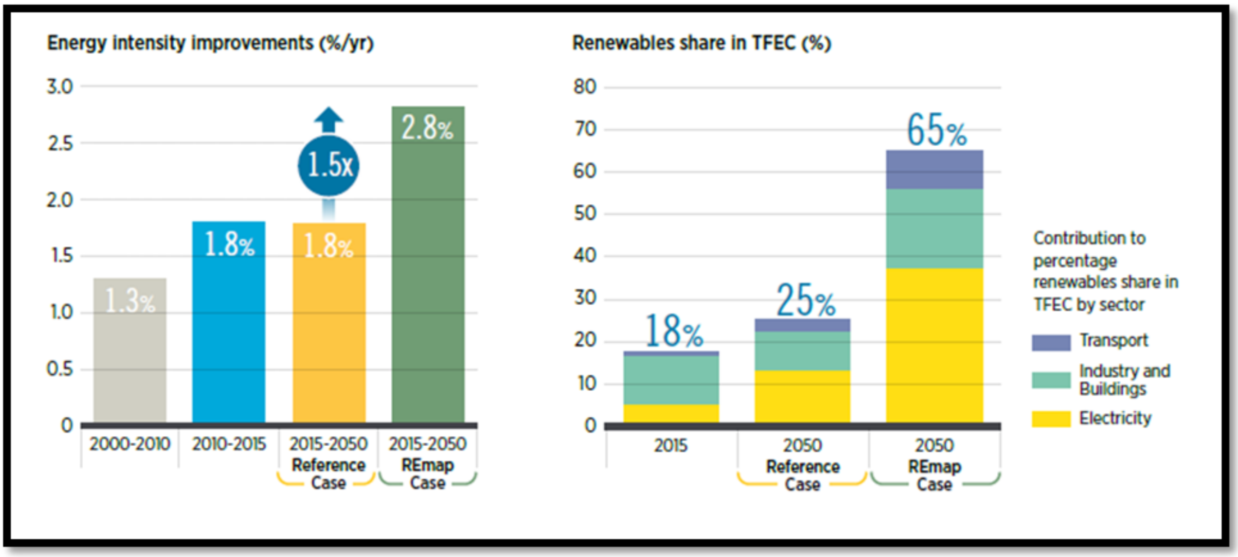


Figure 3: Energy intensity improvement rate (%/yr) and renewable energy share in TFEC (%), Reference: International Renewable Energy Agency (IRENA) 2018

in the same year to somehow less than its amount in 2015. This can be attained , in spite overcrowded cities and economic growth, by substantially improving energy efficiency and conservation.**(**International Renewable Energy Agency (IRENA) 2018)

6. Energy and Buildings:

The global building sector used about 125 EJ in 2016 , the equivalent of 30% of the sum of energy used , construction industry as cement and steel production, represent more than 26 EJ (about 6%) in overall sum of energy consumed (Figure 1). (United Nations Environment, 2017)

Upstream power generation reported that constructions constituted 28% of overall CO2 emissions related to energy, including direct ejection from fossil fuel burning which constitute one third of the total. Construction is one of the energy field which constitute 11% of energy sector carbon– dioxide emission (Figure 1). (Reference United Nations Environment, 2017)

Fortunately, the universal yearly constructions with CO_2 ejection have risen, at least for a while, at about 9.5 gigatonnes of CO_2 ($GtCO_2$) in 2013.Then it wents down to 9.0 $GtCO_2$ in 2016. Nevertheless, this result is caused by the continual initiative to minimize carbon of power generation with direct emissions from constructions regular at about 2.8 $GtCO_2$. On the contrary , CO_2 emissions from buildings remained regular from 3.1 Gt CO_2 in 2010 to nearly 3.7 Gt CO_2 in the year 2016 .The amount of energy used by the field of construction (in terms of energy use per m^2) persists to get better at a yearly paste of about 1.5% . Nevertheless, the total ground area grows by 2.3% per annum, balancing the concentration of energy progress. Keeping on the same scale in the next years will rise the difficulty to fulfil aims of 2°C world or less. (Reference United Nations Environment, 2017)

It is high time we addressed energy and ejections from buildings and construction if we are to attain 2°C as world temperature or even less. By the year 2039, more than one half of new buildings awaited for the year 2060 will be built. Unfortunately, two third of those buildings are awaited to appear in countries that do not recently have compulsory building energy codes in place. Building growth will be especially fast in Asia and Africa. For instance, ground area in India is awaited to double in the year 2035. Nevertheless, only a small amount of the building sector is having mandatory energy building codes. (United Nations Environment, 2017).

6.1. Factors Influencing Building Energy Consumption:

Knowing the above five parameters that impact energy use in construction is prominent to deal with gases released from building sector.

6.1.1. Climate:

The outdoor design situation would differ depending on the respective climate zone and this will in turn dictate all construction elements ' thermo-physical characteristics. Climate can therefore be recognized as a significant factor influencing energy consumption in buildings

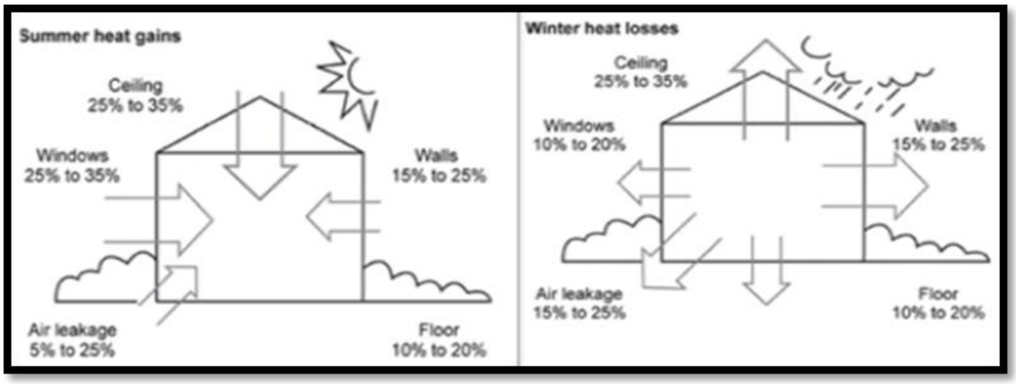


Figure 4: Typical Heat Losses and Gains without insulation in temperate climate (Steppe climate). Reference: M. Mosher, et al, 2013

(Figure 4). In addition, a long-term trend that is' climatology' and short-term behaviour of the atmosphere, i.e. ‘weather’ can be identified as two sub factors under the ‘climate’ category. (M. N. K. De Silva* and Y. G. Sandanayake,2012,)

6.1.2. Building Related Characteristics:

Type, age , size, class, usage hours, geographical location, design/structural parameters,

Figure 5 : Vernacular Architecture Reference: ‘L’Adrere Amellal un écolodge en plein désert Egyptien’, 2018

Figure 6: Contemporary Architecture Reference Laura Meunier 03.31.2016.

orientation, envelop, construction quality, worker density, share of areas served by air-conditioning, lift and illumination, indoor environmental/thermal quality, nature of surrounding, rent and availability of infrastructure were identified as sub factors of ‘building related characteristics’(Figure 5,Figure 6),. These building related characteristics have a tremendous influence on building energy use .As a result, holders can really preserve energy by considering and promoting the above features and parameters. **(**M. N. K. De Silva* and Y. G. Sandanayake, 2012,)

6.1.3. Building Services and Systems Related Characteristics:

The ‘building services and systems related characteristics ‘consists of seven sub factors, such as building services and systems specification, building services and systems load,

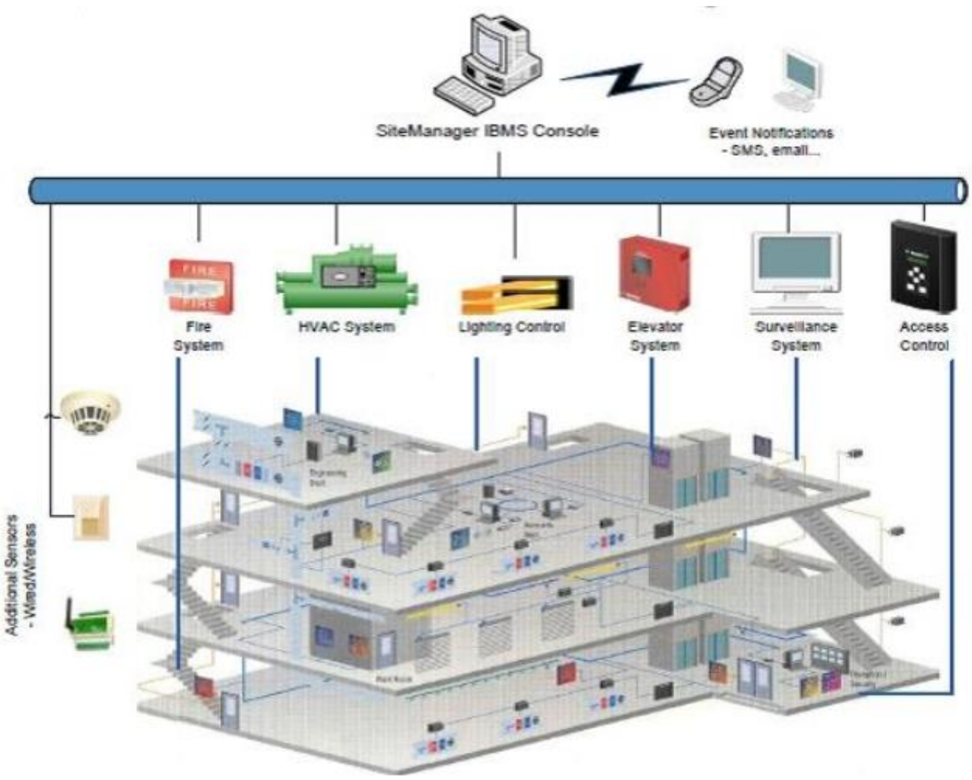


Figure 7: Building systems
Reference: Intelligent Building System and Facility Management, 2017

operation and maintenance schemes, efficiency/condition of building services and systems, age of building services and systems, sub facilities/services offered and appliance ownership (Figure7).

6.1.4. Occupant Related Characteristics:

Buildings do not need energy as opposed to people. whenever the altitude of ownership rises, the use of energy of HVAC, lights , elevators and other plug uses rise too) claimed that buildings users have major roles but less understood and often overlooked role in the built environment (Figure 8).

Figure 8: Example of lighting usage .
Reference: Portrait Profile Child Girl In Glasses Reading A Book In The Night Zooming,2016

6.1.5. Socio-Economic and Legal Characteristics:

Education, culture, income, age of the head / householder, availability of energy resources. On a local level, energy market prices and energy use regulations can be defined as various social and economic as well as legal features influencing building energy use (Figure 9).

Figure 9 : Example of Energy Bills
Reference: Paying bills using a smartphone

6.2. Energy and Buildings in Africa:

EIA claimed that the building is the high energy consumer sector in Africa with a total share of 57% **(**Ürge-Vorsatz .D et AL, 2012). Furthermore, Africa has the highest population growth with a pace of 2.55% per year from 2010 to 2015. It is expected that more than one half of the total population increase between 2019 and the year 2050 in Africa. (Population", 2016). As a consequence, the increase in construction will grow very fast in this content

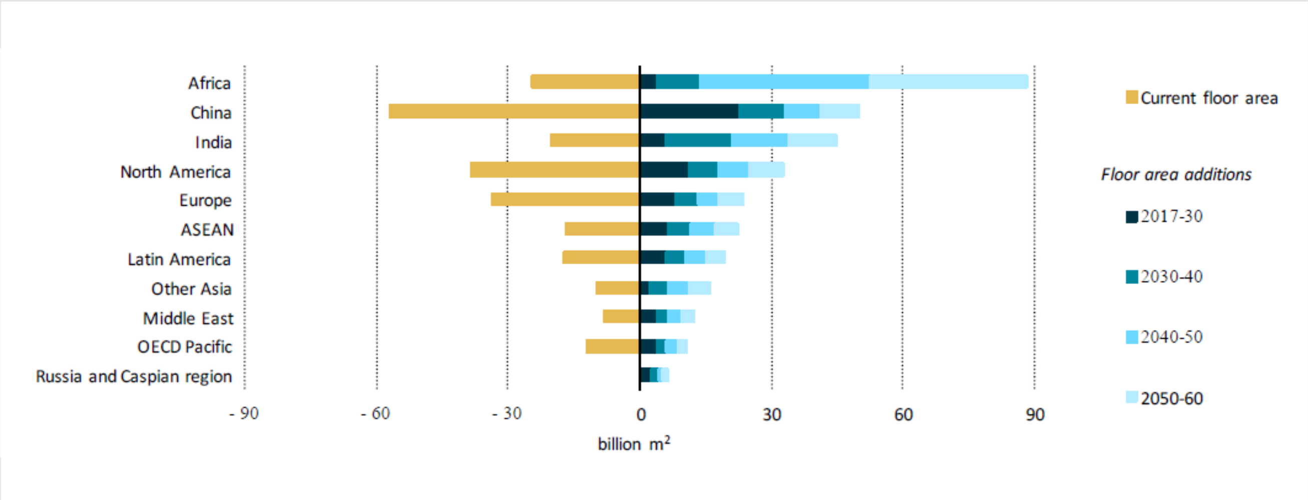


Figure 10: Floor area additions to 2060 by key regions
Reference: United Nations Environment, 2017)

(Figure 10). Leading to a growth in the use of energy in this sector (United Nations Environment, 2017).

6.3. Energy and Buildings in Morocco:

Morocco is a country that depends on energy in the first place. with nearly 95% of energy use being imported (French Facility for Global Environment et al.2017). Beside that, the use of energy in the field of construction represents 36% of the country’s total energy, in which 29% in residential areas and 7% in the tertiary, the use of energy is estimated to grow quickly in future years due to major evolution of the building energy park.(Guechchati.R, et al 2012),In the populated areas , the number of houses represent nearly 6.4 million , at the end of the year 2016. The houses built per year increased of about 150.000 recently. In the tertiary, there is a regular increase in the building of hotels and holiday apartments. (French Facility for Global Environment et al.2017).

6.4. Environmental Practices related to Buildings:

The preservation and sustainability of our earth like the safety of the next generations is extremely prominent .In this regard, the actors in different sectors are making major decisions with their operations to decrease their environmental footprint , One way this is accomplished is through environment-friendly construction methods. (Almusaed.A, 2011).

6.5.1. Bioclimatic Approach:

This notion relates to the concept of creating buildings and manipulating the environment within buildings by operating with natural forces around the building rather than against them in order to ensure optimum physical comfort for humans. (Almusaed.A, 2011).

6.5.2. Energy activity and sustainability in building sector:

Buildings are responsible for many of the world's energy waste and general use of energy, resulting in more degradation of the environment. Energy activity is therefore regarded one of the most important matters linked to environmental construction methods. **(**Harputlugil.T, 2017).

6.5.3. Building Energy Activity Evolution in The Last Century:

The industrial revolution was one of the most important achievements in the 19th century. The steam power was the first example started with electric energy through the grid. The beginning of mass production into many aspects of life and the demands that required the new space. Before the 20th century , the energy efficiency in architecture was the main perspective in terms of climate and negative design systems ; this last was a reaction on improvements of previous experiences (systems and technics included in the vernacular architecture) (Table1). **(**Harputlugil.T, 2017).

With the beginning of the 20th century next to world war one, was the era when inventions and systems that would lead to the development of many systems that today can be used in buildings energy efficiency that started to show up such as the lift, electrical energy, reinforced concrete steel and air conditioning systems, all of these emerged in this period of time. In addition to that, HVAC system has been used for the first time in building; As a result, the amount of energy consumption was increased. **(**Harputlugil.T, 2017).

About the half of the 20th century, due to the industrial revolution around the world, the mass production is increasing almost everywhere and affected the building sector. In architecture, the design of modernism could be seen. HVAC system and its integration developed with the buildings and could provide examples of climate independent design. The renewal movements began to pull up / destroy completely the traces of destruction / ruins in Europe after WW2. With the Second World War, the nuclear energy was developed the sense of improvement aims to the use more efficient to resources. Besides; the experiments of solar energy and geothermal heat pumps were introduced. At the same time, the main social events can be linked as the foundation of EEC, the 60s was a turn point in daily life through technology of space. Alongside the overuse of nuclear energy, the demographic explosion and energy dependency. (Ionescu et al., 2015).

The engineering energy sector has been hit hard by the oil crisis of 1973, which has made many communities find an alternative to this crisis. So that the understanding the importance of energy efficiency in buildings , back to the passive design principles / guidelines (Commission of EU, 1991) and the new revolution of computers has a big impact in this period. At this time, realizing energy saving looks like it develops. **(**Harputlugil.T, 2017).

With the Brundtland Report (World Commission on Environment and Development-WCED, 1987) titled "Our Common Future" presented at the United Nations in 1987, the concept of term “sustainability” it has been used largely for the first time . The problem of environmental impacts is always a topic of debate (Sev,2009) .But the authorities was in the matter too . In this period of time, architecture high-tech construction and set up an innovative design solutions for energy efficiency in the construction of new buildings. This period is at some point energy management could be in the preface of energy efficiency. **(**Harputlugil.T, 2017)

The Kyoto protocol was signed (1997) and the issue of environmental losses have been largely discussed. Consequently, the debate of energy sources are getting more complicated according to the consumption of energy that buildings use and the diversities of energy sources and its impacts on environment. There is a research on renewable energy sources and how they adapt to buildings. The composed design visualized the collaboration of all design actors for energy efficiency became largely used. Incomplete home criteria were added and a variety of detailed level simulations were used, including life cycle analysis. With all of these, the concept of green buildings has been introduced along with energy efficiency The concept of high-tech construction that works with automation system appeared in this period with the idea of reuse, recycling or 3R. System of certification has been allowed to be applied according to the green buildings standards. (Çelebi et al. 2008),

In 2002 and 2010 the European Union released the authoritative decisions on energy action that governs the buildings. In line with these instructions, member states of EU should take into consideration their own circumstances; define standards and principles of implementation. The system of classification for green building and rates of use in the construction sector. Energy efficiency measurement and control mechanisms have been improved gradually due to the standards that have been raised as the time passes .The focus has been set up on renewable energy sources. Studies on climate change had led improvement in the near future and this can be achieved using the construction stocks. Carbon and toxic gas emissions should be studied very well to decrease the influence of waste related to these buildings.**(**Harputlugil.T, 2017).

The EU energy performance 2010, sets up standards, in order to achieve high-tech performance buildings. Nowadays, the process based on renewable energy resources is ascending meanwhile there is a decrease in energy production in terms of fossil resources. Alongside all of these, the produced energy by buildings comparing with consumption is now discussed about positive buildings (+) called energy (Harputlugil.T, 2017).

Table 1: Social Events and Energy Processes in the Last Century

Reference: (Harputlugil.T, 2017).

Timeline	Architectural Movement	Social Events	Effects of Social Events	Energy in Buildings
Before 20th century	Vernacular architecture	Industrial Revolution	Steam power Electric energy through the grid Mass production, specialization Need for new spaces	Passive systems Experience of the past
First quarter of 20th century	Modernism (Futurism)	1st World War Usage of elevator New building materials (reinforced concrete, steel) Invention of air conditioning	First steps of combined heating, cooling and air conditioning	New systems adaptation, Climate independent design
Second and third quarter of 20th century	Modernism	2nd World War Nuclear energy Space technology Establishment of European Economic Community (EEC)	Mass production after the world war The term “optimization” Basics of solar energy usage Basics of geothermal energy usage Basics of heat pump technologies	Systems integration
20th century 1970-1980	Post-modernism	1973 Oil crisis	Back to climate based design principles Passive house principles Development and adaptation of computer technology	Conservation of energy
20th century 1980-1990	High-tech	Destruction of ozone layer 1987 Bruntland report The term “Sustainability” Developments of personal computers	Global development models Sun houses Passive design principles Environmental consciousness	Sustainability and energy management
20th century 1990-2000	Deconstruction	Kyoto agreement Establishment of European Union (EU) Green building certification systems	Environmental consciousness Passive House standards Green buildings	Variety of energy sources Efficiency of renewable energy sources

			Life cycle analysis Energy based simulation software Integrated design Renewable energy sources Smart buildings	
21st century 2000-2010	Sustainability	2002, 2010 EU Energy directives Energy Performance Building Directives (EPBD)	Green building certification systems Energy performance certificates Renewable energy sources New standards for energy efficiency Scenarios for climate change	Standards Reduction of emissions Energy efficiency Reducing carbon print
21st century 2010-2020	Sustainability	2010 EU Energy directive Paris agreement	High performance buildings	Energy efficiency Clean energy
21st century 2020 -			Positive energy	Energy production

6.5.4. Energy Efficiency in Buildings:

Energy-efficient sitting and design buildings ensures economic, social and ecological benefits. For every new evolution should have an evident energy planning, defining how these benefits are to be achieved. The quantity of energy usage in a building is a direct consequence of the climate, the use of the building and its design. It is not exaggeration to suggest that better design of new buildings would result in lowering their energy usage of 50–75 percent, and that suitable intervention in current stocks would result in a decrease of 30 percent. (Almusaed.A, 2011).

In addition, this can lead effectively to reduction of nation’s energy bill, it plays an effective role in reducing environmental impacts and lowering the stressful indoor circumstances that many citizens experience. (Clark JA, 2001). Ensuring the Energy Efficiency in buildings to minimize the impact on the environment requires the Consideration of passive and active strategies which is presented by the following:

A. Solar Passive Concept:

A building's good shape can considerably decrease the demand for heating energy during a heating season, while creating suitable microclimate circumstances during the summer (Givoni. B,1998). In particular, a contemporary, energy-conscious design "solar building" addresses 5 points as shown in the bellow (Cherier M.K):

- The building's location and shape to guarantee excellent sunshine, natural ventilation and lighting conditions (Figure 11, Figure 12).

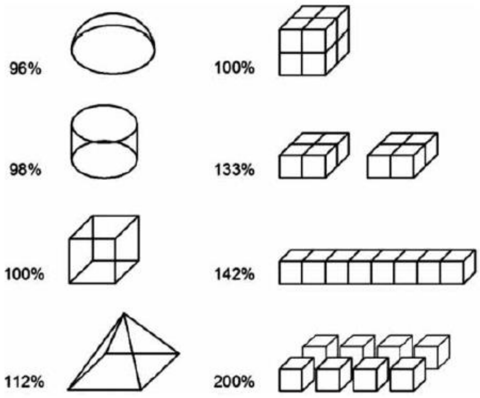


Figure 12 : Compactness The external surface areas of buildings of various three-dimensional shapes with the same volume

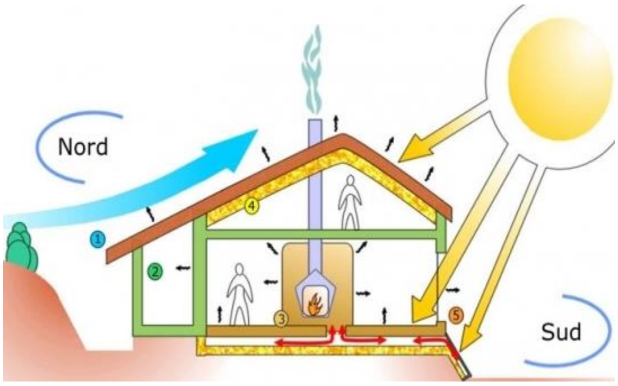


Figure 11 : Building location
Reference : L'architecture bioclimatique : principes de fonctionnement, 2010

- Internal arrangements according to the function and time of use (Figure 13).

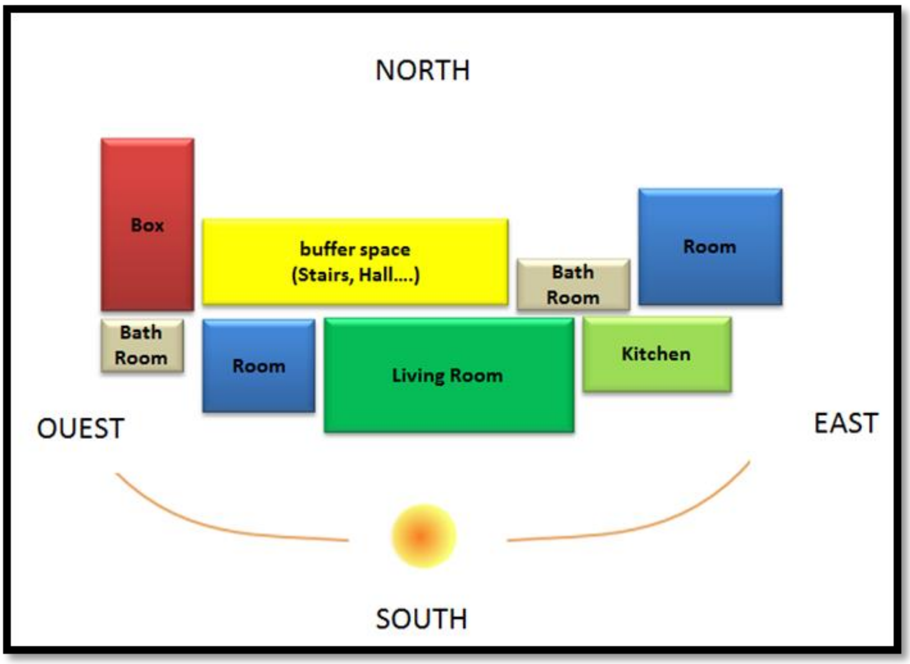


Figure 13: Interior Arrangement
Reference: E-RT2012,2013

- Create or adapt the building for passive use of solar energy using passive solar systems such as solar buffer spaces, solar collector walls or storage walls (Figure14).

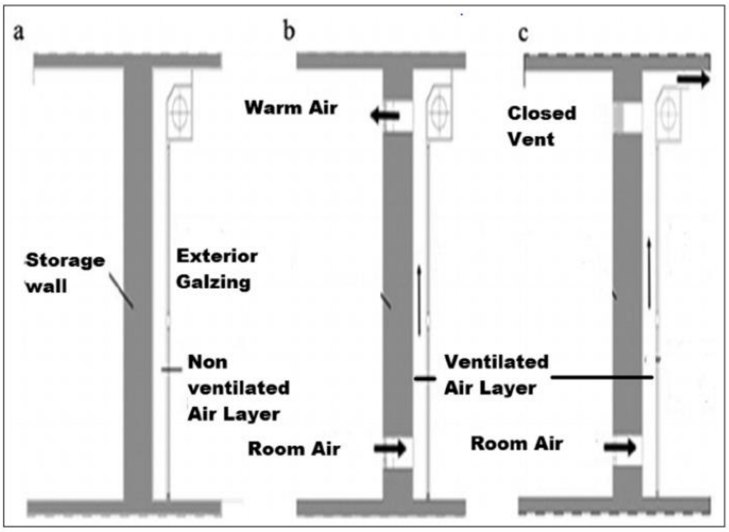


Figure 14: Solar Walls
Refrence : Saadatian.O, et al,2013

- Selection of structural components and their materials to protect against overheating from excessive solar radiation (Figure 15).

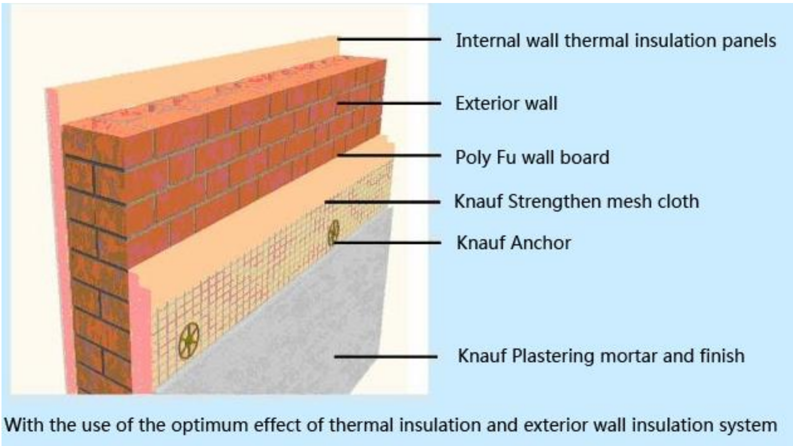


Figure 15: Wall insulation system
Reference: Knauf

- Take into consideration a building's neighbourhood for improving or reducing the available solar energy, natural heating and ventilation (Figure 16).

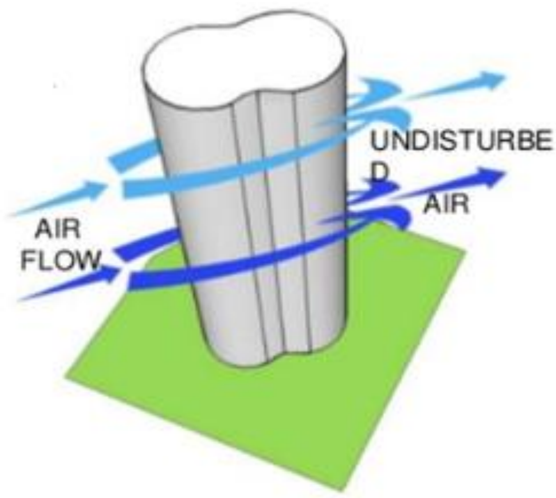


Figure 16: Aerodynamic form of a building to redirect the wind.
Reference : Shandilya.U, 2014

- ## Passive Heating:

Passive heating strategies in buildings are specifically used to collect, store and distribute solar heat benefits to decrease the demands for space heating. They do not require mechanical equipment because the heat flow (radiation, convection and conduction) is natural and the thermal storage is in the building shape. (Cherier M.K)

Moreover, the latest strategies provide natural lighting through windows. To prevent thermal leakage , the layout should be well thought out and integrated , so that all elements of the building must be well insulated even the windows .The presence of huge buildings with walls and insulated ceilings allows to store and subtract the heat out while providing good ventilation. (Figure 17). These buildings are generally known for their high temperature and opaque mass, paired with the floor and compact with the scheme. (Cherier M.K)

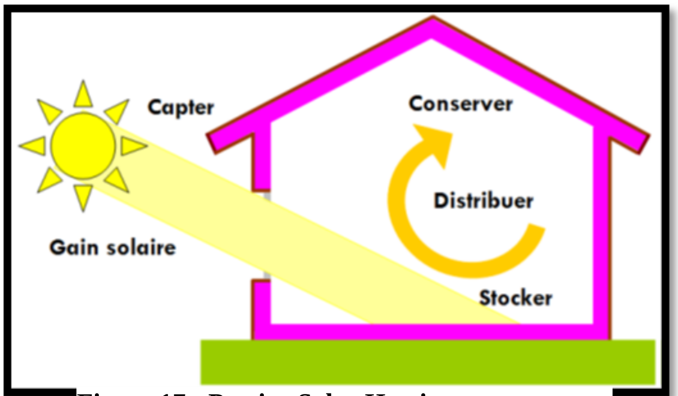


Figure 17 : Passive Solar Heating
Reference : (Cherier M.K)

➢ Passive cooling:

Passive cooling works considerably in controlling the cooling system in buildings and significantly reduces its consumption because it provides comprehensive coverage of all processes including preventive measures needed to avoid high temperature rise within the building strategy , and rejection outside the building's internal temperature . (Figure 18). The latter produced inside the building envelope or penetrated it. Either through natural thermal transfer procedures: conduction, convection, radiation, natural evaporation cooling or mechanically improved with the use of small fans or pumps (hybrid cooling), heat rejection can be accomplished. During the summer, to prevent overheating and generate thermal comfort within houses. Strategies for refreshment should be designed at three levels (Cherier M.K):

- Prevention of heat gains through suitable design at the building site: for instance, using vegetation that can contribute to lowering cooling loads).
- Heat gain modulations: a building's thermal mass (usually contained in walls, floors and partitions, made of high heat capacity material) absorbs heat during the day, regulates the magnitude of changes in indoor temperature, reduces the maximum cooling load
- Heat rejection from inside the building as the natural ventilation.

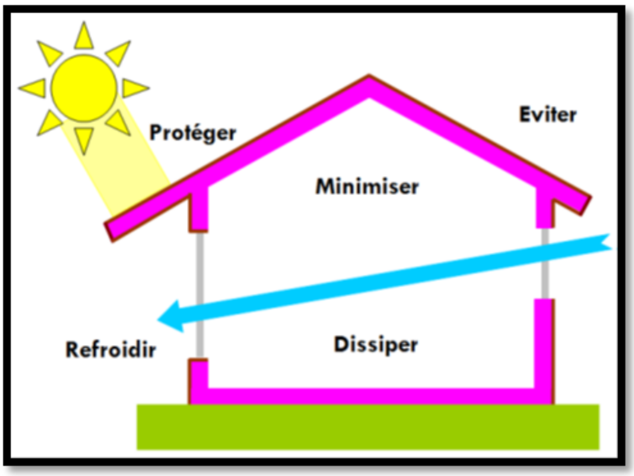


Figure 18 Passive Cooling Stratégies
Reference : (Cherier M.K)

PS: A building's heating and cooling efficiency can be enhanced by decreasing the volume ratio of its surface area. This can be achieved by minimizing exterior walls and roofs in order to create a more compact house shape.. (Cherier M.K).

- **Natural lighting:**

Natural lighting is intended to maximize the level of daylight within the building, but it optimizes the light environment quality. It has strategies that can be split into two groups. The first involves side lighting methods in which light is carried in the interior space. .(Window is this strategy's easiest example). The second group involves monitoring systems where light is carried from a building's top and dispersed indoors. A skylight is such a system's simple example. The approach for natural lighting involves four concepts (Cherier M.K):

- Penetration: collection of natural light inside the building,
- Distribution: homogeneous distribution of light in spaces.
- Protection: reduce light by external shading devices,
- Control: control the penetration of light by moving screens to avoid visual discomfort.

b. Active Strategy:

Active strategy is the strategy to use electro-mechanical devices in the conditioning room to achieve the necessary amount of comfort. The active strategy such as air conditioning systems, transportation systems, fire protection systems, plumbing systems, audio systems, bangunan cleaning systems can be used by almost all utility systems in construction. Especially for thermal environment, the active system is used for (Sahid, ST, et al,n.d):

(Sahid, ST, et al,n.d) :

- Artificial air circulation
- Ventilator
- Humidity regulator
- Air cooler

On air conditioning systems for lighting, cooling or room heating and ventilation systems, active strategy is used. Active systems are used on lighting systems to illuminate the space, particularly at night. Lighting is also used for aesthetic purpose in relation to illuminating the space. The main factors for ideal performance are the choice of light type, position and duration of use. Active strategy is used on cooling or heating devices to cool the space with cool air and run it at the required temperature in the room. For optimum performance, selective efforts are needed to choose the type of electromechanical equipment relative to building features and comfort requirements. (Sahid, ST, et al,n.d).

Since active strategy uses a range of electro-mechanical machinery for building conditioning system so that the deficiency is the big quantity of energy needed and emissions. Large consumption of energy also implies higher financial expenditures. While the benefits of using active strategy are the ease of achieving the anticipated comfort circumstances. To minimize the consumption of energy (Sahid, ST, et al,n.d):.

c. Energy generation:

Using sustainable energy in buildings. Renewable energy relates to energy resources that occur naturally and repeatedly in the environment and which can be exploited for human benefit. This type of energy comes from the Earth's natural flow of sunlight, wind, or water. We can catch some of this energy and use it in our homes and businesses with the use of unique collectors. As long as sunlight, water and wind keep flowing and trees and other plants continues to grow, we have access to a ready supply of energy. (Almusaed.A, 2011).

7. Building Energy Codes:

Integrating energy efficiency into building codes is a known approach in the residential and commercial industries to decrease energy consumption. Throughout the world, energy efficiency policies and programs in residential and commercial buildings are designed and implemented independently to reduce energy waste in the new building stock. (Young. R, American Council EEE, 2014)

7.1. France:

Building sector is considered one of the priorities in the field of energy and climate in France. Under Grenelle Environment, a program is implemented to reduce energy consumption in buildings (Environmental Roundtable). At the national level, France has made efforts to deliver a high quality and dynamic range products and services. (ADEME 2012)

The various actions taken for both new and existing buildings are presented in the following:

7.1.1. New buildings:

RT2005 (reglementation thermique 2005) was considered the first thermal regulation after EPBD and this was in 2006 and was associated with all new facilities. Thereafter, France launched RT2012 (Thermal Resettlement 2012) which is the current thermal regulation in response to EPBD (Appendix).). It was mandatory for only some public buildings since the end of 2011, and for all new buildings since 2013. This regulation is the outcome of a two-year dialog with all stakeholders, including seven advisory conferences, presenting the work underway. The next heat regulation is scheduled for 2020 and will include even more ambitious goals, as it will also include environmental requirements, most probably based on a life-cycle analysis. (Bordier R, et al, 2018).

a. Requirements for new buildings:

RT 2012 is based on three Performance requirements as follow:

- Minimum energy efficiency requirements in buildings (Bordier R, et al, 2018 have a limited level of energy demand in terms of heating, cooling and lighting associated with the (Bbio) index. (Appendix) (Videau. J.B, et al 2013).
- A requirement for primary energy consumption (Bordier R, et al, 2018), by reducing the total consumption of heating, cooling, domestic hot water, lighting and auxiliary systems (fans, pumps ...) in primary energy denoted Cpe. (Appendix) (Videau. J.B, et al 2013).
- The summer comfort. (Videau. J.B, et al 2013).

Table 2: BBJOMAX AND CPEMAX FOR VARIOUS NEW BUILDINGS' TYPOLOGIES

Reference: (Bordier R, et al, 2018),

Type of building		**Bbiomax**	**Cpemax (kWh/m².year)**
Individual House	EC1	60	50
	EC2	80	60
Apartment building	EC1	60	90
	EC2	90	105
Office building	EC1	70	70
	EC2	140	110
Secondary education building (day time)	EC1	40	55
	EC2	50	70
Secondary education building (night time)	EC1	60	90
	EC2	90	105
Shop	EC1	140	320
	EC2	250	520
Catering 2 meals/day 6 days a week	EC1	75	110
	EC2	85	125
Hospital (day time)	EC1	230	270
	EC2	270	330
Hospital (night time)	EC1	120	130
	EC2	180	190
EC1: AC not required | EC2: AC required Bbiomax: Maximum bioclimatic need (without unity) | Cpemax: Maximum primary energy consumption			

Lastly, Renewable energy in houses depends on the requirements of RT2012 and its forms vary according to the quality of energy such as solar panels at the lowest level.

b. Status of Nearly Zero Energy Building "NZEB" in France:

Buildings that do not consume large energy are called in France as "Low Energy Buildings "(Bâtiments Basse Consommation - BBC) . With the beginning of 201 NZEB is compulsory for all new buildings, including public buildings, as the Low Consumption Energy Buildings requirements are the same as in RT2012. The country now reaches approximately 1.2 million new NZEB buildings (Bordier R, et al, 2018).

7.1.2. Existing Buildings:

The existing buildings have two thermal regulations. The first was published in 2007 and is called (Regulation by Building Component). The second is called "RT globale "global thermal regulations. Figure 5 demonstrates how the required regulation can be determined, based on the type of refurbishment (significant or minor). Both regulations were evaluated in 2016 and the fresh specifications will enter into force in 2018, followed by additional envelope component specifications in 2023. (Bordier R, et al, 2018).

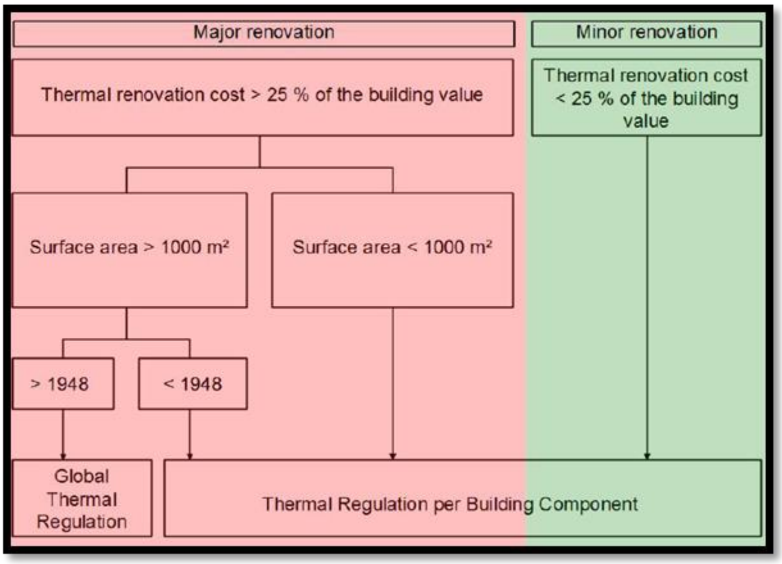


Figure 19 : Thermal Regulations for existing buildings. Reference:(Bordier R, et al, 2018)

a. Energy Consumption Level Required For Existing Buildings:

The level required for existing buildings under renovation is around 150 kWh / m.year (primary energy) for housing (expressed as compared to a reference building) and, for non-residential buildings, the energy consumption of the building must be reduced by at least 30 per cent before renovation. While this rate is quite high, the French Government has created quality labels to encourage owners to go beyond the regulatory demands (Bordier R, et al, 2018).

Two quality labels are needed for houses after refurbishment. They each have a distinct objective: the less stringent one, called ' High Energy Performance 2009 ' (HPE 2009), requires a level of 150 kWh / m .year (primary energy); a high-quality building called ' Low Energy Consumption Renovation 2009 ' (BBCR 2009) may be granted if it reaches 80 kWh / m. (Bordier R, et al, 2018).

There is a unique label for non-residential buildings, the ' Low Energy Consumption Renovation 2009 ' (BBCR 2009), which can be acquired if the building consumes more than 40% less energy after renovation. (Bordier R, et al, 2018).

b. Status of the existing building stock:

By the end of 2016, the quality seal ' Low Energy Consumption Renovation 2009 ' was awarded to 56,000 residential buildings and about 1,35 million renovated m2 of non-residential buildings.. (Bordier R, et al, 2018).

7.1.3. Energy performance certificate (EPC) in France:

In 2006, the EPC was launched in France and is called ' Diagnostic de Performance Énergétique (DPE). Since this new document had to be presented when one sells or rents a property, it is part of the existing real estate diagnosis file.

Diagnostic de performance énergétique - logement (6.1)

N° : 0 APPARTEMENT
Valable jusqu'au : 10/02/2023
Type de bâtiment : Appartement
Année de construction : Entre 1963 et 1988
Surface habitable : 50,00 m²
Adresse :

Date : 11/02/2013
Diagnostiqueur :
Signature :

Propriétaire :
Nom : [redacted]
Adresse : [redacted]

Propriet. des installations communes (s'il y a lieu) :
Nom : [redacted]
Adresse : [redacted]

Consommations annuelles par énergie
obtenus par la méthode 3CL, version 1.3, estimées à l'immeuble, prix moyen des énergies indexés au 15 Août 2011

	Consommations en énergies finales	Consommations en énergie primaire	Frais annuels d'énergie
	Détail par énergie et par usage en kWh_{EF}	Détail par usage en kWh_{EP}	
Chauffage	Réseau de chaleur : 5763 kWhEF	5763 kWhEP	431,08 €
Eau chaude sanitaire	Réseau de chaleur : 2688 kWhEF	2688 kWhEP	201,07 €
Refroidissement			
CONSOMMATIONS D'ÉNERGIE POUR LES USAGES RECENSÉS	Réseau de chaleur : 8451 kWhEF	8451 kWhEP	632,14 € Abonnements compris

Consommations énergétiques (en énergie primaire) pour le chauffage, la production d'eau chaude sanitaire et le refroidissement
Consommation conventionnelle : 169 kWhEP/m².an
sur la base d'estimations à l'immeuble

Emissions de gaz à effet de serre (GES) pour le chauffage, la production d'eau chaude sanitaire et le refroidissement
Estimation des émissions : 34,5 kg éqCO2/m².an

Figure 20 : Energy Performance Diagnosis
Reference : (Bordier R, et al, 2018).

The EPC describes two elements of

a building: its energy consumption and the effect on greenhouse gas emissions of its consumption. On the first page, the calculated or measured heating, cooling and DHW consumption expressed in final and primary energy and the corresponding annual costs are shown. (Almeida. M, 2014).

The consumption range ranges from A (low power consumption, high efficiency) to G (high power consumption, poor efficiency). The real benefit of EPCs lies in the recommendations provided to the owner of the building and is abbreviated on page 4 of the certificate (Almeida. M, 2014).

7.2. Morocco:

A key factor in Morocco's energy strategy is controlling energy consumption in building (French Facility for Global Environment, et al 2017). The country has created an energy efficiency plan for this sector with the aim of clarifying the link between administrations and operators, creating a public management scheme for institutionalized energy efficiency, a suitable legislative and regulatory framework and suitable norms. In this vein, Morocco promulgated the Law 09-47 on Energy Efficiency, which requires, in Article 3, the completion of urban planning legislation “General Construction Regulations”. Energy performance rules are also established to ensure good energy balance and are integrated with orientation, lighting, isolation, thermal flow in addition to renewable energy contributions to enhance the performance of current or new buildings (Molina-García A, et al, 2019).

7.2.1. The construction Thermal Regulation in Morocco

The National Agency for the development of renewable energies and production capacity (ADEREE) as Moroccan organism aiming to reduce energy consumption of the building sector. This agency introduces under the decree issued in October 2014, the thermal building regulation RTCM in November 2015. According to this last has an objective to reach the eco of energy estimated at 1.2 Mtoe / year by 2020.and to reduce the gas amount in greenhouse of environment 4, 5 MTECO2 (ADEREE,2014).

The National Renewable Energy and Energy Capacity Development Agency (ADEREE) introduced the Construction Thermal Regulation in Morocco (RTCM) in November 2015 under the decree issued in October 2014. Whose primary goal is to decrease this sector's energy usage. Quantitatively, the primary goal of this regulation is to achieve an estimated energy economy At 1.2 Mtoe / year by 2020.and greenhouse gas decrease 4, 5 MTECO2. (ADEREE,2014).

a. Targeted buildings of RTCM:

It concerns only the building envelope and covers both the housing sector and the tertiary buildings. Although the problem of energy efficiency in existing buildings stock is very important Morocco, the proposed thermal regulation covers initially only new buildings. The treatment of the existing building segment can be addressed through energy audits and the implementation of energy efficiency measures that result. (ADEREE, 2014).

b. Climatic zones in Morocco:

The Moroccan territory has been subdivided into homogeneous six climatic zones (Figure 21) based on the analysis of climatic data recorded by 37 weather stations over the period 1999-2008 (10 years) (Figure 8). (ADEREE, 2014).

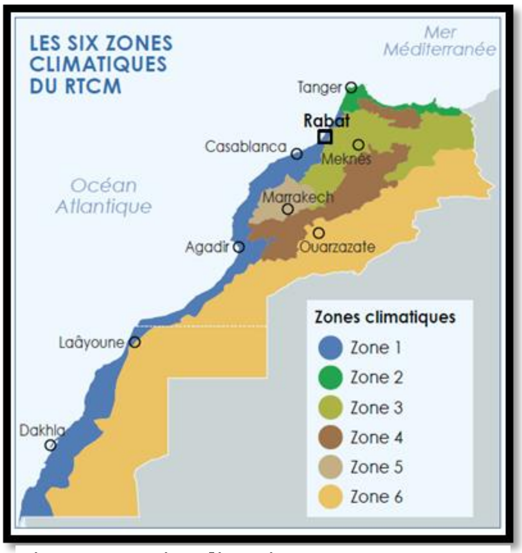


Figure 21 : Six Climatic Zones In RTCM Reference: (French Facility for Global Environment ,et al 2017),

c. Technical specifications:

Taking into account the additional investment costs on the one hand and the thermal simulations on the other hand as iterative process which leads to set reasonable levels of the envelope performance requirements to be considered as regulatory levels. These levels have been defined from the energy saving options that represent a good technical and economic compromise (ADEREE, 2014).

➢ RTCM Minimum Thermal Performance:

The maximum energy consumption for space heating and cooling, expressed in kWh / m2 / year for each climatic zone (Table 3). (ADEREE, 2014):

Table 3 : Minimum Thermal Performance of residential building in Morocco
Reference: (ADEREE, 2014).

Thermal performance of buildings area residents in kWh / m2 / year		
Z1	Agadir	40
Z2	Tanger	46
Z3	Fés	48
Z4	Ifrane	64
Z5	Marrakech	61
Z6	Errachidia	65

d. Socio-economic Analysis of the RTCM:

This analysis is about the economic feasibility of the implementation of the proposed regulation by assessing their positive or negative impacts. The results of this analysis serve, moreover, as the basic elements for consultation with different stakeholders in the sector. The analysis then focuses on the following indicators (ADEREE, 2014):

Table 4 : Economic Analysis Indicators of RTCM
Reference: (ADEREE, 2014)

At the level of the final consumer	At the State and Community level
• Additional investment costs related to the implementation of technical specifications;	• Gains in primary energy;
• Energy final gains in terms of fuel and electricity;	• Subsidies averted by the state on displaced conventional energy;
• Gains on the energy bill;	• Impacts on the electric charge curve at the national level;
• Gains on investments related to cooling and heating power;	• Electrical capacities avoided and consequent investments differentiated;
• Return time compared to the	• Emissions avoided;

additional costs invested.	
	• cost of primary TOE saved compared to the cost of supply in the international market, etc.

7.3. Germany:

The German government aims to reduce primary energy demand by 80% until 2050. Besides the need for additional efforts to achieve this target, Germany implemented a set of policies and programmes to increase investments in energy efficiency (Hermann. A, Karsten, 2011).

7.3.1. The German Energy Saving Ordinance (EnEV):

It is a central instrument within German energy and climate protection policies. Its purpose is to ensure that the targets of the Federal Government's energy policies are achieved in particular a largely climate neutral inventory of existing buildings by 2050 and around 60 percent savings in final energy consumption through efficiency measures on the building envelope and construction technology compared with 2010. The ordinance defines structural and heating system standards for buildings and specifies the energy efficiency for new builds and the refurbishment of existing buildings. EnEV is based on the Energy Saving Act (EnEG); its effectiveness is further supported by other standards and laws such as the Renewable Energies Heat Act (EEWärmeG) (DENA, 2017),

The current Energy Saving Ordinance (EnEV) 2013, implements the new requirements of the EPBD, Directive 2010/31/EU. Furthermore, strengthened minimum requirements, which are seen as a step towards NZEB, were fixed and came into force for all new buildings from 1 January 2016 (application for building permit) (Schettler-Köhler. H-P, et al, 2018).

7.3.2. Energy performance in the new buildings:

The main energy performance requirements for new buildings are defined in the Energy Saving Ordinance (EnEV) comprising (Schettler-Köhler. H-P , et al,2018):

• A maximum non-renewable primary energy demand, which is determined individually for each building using a reference building with similar building geometry, orientation and use, but with a certain quality of all energy-relevant systems and components.

• A minimum requirement for the energy performance of the building’s thermal envelope, which is determined for residential buildings, using the reference building approach as well, and for non-residential buildings, by a certain set of maximum mean U-values for opaque and transparent elements respecting the design indoor temperature of the building’s zones;

• A minimum percentage of RES used for heating, domestic hot water and cooling; the percentage is different for the various technologies.

a. NZEB in Germany:

As a first step towards NZEB, the requirements for new buildings were tightened in January 2016 (Table 2). The maximum primary energy demand now equals 75% of the 2014 value, whereas the requirements addressing the thermal envelope were strengthened by 20%. The German report10, as required by Article 5 section 2 of the EPBD, proved the 2016 requirements to be cost-optimal. Additional measures to further implement the NZEB level are currently in preparation. (Schettler-Köhler. H-P , et al,2018)

7.3.3. Energy Performance in Existing buildings:

The non-renewable primary energy demand of the building stock needs to be reduced by. The three instruments considered to be used in that strategy are regulatory law, financial incentives, as well as information and advice with aim to reach a reduction of 80% on the demand of the non-renewable primary energy from the building stock (Schettler-Köhler. H-P , et al,2018).

Requirements to upgrade the building stock comprise conditional requirements in case of relevant refurbishments, mandatory update requirements to be met without any triggering measures (e.g. insulation of the highest floor slap) and requirements in case of extensions.

Whenever relevant refurbishment is done, the minimum requirements given by the Energy Saving Ordinance have to be met. The requirements of the

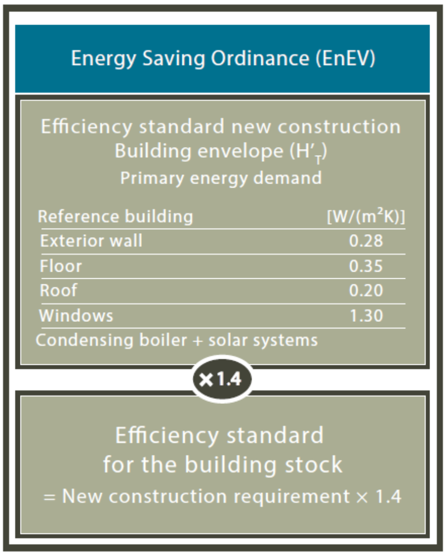


Figure 22: Relevant efficiency standards defined by the German building code RENOVATING GERMANY’S BUILDING STOCK.

Reference: Buildings Performance Institute Europe (BPIE), 2015

ordinance can be fulfilled in two ways (Schettler-Köhler. H-P , et al,2018):

• Either by meeting specific energy performance requirements for building elements and installations;
• Or by attaining 140% of the performance requirements for a new building (calculated using the reference building status 2014) (Figure 22).

If the area that is heated or cooled is expanded, such area has to meet requirement for new buildings. above a certain expansion threshold, or, if below an expansion threshold, such area must meet minimum requirements for building elements and requirements for heating/hot water supply/cooling.Extensions and expansion of more than 50 m² have to fulfil the requirements for summer conditions.('Germany, Building Code Implementation - Country Summary", n.d)

Due to a number of policies that promote energy efficiency and provide financial support, a lot of buildings are retrofitted to a higher energy performance level than required. Programmes like the KfW programme for residential and non-residential buildings, the incentives programme for energy efficiency (IPEE) and the incentives programme for heating with RES (MAP) contribute to the goal of an energy-neutral building stock. In the past 10 years, for example, the KfW has accepted about two million applications for financial support for the retrofitting of residential buildings (Schettler-Köhler. H-P , et al,2018).

a. The building retrofitting achievements in terms of Energy:

The refurbishments that were completed in 2015 led to a reduction of 7,008 MWh/year in 2016 (in comparison, refurbishments completed 2013 resulted in a reduction of 7,366 MWh/year in 2014, and those completed in 2014 in a reduction of 8,556 MWh/year in 2015, respectively). Further refurbishments are currently carried out or are in the preparation stage(Schettler-Köhler. H-P , et al,2018).

7.3.4. Energy Performance Certificate:

According to the German Energy Savings Ordinance, EPCs are compulsory for new and existing buildings when rented or sold, or when buildings undergo major energy renovations. Building owners must register their EPC in a national database, which is also being used for quality control. (Factsheet: Germany, n.d), In case of non-compliance between the EPC and the building performance a penalty can be issued to the owner by the local authorities. (Schettler-Köhler. H-P , et al,2018).

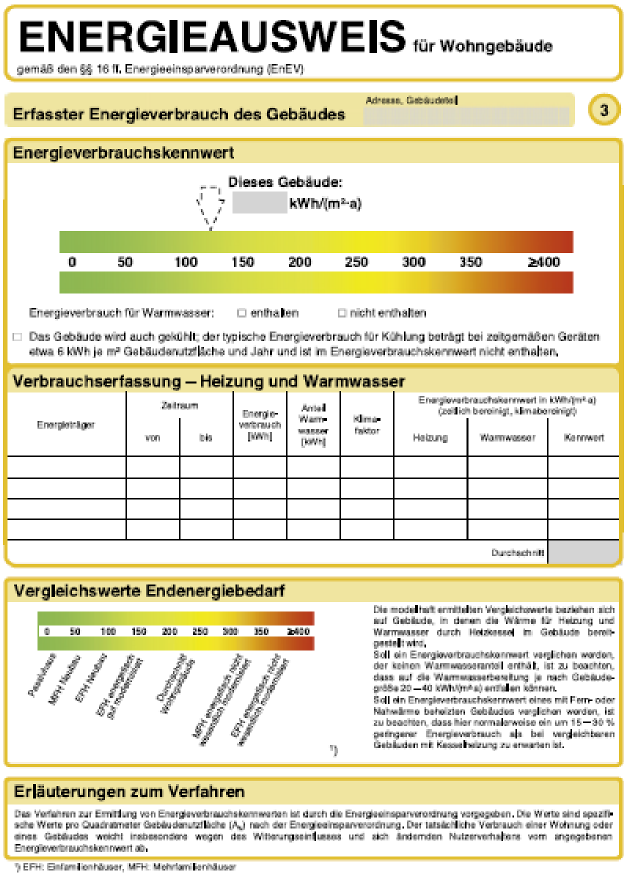


Figure 23: The operational rating form of the German EPC.

Reference: Amecke. H, 2012,

8. Building Dynamic Thermal Simulation:

BES models represent useful tools to predict the behaviour of a complex system starting from a set of predefined physical laws, that is, energy balance, mass balance, conductivity, heat transfer, and so on. Therefore, such tools allow the year-round computation of the heat balance at discrete time steps based on the physical properties of the building, the mechanical systems, and all the remaining dynamic input data in terms of climate zone, occupant schedule, and so forth, in this way, the year-round energy required in order to maintain determined building conditions, that is, indoor ambient temperature and relative humidity, is predicted by taking into account the impact of time-varying inputs such as weather boundary conditions, occupancy levels and schedules, internal loads, and so on (Castaldo. V.L; Pisello.A.L,2017).

8.1. Detailed simulation models for BES:

There are different classification approaches for building dynamic simulation methodologies (Table5). However, detailed simulation models are having a potential represented by the fact that they are based on the realistic physical characteristics and boundary conditions of the buildings rather than to statistical and mathematical relations as used in the other approaches. For this reason, They are largely used for providing support and guidelines to designers from preliminary phases of the projects. In fact, they can help them to investigate multiple design options by iteratively and easily varying the input parameters in order to analyze how they are able to affect the final building thermal-energy performance. This allows the design and realization of more energy efficient and environmentally sustainable buildings (Castaldo. V.L; Pisello.A.L,2017).

BES approaches
• Black-box approach. • Gray-box models. • Detailed model calibration Approach. • Simplified analytical models. • Building performance surrogate models. • Detailed simulation models.

Table 5: The building Dynamic Simulation Approaches (Castaldo. V.L; Pisello.A.L,2017).

8.2. Objectives of BES:

The objectives of building dynamic simulation models are several, as better explained by the following (Castaldo. V.L; Pisello.A.L, 2017):

The use of dynamic simulation tools allows the accurate forecast of

- Energy consumption,
- Thermal comfort,
- Daylight.

Therefore, it supports the design choices from early design stages which help to explore different design options without a huge effort for the production of prototypes (Castaldo. V.L; Pisello.A.L,2017).

8.3. Tools for Building Energy Performance Dynamic Simulation:

Over the years, several different tools and software have been implemented to perform whole building performance simulations. Such dynamic energy simulation tools allow to accurately predict the building thermal-energy performance in order to determine which are the key variables influencing the thermal comfort and energy consumption and therefore support the building design process. Among the software used to run simulations are: IES VE, IDA ICE, DOE-2, TRNSYS, ENERGYPLUS, DESIGN BUILDER and ESP-r (Castaldo. V.L; Pisello.A.L,2017).

9. Conclusion:

From this chapter we conclude that various actors make enormous efforts to decrease the energy consumption of buildings by implementing solar designs. This later mixes traditional techniques with new technologies and adapts to each region's climatic conditions. Socioeconomic development and environmental protection are also two significant advantages that can be derived from this above designs.

Buildings Insulation

1. Introduction:

Warmth is a valuable commodity and it will seek every possible means of escape from the building envelop. Heat transfer through building components can be modified by the choice of materials. The main heat transfer process for solid, opaque building elements is by conduction. Thermal insulation, which provides a restriction to heat flow, is used to reduce the magnitude of heat flow in a 'resistive' manner. Since air provides good resistance to heat flow, many insulation products are based upon materials that have numerous layers or pockets of air trapped within them. Such materials are thus low density and lightweight, and, in most cases, not capable of giving structural strength. Generally, the higher the density, the greater the heat flow. Since structural components are often, of necessity, rather high in density, they are unable to provide the same level of resistive insulation (Smith.P.F, 2005). In this chapter we highlighted the main terms related to the heat transfer, classification of insulation materials following with examples of the most used ones within the globe, after that we suggested some insulation techniques of the building envelop.

2. Main Modes of Heat Transfer:

Heat transfer is the transition of thermal energy, or simply heat, from a hotter object to a cooler object. There are three main modes of heat transfer:

2.1. Convection:

Convection is usually the dominant form of heat transfer in liquids and gases. Convection comprises the combined effects of conduction and fluid flow. In convection, enthalpy transfer occurs by the movement of hot or cold portions of the fluid/gas together with heat transfer by conduction (NETZCH, 2010).

$$Q = h\,A\,(\Delta T)$$

Q = rate of heat transfer (BTU/hr).
A = surface area for heat transfer (m^2)
h = convective heat transfer coefficient.
ΔT= Temperature Difference.

2.2. Radiation:

Radiation is the only form of heat transfer that can occur in the absence of any form of medium (i.e., in a vacuum). Thermal radiation is based on the emission of electromagnetic radiation, which carries energy away from the surface. At the same time, the surface is constantly bombarded by radiation from the surroundings, resulting in the transfer of energy to the surface (NETZCH, 2010).

- Radiant heat transfer rate from a black body to its surrounding can be expressed by the following equation: Engineering ToolBox, (2003)

$$Q = \sigma A T^4$$

Q = rate of heat transfer (BTU/hr).
A = surface area (ft^2)
σ = Stefan–Boltzmann constant.
T= Temperature (^oR)

- Two black bodies that radiate toward each other have a net heat flux between them. The net flow rate of heat between them is given by an adaptation of Equation below: Engineering ToolBox, (2003)

$$Q = \sigma A(T_1^4 - T_2^4)$$

A= Surface area of the first body (ft^2).
$T_{1=}$ temperature of the first body (^oR)
$T_{2=}$ Temperature of the second body (^oR).

- Radiative heat transfer rate between two gray bodies can be calculated by following equation: Engineering ToolBox, (2003)

$$Q = f\sigma A(T_1^4 - T_2^4).$$

f: is a dimensionless factor sometimes called the radiation configuration factor which take Ito account the emissivity of both bodies and their relative geometry.

2.3. Conduction:

Is the most significant means of heat transfer in a solid. On a microscopic scale, conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighbouring atoms and molecules, transferring some of their energy (heat) to these neighbouring atoms. The free movement of electrons also contributes to conductive heat transfer. To quantify the ease with which a particular medium conducts, the thermal conductivity, also known as the conduction coefficient, λ, has been employed. The thermal conductivity λ is defined as the quantity of heat, Q, transmitted in time (t) through a thickness (x), in a direction normal to a surface of area (A), due to a temperature difference (ΔT). A quantitative expression relating the rate of heat transfer, the temperature gradient and the nature of the conducting medium is attributed to Fourier (1822; Fourier's Law, 1-dim.) (NETZCH, 2010):

$$Q=\lambda\ A\ \frac{T_2-T_1}{\Delta x};\ q=-\lambda\ \frac{\Delta T}{\Delta x}$$

3. Definitions of Relevant Technical Terms of Heat Transfer:

It is necessary to know and understand certain technical terms to be able to calculate heat losses and understand the factors that are involved (FAO, 2004).

3.1. Thermal Conductivity

Thermal Conductivity λ is a thermo physical property that determines the ability of a material to transfer heat. The value of the thermal conductivity is characterized by the quantity of heat passing per unit of time per unit area at a temperature drop of 1°C per unit length. It depends on the medium's phase, temperature, density, molecular bonding, humidity and pressure (NETZCH, 2010).

$$\lambda\ =\frac{\Delta Q}{\Delta t}\frac{1}{A}\frac{x}{\Delta T}$$

Where $\frac{\Delta Q}{\Delta t}$ the rate of heat flow, λ is is the thermal conductivity; A is the total cross sectional area of conducting surface. ΔT is temperature difference, and x is the thickness of conducting surface separating the 2 temperatures. Thermal conductivity, 2011

3.2. Thermal resistance (R-value):

The thermal resistance (R-value) is the reciprocal of λ (1/λ) and is used for calculating the thermal resistance of any material or composite material. The R value can be defined in simple terms as the resistance that any specific material offers to the heat flow. A good insulation material will have a high R-value. For thicknesses other than 1 m, the R-value increases in direct proportion to the increase in thickness of the insulation material. This is d/λ, where d stands for the thickness of the material in metres (FAO, 2004).

$$R = \frac{d}{\lambda} = thermal\ resistance$$

$$(\Delta T = Rq)$$

Often in heat transfer the concept of controlling resistance is used to determine how to either increase or decrease heat transfer (NETZCH, 2010).

3.3. Coefficient of heat transmission (k or U) (kcal m-2 h-1 °C-1):

Coefficient of heat transmission represents how much heat is able to transfer through any section of a material or a composite of materials. Coefficient of heat transmission units are kcal per square metre of section per hour per degree Celsius, the difference between inside air temperature and outside air temperature. It can also be expressed in other unit systems. This coefficient includes the thermal resistances of both surfaces of walls or flooring, as well as the thermal resistance of individual layers and air spaces that may be contained within the wall or flooring itself (FAO, 2004), (NETZCH, 2010).

$$K = \frac{\lambda}{d} = U\ value\ (K\ value)$$

4. Classification of building insulation materials:

Despite all insulation materials serve the same purpose to reduce the rate of heat release/gain through the desired enclosed space some particular materials serve a certain specific role, hence they are categorized accordingly. These categories classify insulation materials into: according to the function, form and composition. (L. Adityaa et al 2017)

4.1. According to heat exchange properties:

Insulations can be categorized into two main classes per their function in manipulating the heat transfer: mass insulation and reflective insulation, defined by the following:

4.1.1. Mass insulation:

Objects with high thermal mass absorb and retain heat, slowing the rate at which the sun heats a space and the rate at which space loses heat when the sun is gone. Regarded as the most commonly used type of thermal insulation, mass insulation diminishes heat flow rate by conduction at the case where practically no convection and radiation occur by heat transfer. Due to this, the effectiveness of mass insulations is highly depending on insulation material thickness. Increasing the thickness proportionally increases the thermal performance of the mass insulation, and these materials usually have low rate of heat conduction. Apart from that, the thermal performance of thermal insulation material is also depending on the condition of subdivision or density of material. Mass insulation usually contains a huge number of tiny air trapped pockets, which reduces conductive heat transfer. These tiny pockets of trapped air act as barriers for heat flow. Therefore, any attempt to condense or compress the mass insulation will reduce its effectiveness. (L. Adityaa et al 2017)

4.1.2. Reflective insulations:

Reflective insulations are thermal insulation which reflects radiation heat, preventing transfer from one side to another due to a reflective (or low emittance) surface. This simultaneously decreases the amount of heat transference or solar heat gain impacting the building and improves interior temperatures and air quality. The amount of energy radiated depends on the surface temperature and a property called emissivity; the higher the emissivity, the greater the emitted radiation at that wavelength. Reflective insulation utilizes one or more low-emittance reflective surfaces that enclose air spaces, which are usually used in home attics, roofing and wall systems [14, 15]. The reflective insulation has at least one reflective surface that faces an air space by this application. (L. Adityaa et al 2017)

4.2. According to form:

Provides information about forms of insulation, such as batts, loose-fill, spray-on, and rigid board will help on identifying the best applications for each form, and installation tips. (Baechler.M.C et al 2012)

4.3. According to composition:

In general, composition of insulation material indicates the insulation characteristics which directly linked to its chemical and physical structure. Papadopoulos classified insulation materials based on their composition, which mainly are organic, inorganic, combined-material and new technology material. (L. Adityaa et al 2017)

4.3.1. Inorganic and organic materials:

Inorganic insulation materials are made from non-renewable materials but from plentiful available resources. Some example of inorganic insulation materials are mineral wool, perlite, aerated concrete blocks and foamy glass. On the other hand, organic insulation materials are derived from natural vegetation and renewable resources, such as wood wool, cellulose, expanded rubber, wood fiber, sheep's wool, etc. There is an increasing interest in organic insulation materials due to their attractiveness; they are renewable, recyclable, non-toxic, and environmentally friendly and require very low resource production techniques. The energy that is required to manufacture organic insulation materials is lesser than that of the traditional insulation materials. However, inorganic insulation materials generally offer higher thermal insulation properties and lower costs for the same thermal performance. Also, they show higher resistance to fire and moisture. (L. Adityaa et al 2017)

4.3.2. Combined and new technology materials:

Combination of insulation materials is a feasible approach to improve thermal performance and energy efficiency at optimized cost. Apart from that, new technology materials have been discovered for the application of thermal insulation system. Nowadays, transparent insulation materials are being used as the replacement of the traditional opaque insulation materials because of their advantage of thermal insulation and solar collection. Besides, the application of dynamics insulation that utilizes the ventilation system has been introduced in order to improve insulation performance. Many researches have studied different potential insulation materials for their insulation properties (bulk density, thermal conductivity, embodied energy and thermal attribute) and their resistivity to biological threat (insects, pests, etc.). Additional minor classification of insulation materials is based on the raw resources. Furthermore, a good insulation material with proper designed is essential for effective energy conservation in buildings. There are relevant factors to be considered during material selection, such as cost, durability, climate factor, availability, heat transfer mode, the ease level of installation and building orientation. Combined and new technology materials can be one of a good thermal building insulation material as long as has been designed properly and all the relevant factor are considered. The following materials are the variant of the combined and new technology materials, namely the mineral wool, cellulose, expanded polystyrene (EPS), cork, polyurethane(PUR), extruded polystyrene (XPS) and other building materials such as wood, stainless steel, carbon steel, brick, stone and glass. (L. Adityaa et al 2017)

5. Examples of Insulation Materials:

The insulation materials are with a huge number in the globe. Hereby, a number of the most known and used materials according to the previous classifications.

5.1. Inorganics Materials:

5.1.1. Glass wool:

Glass wool is produced mixing natural sand and glass (usually recycled) at 1300–1450 °C. The transformation in fibers occurs thanks to centrifugation and blowing processes; then fibers are bound thanks to the addition of resins. Thermal properties are similar to those of stone wool. Researches demonstrated that the thermal insulation performance of glass wool materials for building application seems to be not affected by high temperature and moisture conditions. Used glass wool can be recycled by the producing manufacturers. An innovative product made of glass wool with dynamic stiffness between 8 and 11 MN/ m3 is currently commercialized. (S. Schiavoni et al 2016)

Figure 24: Glass Wool

Reference: Lily Xing Beijing CONING Building Materials Co, Ltd

5.1.2. Stone wool:

Is manufactured by melting at 1600 °C several kinds of rocks, such as dolostone, basalt and diabase, obtaining fibers that are then bound together using binders usually resins, food-grade starches and oils. Stone wool is commercialized as panels, felts, pipe sections, or rolls. These commercialized materials are usually characterized by values of thermal conductivity ranging from 0.033 to 0.040 W/m K, density from 40 to 200 kg/m3 and specific heat from 0.8 to 1.0 kJ/kg K. Moreover they are quite cheap and can be easily handled by operators without losing thermal performance. Researches demonstrated that the thermal insulation performance of stone wool materials for building application is negatively affected by water vapor condenses. Stone wool can be considered a good sound absorber and it is often used for cavity insulation. Stone wool materials can be recycled by the producing manufacturers or disposed into landfills.(S. Schiavoni et al 2016)

Figure 25: Stone Wool

Reference: HUAMEI,

5.2. Organics Materials:

5.2.1. Expanded Polystyrene:

Expanded polystyrene EPS is usually obtained by evaporating the pentane added into polystyrene grains. This process allows the realization of a white, rigid and closed-cell foam characterized by thermal conductivity from0.031to0.037W/ mK, density from15to75kg/m3 and specific heat about1.25kJ/kgK; the higher the density,the higher the insulation performance. Researches demonstrated that thermal conductivity of EPS is affected by moisture in such away: keeping dry EPS materials in a climatic chamber with relative humidity at 90% for 4h,a thermal conductivity increase between1.4%and2.1%was detected. EPS shows no significant acoustic property,because of the closed porosity and low density. Since the material is easily flammable and burning releases dangerous gases ,a fire retardant is often added in the manufacturing process .They are usually commercialized as panels, which can be easily handled and cut without losing their performance. Recycling process of these kinds of materials is performed by specialized industries. (S. Schiavoni et al 2016)

Figure 26 : Expanded Polystyrene

Reference: Expanded Polystyrene – EPS

5.2.2. Extruded Polystyrene

Is produced by melting the polyester grains into an extruder, with the addition of a blowing agent. XPS has insulation properties similar to EPS, but it absorbs less moisture (0.3% vs. 2–4%) and it is also characterized by higher specific heat (between 1.3 and 1.7 kJ/kg K). Moisture affects negatively the values of thermal conductivity. Nevertheless XPS costs usually 10–30% more than EPS. Concerning recycling and combustion issues, there are the same problems reported for EPS. (S. Schiavoni et al 2016)

Figure 27: Extruded Polystyrene

Reference: eezee

5.2.3. Cork:

Cork can be used in many applications. Cork oak materials are commonly used in the building sector thanks to their thermal and acoustic performance. The thermal conductivity of these materials is comprised between 0.037 and 0.050 W/m K, the density between 110 and 170 kg/m3 while the specific heat is between 1.5 and 1.7 kJ/kg K. Materials made of cork grains are also characterized by good acoustic properties for impact insulation, air borne insulation and sound absorption. This material is commercialized in panels, stripes, loose or added to plaster, and it can be easily recycled. (S. Schiavoni et al 2016)

5.2.4. Melamine Foam:

Is ideally suitable for sound absorption with a coefficient higher than 0.9 for frequencies above 2000Hz for a sample of thickness equal to 50 mm. It is based on melamine resin which is highly effective product as sound absorption material. Because of its structure, it is at the same time an excellent thermal insulation product with a thermal conductivity of: <0,035 W/mK. It has a grey colour: with a density of between 8,0 to 11,00 kg/m³. (MAAD, 2014)

5.2.5. Phenolic Foam:

The phenolic foam (PF), is an organic material characterized by low thermal conductivity values, 0.018-0.028 W/mK, and a density higher than other plastic foams (up to 160 kg/m3). Thermal conductivity of phenolic foam materials may increase with water content. The specific heat is about 1.3-1.4 kJ/kg K. These materials are usually characterized by good reaction to fire even if they tend to release smoke under fire. (S. Schiavoni et al 2016)

5.2.6. Sheep Wool:

Virgin and recycled wools are used for the production of building insulation materials; fibers can be mixed with polyester or fixed to a polypropylene grid. The material is usually commercialized in rolls and its elasticity allows the use as resilient material in floating floors (dynamic stiffness about 5 MN/ m3). The density of sheep wool materials are comprised between 10 and 25 kg/m3, the thermal conductivity between 0.038 and
0.054 W/mK and the specific heat between 1.3 and 1.7 kJ/kg K; so, even if sheep wool materials are useful for winter thermal insulation, their performance for unsteady states in summer conditions are rather poor. The acoustic absorption of these materials are very interesting; Ballagh measured values of sound absorption higher than 0.8 for frequencies above 500 Hz for a sample of thickness equal to 75 mm; the same sample allowed to increase the sound reduction index of a wall of 6 dB. Similar acoustic performance can be achieved with current commercialized materials. Evaluated thermal, acoustic and hygro-thermal performance of several samples of sheep wool materials, varying thickness and density. As expected, the higher the moisture content, the higher the thermal conductivity (from 0.036 to 0.081 W/m K). The tested samples of sheep wool were characterized by high hygroscopicity values (up to 35%). The high hygroscopicity of wool makes this material an optimal humidity regulator. Before using in building application, sheep wool must be treated with fire retardants, antimoth and parasiticides. The exhaust material can be reused, recycled, stocked in landfill or used for compost production; the latter solution is possible only if plastics can be separated from wool. (S. Schiavoni et al 2016)

5.2.7. Cellulose:

Cellulose for thermal and acoustical insulation purposes is produced grounding in a mill recycled papers, wood fibers and some chemical composites aiming at improving its vermin, fire and rotting resistance. Even if panels and mats can be manufactured, it is more widely commercialized as a loose material to be blown in wall cavities. Cellulose is characterized by a thermal conductivity between 0.037 and 0.042 W/m K, a density between 30 and 80 kg/m3 and a specific heat between 1.3 and 1.6 kJ/kg K. The quality of the source newsprint can affect thermal performance of the material. Concerning the acoustic performance, if panels are used, their elasticity allows the use as resilient materials in floating floors, while porosity and flow resistivity values are adequate for sound absorption and cavity insulation. These materials should not be compressed after the blowing operation to avoid unwanted decreases in insulation properties. These materials can be recycled but are not suitable for composting purposes due to the content of boron salts. S. Schiavoni et al 2016

5.2.8. Coconut Fibres:

Coconut fiber was obtained from the fibrous husk (mesocarp) of the coconut (Cocos nucifera) from the coconut palm, which belongs to the palm family (Palmae). Coconut fiber has high lignin content and low cellulose content, so as resulted of resilient, strong, and highly durable materials characteristics. Y, Mohd Yuhazri, 2011 **.** The coconut thermal conductivity of k is 0.048 W/m.K, with density of 174 kg/m3, and heat capacity f 2600 J/KgK. Danny S M, et al 2015

5.3. Combined Materials:

5.3.1. Wood Wool Slabs:

Wood wool slabs give good thermal insulation. Thermal conductivity is, however, relative to their density. At a density of 400 kg/m3 the thermal conductivity is about 0.085 W/mK in practice. Wood wool slabs have very good acoustic properties and are often used to absorb sound in. It has very good fire resistance, tolerates damp and is not at tacked by mould or rot. Wood wool have good resistance to insect pests, as termites. Compared to many other insulation materials, wood wool slabs have good bending and com pression strength. They are easy to saw, drill and nail. They have good ad he sion to rendering/plastering mortars and concrete. The material is considered to be healthy, since it has very low emissions of harmful compounds. (Erik Johansson, 1994)

5.4. New Technology Materials:

5.4.1. Transparent materials:

Transparent or translucent insulation materials are having important applications for improving the energy balance of buildings. The definition of such material is that it has a high transmission for solar radiation and good thermal insulation properties. These materials can either be clear as in glazing, or in transmission they can disperse the light. (A. Goetzberger, 2005)

5.4.2. Dynamic materials:

In comparison with the static insulation, dynamic insulation elements can exhibit changeable thermal parameters, such as thermal conductivity and emissivity. These allow buildings facades to be responsive elements regarding the surrounding thermal environment. In addition, dynamic insulation elements can also be used to achieve variable thermal storage by coupling or decoupling a storage wall from a compartment, as the dynamic insulation layer is able to change between states of low and high conductivity. **(**J.T. Lopes Alves Homem. 8/8/2016)

5.5. Comparison between the materials:

From the literature review findings, we created the following table to compare between the above materials:

Table 6: Comparison table between the materials

Materials Classificaitons	**Material**	**Thermal conductivity (W/m K)**	**Available Thikness (mm)**	**Cost per thermal resistance**	**Environmental of production and Use**
Inorganics Materials	Glass wool	0,031-0,037	10 -150	Low	Low
	Stone wool	0,033-0,040	30 -120	Low	Low
Organics	Expanded Polystyrene	0,031-0,037	10-180	Low	High
	Extruded Polystyrene	0,032-0,037	10-180	High	High
	Cork	0,037-0,050	10-120	High	Moderate

Materials	Melamine Foam	0,035	10 - 50	Low	Low
	Phenolic Foam	0,018-0,028	20-50	Moderate	High
	Sheep Wool	0,038-0,054	50-125	High	Low
	Cellulose	0,037-0,042	Personalized according to the needs	Low	Low
	Coconut Fibres	0,048	A diameter between 0,1-0,45	Low	Low
Combined Materials	Wood Wool Slabs	0,085	15-150	Moderate	Moderate
New Technologie materials	Transparent materials	Use of Solar transsmitance parameter	Depends on the desing needs	Depends on the complexity	Depends on the components
	Dynamic materials	Changeable Thermal parameters	Depends on the desing needs	Depends on the complexity	Depends on the components

6. Building Fabric Heat Losses:

The total fabric heat losses emerged through the external building elements such as floors, walls, windows, doors.. etc. and the thermal bridges as presented in the figure bellow ZCH. 2016:

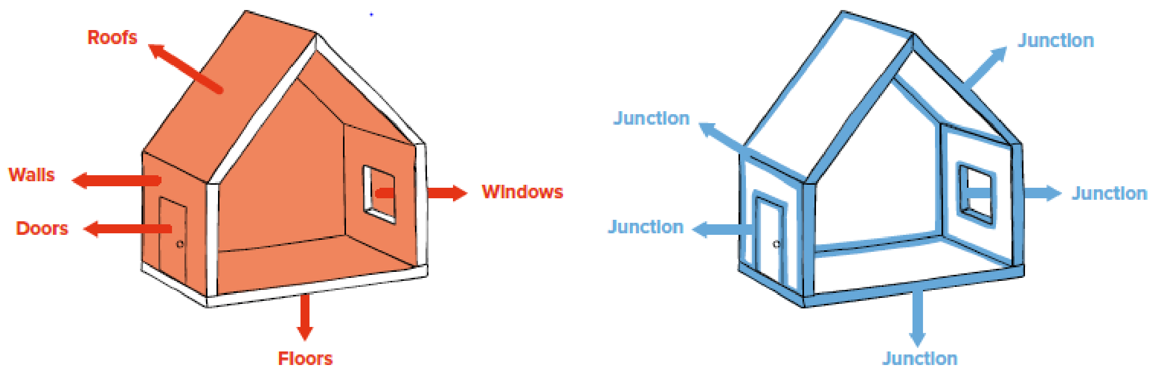


Figure 28: Fabric Heat Losses

Reference: Thermal Bridging Guide

6.1. Thermal bridge:

A thermal bridge (sometimes called a cold bridge) is a localised weakness or discontinuity in the thermal envelope of a building. They generally occur when the insulation layer is interrupted by a more conductive material. Their effect is increasing heat loss in a typical new build home. As homes become better insulated thermal bridges become even more significant. (ZCH, 2016). There are two types of thermal bridges in buildings cited as follow:

6.1.1. Non-repeating thermal bridge:

Non-repeating or linear thermal bridges. These occur at junctions between elements, such as a wall and a floor or a window and a wall. At these locations heat is more able to transfer through the construction, resulting in greater heat loss from the dwelling and localised 'cold spots' in the building envelope. (ZCH. 2016)

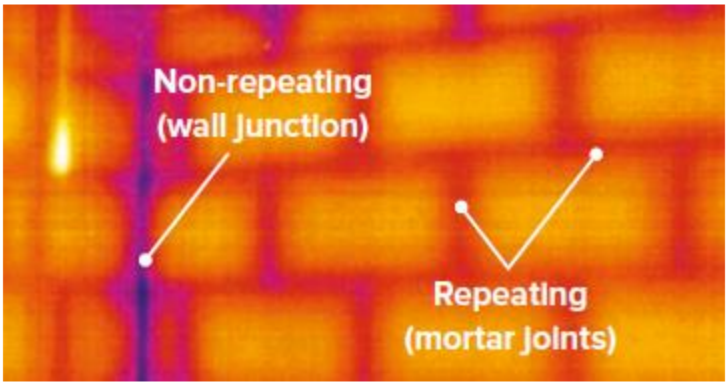


Figure 29: REPEATING AND NON-REPEATING THERMAL BRIDGES

Reference: Thermal Bridging Guide

6.1.2. Repeating thermal bridge:

Examples of repeating thermal bridges are mortar joints and wall-ties in masonry construction or timber or steel studs in framed construction. Where the frequency of these is known and consistent their effects can be accounted for directly in the U-value calculation for the building element itself (Figure 29). (ZCH. 2016)

6.1.3. Examples of thermal bridge heat losses improvements:

Reducing the thermal bridging heat losses is very essential for building energy performance., Thus, different solutions have been used and some of them are cited as follow (ZCH. 2016. Anderson. (J et al 2012):

- Using lower conductive structural elements**,**
- Reducing connectivity though the envelope.
- Specific assembly of the insulation material in the junctions (Figure 30).

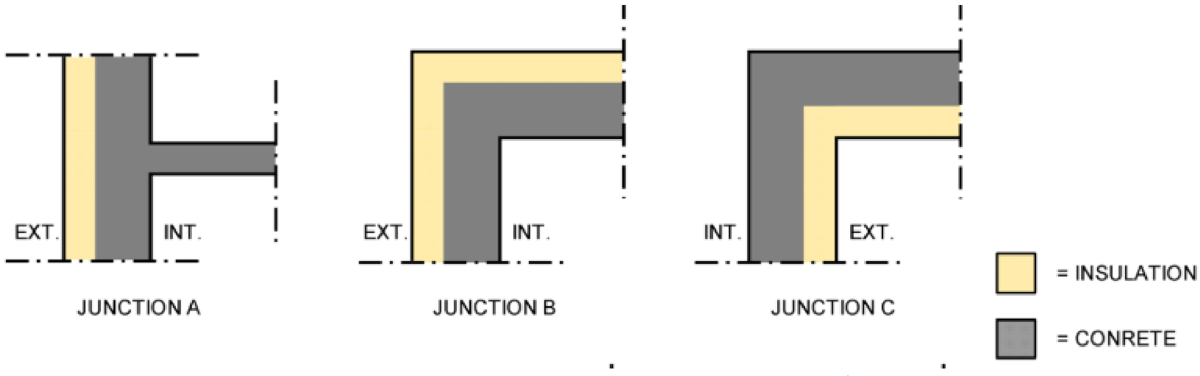


Figure 30: specific assembly of the insulation material in the junctions

Reference: Thermal Bridging Guide

6.1.4. Windows:

Windows are thermal weak spots. Heat transfers have two origins (Denker. A et all. 2014):

- Heat transmission through glazing and carpentry.
- Parasitic air passages between opening and frame.

To improve the thermal performance of windows, several solutions exist:

- Use of caulking products to reduce the airtightness between the opening and the frame (foam sealant, silicone sealant, etc.); for reasons of hygiene, it is necessary to caulk indiscriminately in order to preserve the renewal of the air of the premises.
- Laying double or triple insulated glass units.
- Reducing radiation from one glass to another; the emissivity of the glazing is reduced by depositing a thin film of metal oxides on the internal faces of the double glazing; this is called low-emissivity glazing.

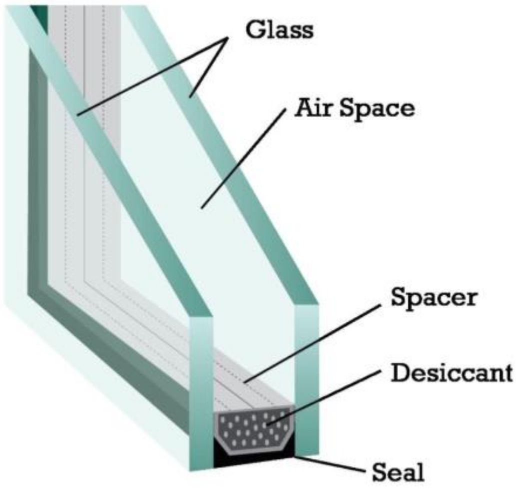


Figure 31:Double Glass, solution for bay window thermal improvements.

Reference: Glass Doctorx

- Dou-ble windows; this solution is effective both thermally and acoustically.
- Closures (shutters, stores, etc.); the establishment of a closure makes it possible to create a substantially immobile air space, and therefore to improve the thermal performance of the windows.

6.1.5. Exterior Walls and Roofs:

Different factors affect heat transfer through roofs and vertical walls. During the daytime, heat transfer through the roof is dominated by two factors: absorption of solar radiation and infrared emission to the atmosphere. These effects are much less important in walls, where heat transfer is predominantly convective. This difference occurs because solar radiation hits roofs at a much higher angle during the hours of greatest intensity. Roofs also have a greater view of the atmosphere than any vertical wall, so they will lose a much greater amount of heat to the atmosphere through infrared radiation. Convection strongly depends on wind direction; the convective heat loss coefficient is highest for upwind walls, followed by roofs, side walls and downwind walls, in that order. Optimal thickness is an economic term, where the cost of purchasing and applying thermal insulation is subtracted from the energy savings accrued during the useful life of the insulation. Given the different mechanisms of heat transfer that affect roofs and walls, the optimal thicknesses of thermal insulation for roofs and walls are not necessarily the same for any given building. (Jorge L et al 2016)

a. Technics to insulate walls:

Several techniques for insulating exterior walls and the following are some examples (Denker. A et all. 2014):

- Insulation from the inside,
- From the outside,
- By filling,
- Use of formwork insulators of lost.

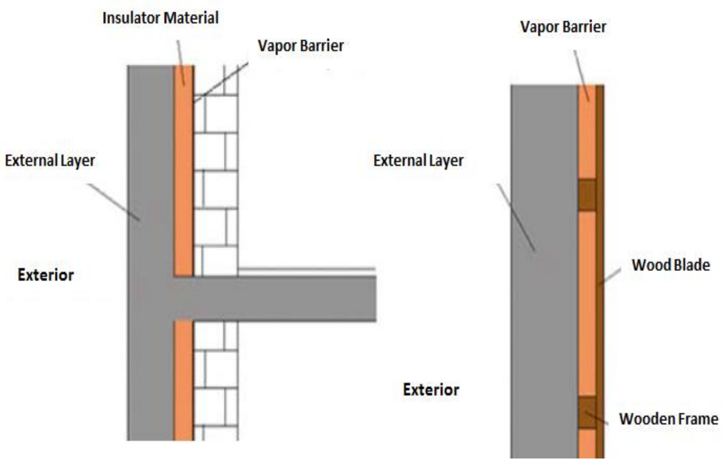


Figure 32: Examples of interior insulation

Reference: Denker. A et all. 2014

b. Technics to insulate Roofs:

The insulation methods of roofs depend on the type of roof, the available space for insulation, and ease of access. Thus, there are many different types of insulation methods for roofs and as example of them are cited as follow (Carbon Trust 2017):

Figure 33: •Example of insulation Between wooden frame members rafters.
Reference: Man installing thermal roof insulation layer – using mineral wool panels. Attic renovation and insulation concept.

- Between wooden frame members rafters.
- Extra layer of insulation applied to the underside of

flat roof using studs or other fixing method.

6.1.6. Floors:

For all the buildings the floor should be insulated otherwise the thermal performance will be poor. For buildings with relatively small ground floor areas (primarily domestic properties), if the ground floor is left uninsulated, the thermal performance will be poor. To enhance the thermal performance, complete insulation of the ground floor should be adopted. For buildings with large ground floor areas (primarily non–domestic properties), complete insulation of the ground floor may be unnecessary. (Kingspan GreenGuard, 2015)

a. Technics to insulate the floors:

Different insulation methods exists depending on the type of floor and by the following we present some of them (Denker. A et all. 2014):

- Floors on crawl space:

- Insulate the wall from the outside; in this case there is interest in extending the insulation of walls along the bedrock up into the soil to a depth of about 30 cm;
- Insulate to the inner lap if the height of the crawl space allows it (> 80 cm); on can use expanded polystyrene panels or polyurethane;

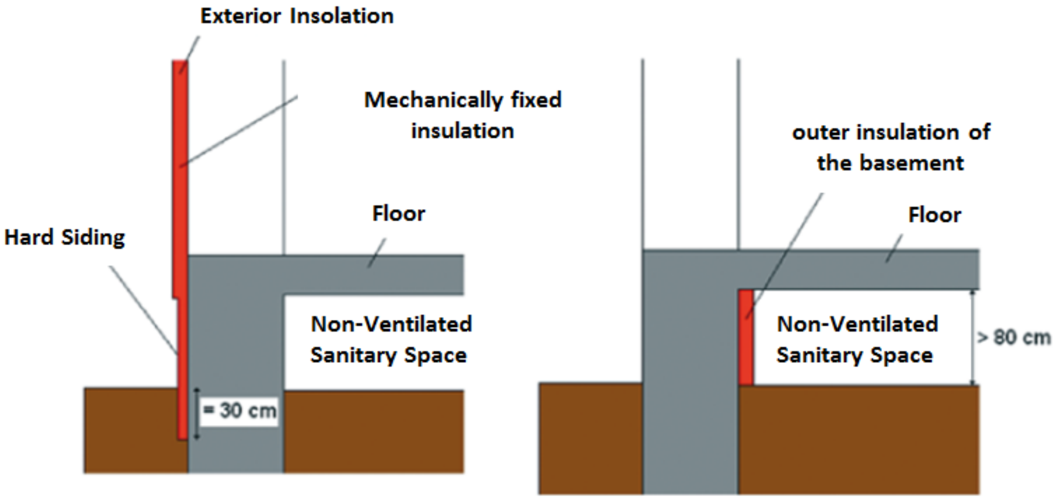


Figure 34: Insulation of low floors on crawl space
Reference: Denker. A et all. 2014

- Place insulation under the floor as in the case of a floor on local no conditioning.
- Floors on unheated premises:

Under floor insulation of panels manufactured; in this purpose there is a use for complex insulating-plate panels of plaster, rigid fibreboard mineral; these panels are screwed into the floor either directly or through smooth wooden or metal; he do not put a vapor barrier;

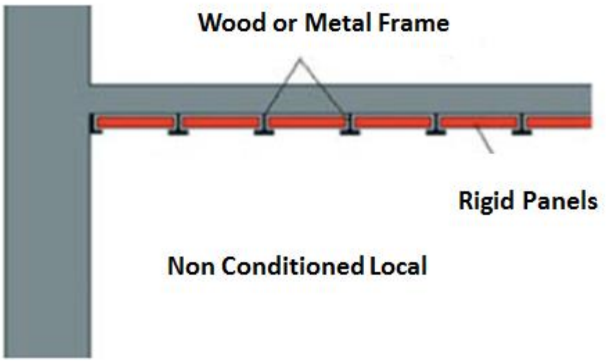


Figure 35: Insulation of low floors on non-conditioned premises

Reference: Denker. A et all. 2014

- Floors on land-full:

When low floor, is based on concrete slab armed rests on the ground or on a lifting of gravel and sand. The most interesting solution is to isolate the walls from the outside, that is to say

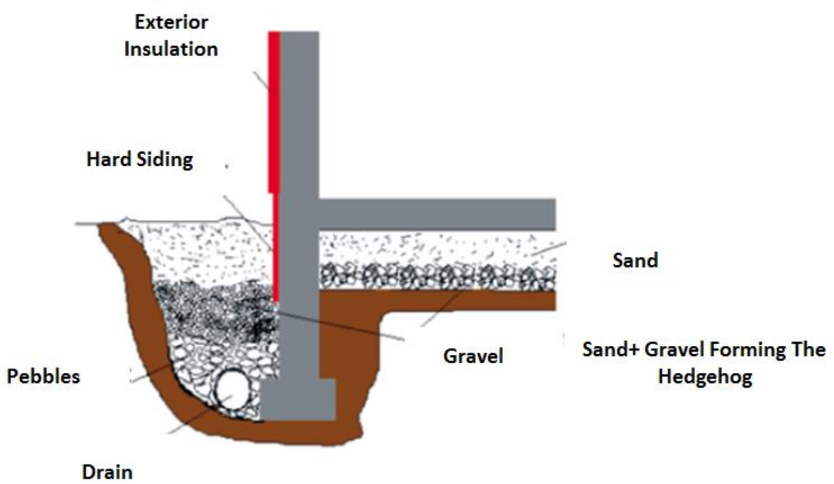


Figure 36: Isolation des planchers bas sur terre-plein

Reference: Denker. A et all. 2014

isolate the basement on its periphery as an extension of the insulation of the walls. This solution makes it possible to limit losses, to remove thermal bridges and benefit from the thermal inertia of the median.

7. Conclusion:

Enhancing the levels of insulation for lower energy consumption and cost related to buildings thermal system needs to take in consideration the four following parameters: material selection, cost, environmental impact, experience and supervision in the implementation. In addition, the insulation is one of the crucial solutions for energy building sector and it contributes to socioeconomic and environmental benefit.

JuaJamii Team and JuaHouse Project

1. Introduction:

This chapter describes JuaJamii project which is the JuaHouse, the project was selected in the international competition solar decathlon Africa 2019 and it will be exposed to the public and expert from all over the world to be tested as a future smart house concept that will be a starting point to a construction company which is composed of students from the Pan African University Institute of Water and Energy Sciences Including Climate Change and whose many scientific research topics has been developed under, aiming to reach the team's short and long terms objectives.

Additionally, this house is going to compete in international competition called Solar Decathlon Africa in the next 13 September 2019. We JuaJamii, as a future company in the consruction field, are composed of students from the Pan African University Institute of Water and Energy Sciences Including Climate Change and we have developed different scientific researches as the present, aiming to reach the team's short and long terms objectives. Therefore, in this chapter we describe the different features related to the team, project and the competition.

2. Emergence of JuaJamii:

Six students from the Pan African University Institute of Water and Energy Sciences (PAUWES) sat at a college corner on February 27, 2018, considering whether it was possible to apply to the Solar Decathlon Africa Competition with only 16 days left until the application deadline. A timeline was drawn and responsibilities spread

First priority was to bring the competition to the institution. We requested for a meeting with the director of PAUWES and with open arms he accepts to meet the six of us. Then, the time came and we climb upstairs to meet him, we were positively filled but not without some traces of fear. As we knocked on his door, but a new chapter was about to begin. Busy as he always is, he asked us to enter and to sit with a smile on his face. Who will start talking? We all looked mild. He looked at us and asked how he could be of assistance, there was a short pause and then discussions began.

“15 minutes later the institution support was a go! “

In Algeria, Friday’s are days off but that didn’t stop the JuaJamii Team. With little to no time left other means of working space had to be created. From classrooms, conference rooms to church rooms etc. A series of successive meeting and work sessions were held until the submission of the proposal.

Despite the pressures and stress, the team’s bond grew tighter and stronger and so did the idea to build a better, smarter and sustainable Africa.

Then came April 6th 2018- a day break moment. It had been an anxious week, awaiting responses from the competition organizers-IRESEN & UM6P. We anticipated notification at the end of March, 2018 but It was almost a week into April and nothing was said, except an email on conceptual design. Are we in? or we are out? Was our proposal not good enough? these questions ringed loudly in our heads all week but we stood determined. Our team leader calmed everyone down to let the process work and as well promised to facilitate a visit to the famous Renaissance hotel for celebration once we got accepted. On April 6th 2018, three days after the team leader’s remarks; a beautiful spring friday evening notification of acceptance arrived. JuaJamii Decathletes were born! A team of Pan African students’ competing in the Solar Decathlon Africa Competition by designing, building and operating the JuaHouse (net zero energy solar house using recyclable containers) with a soul mission to create and contribute to the development of green and energy self-sustainable buildings in Africa began.

- Meaning of JuaJamii: is a Swahili term meaning: “Solar Community”
- Meaning of JuaHouse: is Swahili-English combination, meaning: “Solar House”

3. Solar Decathlon:

It is a competition that challenges student teams to design and build highly efficient and innovative buildings powered by renewable energy. The winners will be those teams that best blend design architectural and engineering excellence with innovation, market potential, building efficiency, and smart energy production. (U.S. Department of Energy)

The U.S. Department of Energy Solar Decathlon launched the Solar Decathlon competition in USA where the first edition was held in 2002; the competition occurred biennially

Figure 37: Solar Decathlon Exibition

Reference : Mohamed Kone, 29/01/2019

in 2005, 2007, 2009, 2011, 2013, 2015, and 2017. Thus, it involved more than 150 collegiate teams. The next Solar Decathlon is planned for 2019-2020. Additionally, under the partnership between the U.S. Department of Energy Solar Decathlon and other governmental and educational organisations, the competition Expanded to Europe, China, Latin America, Africa, and the Middle East to involve an additional 160 teams through Solar Decathlon Europe 2010 and 2012 (Madrid, Spain), Solar Decathlon Europe 2014 (Versailles, France), Solar Decathlon China 2013 (Datong) and 2018 (Dezhou), Solar Decathlon Latin America and Caribbean 2015 (Santiago de Cali, Colombia), and Solar Decathlon Middle East 2018 (Dubai, United Arab Emirates). In 2019, three Solar Decathlon competitions will take place: Solar Decathlon Europe (Szentendre, Hungary) in July, Latin America and the Caribbean (Columbia) in December, and Solar Decathlon (Morocco) in September. (U.S. Department of Energy)

The Solar Decathlon Africa will be held in the green city Mohamed VI of Benguerir, Morocco. The location of the site that is going to host the three-week event is juxtaposed to both Green Energy Park and Green & Smart Building Park. Under the aegis of the Moroccan Ministry of Energy, Mines, Water, and the Environment (MEMEE) and organized by the Moroccan Research Institute in Solar Energy and New Energies (IRESEN) and Mohammed VI POLYTECHNIC UNIVERSITY (UM6P). A new spirit of the African edition is conceived, and will be adapted to the needs of the African continent. The main objectives are generating knowledge of net zero energy buildings within the emerging continent, highlighting the perks of decentralized solar energy in leaping forward an increasingly electrified continent, speeding up actions on reaching sustainable energy for all Africans, and valorizing the African local materials and knowhow in the building sector. The competition is expected to have environmental, social and economic impacts on Africa. (Origin of Solar Decathlon Africa)

4. JuaJamii Objectives:

JuaJamii is considering its participation on the competition as a path to evolve into a start-up in the construction field. Therefore, its objectives touch Entrepreneurial, Social and Sustainability aspects as follow:

4.1. Entrepreneurial Aspect:

JuaJamii will offer both products and services: The construction branch sells ready-made zero-energy houses at different price ranges ("Jua House prefab" – basic, business or premium) to development programmes, companies or individuals. A lump sum is charged for manufacturing, shipment, and in situ instalment. The consultancy branch advises architects, construction companies, public sector agencies or NGOs on green and energy-efficient buildings. The client is charged according the scope and complexity of the provided advisory services. JuaJamii's third business model is a hybrid between service and product: The Jua house flex is tailored to the client's needs and demands, either complementing existing housing systems, or as a new building. In this case, both the design and construction are charged. Furthermore, JuaJamii offers remote monitoring systems attached to sold Jua Houses, enabling efficient operation and maintenance on a flat rate basis. (JuaJamii 2019)

4.2. Social Aspect:

JuaHouses will help bridge the housing deficit in Africa and are tailored to provide housing contribute to the development of a sustainable and energy efficient building sector. Additionally, JuaHouses are modular and rapid in the assembly which helps to speed up the process of urbanisation in the different African countries The clients include middle-class income people households, government and private institutions companies, as well as government, development and aid programmes supporting low income areas in Africa. Middle-income families will benefit from a unique modern, affordable, and comfortable housing system that can flexibly adapted to their needs and preference. The zero net energy demand and optional features such as the aquaponics system make it particularly interesting for environmentally conscious people with a limited budget. For private institutions companies, the fast and modular construction, the autonomous operation, and the visible sustainability component make it a valuable option for providing housing to workers at remote sites e.g. at construction or field research sites. Finally, government, development and aid programmes are provided with fast, simple, safe and resilient housing systems made from locally available and recycled material. For them, the JuaHouse is a viable solution to upgrade slum and peri-urban low-income areas, or to provide shelter to refugees in need of immediate support after conflicts, epidemies or natural disasters. (JuaJamii 2019)

4.3. Sustainability Aspect:

The JuaHouse address the most stressing problems of the African continent: water, energy, food security, affordable housing and climate change. The design reflection of JuaHouse has integrated new trends to ensure a good quality life standards and sustainability as well. The trends are: Renewable Energy, Bioclimatic solutions, Energy Efficiency Measures, Internet of Things system, Recycling Water, Aquaponic system, Recycling Containers, Local Materials. Thus, one JuaHouse promotes four sustainable development goals (SDG's) out of 17 which are (JuaJamii 2019):

- SDG 6: Ensure availability and sustainable management of water and sanitation for all.
- SDG 7: Access to affordable, reliable, sustainable and modern energy for all,
- SDG 11: Inclusive, safe, resilient and sustainable cities and human settlements,
- SDG12: Sustainable consumption and production patterns.

5. Design Strategies of JuaHouse:

The strategies of complete JuaHouse with the different services and components are cited as below (JuaJamii, 2018):

5.1. Architecture:

- Use of recycle containers which are highly available in Africa and adapting Appropriate techniques, technologies and decoration to provide comfortable affordable and sustainable housing that fit with the African context.
- Use of bio-climatic architecture principles.
- Both the exterior and interior designs of the house portray the African culture in this new era with the aim of being accepted across the continent.

- The first JuaHouse has a surface of 84m^2 which is planned to be habited by five persons. It contains 3 bedrooms, a living room, kitchen, dining spaces, bath room and aquaponic space for food production.
- Use of outdoor elements to create a semi private space.

5.2. Engineering and Construction:

- Assembly and disassembly approach that ensures the construction of the house in a small period. This later is due to the modularity of the main components as the containers and the prefabricated framings for finishes.

- Well-integrated technologies to the design house.

5.3. Appliances:

- Install lavatory and kitchen faucets, showers, dishwashers and clothes washers that are water efficient.
- Select high energy efficiency affordable appliances available on the African market.

5.4. Health and Comfort:

- Use Evacuated Tube Solar Collectors, more efficient and which can produce enough heat for space heating or space cooling.
- Use a humidity stabilizer: The purpose of the system is to regulate humidity to provide comfort, the system uses humidity filter s which catch and regulate the moisture.
- Use of carbon dioxide sensors to monitor ventilation rates and to provide real time information about air quality
- Use of planting options to create a micro climate around the house with aim to improve outdoor and indoor air quality.
- To ensure comfort and reduce mechanical energy used for heating, cooling and air conditioning, JuaHouse has tight construction with the use of appropriate insulation (local materials), appropriate wall colors, low emissivity windows and the patio which helps to capture the wind and fresh air available on site and.
- Use of natural light through the openings, walls colors and new techniques as natural skylights.

5.5. Electrical energy balance:

- Use of onsite solar PV system on the roof to provide power to the home.
- Use of a small batter y bank of 5 kWh to store electricity for emergency use and achieve high self-consumption rates from the PV system.
- A hybrid inverter to convert DC power from modules to usable AC power that can be used to power loads or fed into the grid.
- Grounding equipment that provides a well-defined, low-resistance path from the system to the ground, to protect the system from current surges from lightning strikes or equipment malfunctions.
- DC/AC Disconnect s automatic and manual safety disconnects protect the wiring and components from power surges and other equipment malfunctions.

5.6. Innovations:

This contest oversees all the innovative solutions adopted in the previous contests; In addition to the following innovations:

- The use of internet of things to control automatically the different components of the house as well as the windows, energy, HVAC..etc.
- The use of aquaponic system to produce fishes and vegetables.
- Rain water harvesting system adding to water recycling system.
- Efficient house in terms of energy consumption.

6. Conclusion:

JuaJamii's vision is targeting different problems in the African continent specifically and in global levels generally by providing a new and unique housing experience adapted to the needs of the costumers, through the development of green and sustainable buildings. Therefore, future scientific research development to enhance the products and entrepreneurial spirit are the two main components for the team to grow as a company.

Results and Discussion

1. Introduction

The selection of suitable material for JuaHouse will follow a top-down approach where we will identify three best insulation materials from the literature review, taking into consideration Moroccan market. We will then follow a bottom-up approach by making a computational analysis to the outcomes.

2. Pre-selection based on the literature review and Moroccan Market Analysis:

By using the comparative table between the insulation materials described in Chapter 2 and the priorities outlined in (Figure 38), we identify the three best materials to be used for computational analysis. Thus, Glasswool, Stonewool and Melamine foam are the best products described (Table 5).

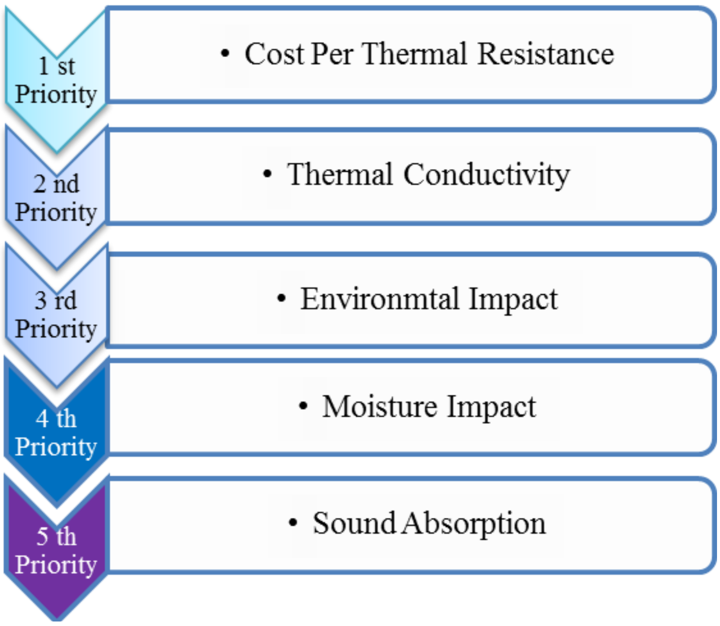


Figure 38: Priorities for the selection of insulation materials.

Materials	Cost Per Thermal Resistance	Thermal Conductivity	Environmtal Impact	Moisture Impact	Sound Absorptio n

Glass wool	Low	0,031-0,037	Low	Not Affected	Good
Stone wool	Low	0,033-0,040	Low	Affected	Good
Melamine Foam	Moderate	0,035	Low	Affected	Excellent

Table 7: Three best materials to be used for computational analysis.

2.1. Moroccan Market analysis:

We have done this analysis, with aim to facilitate the work when implementing the proposed idea on the real world:

Table 8: Moroccan Market analysis for Glass Wool, Stone Wool, Melamine Foam

	Availability	Thermal Conductivity	Material Price (Euros/ m^2.5cm)
Glass Wool	Yes	0,036	3.46
Stone Wool	Yes	0,038	6.94
Melamine Foam	Yes	0,035	4.89

3. Computational Analysis:

We will use Design Builder Software to perform thermal simulation of JuaHouse, and the findings will be analysed economically.

3.1. Design Builder:

Design–build is a project delivery system used in the construction industry. It is a method to deliver a project in which the design and construction services are contracted by a single entity known as the design–builder or design–build contractor. It can be subdivided into architect-led design–build (ALDB, sometimes known as designer-led design–build) and contractor-led design–build.

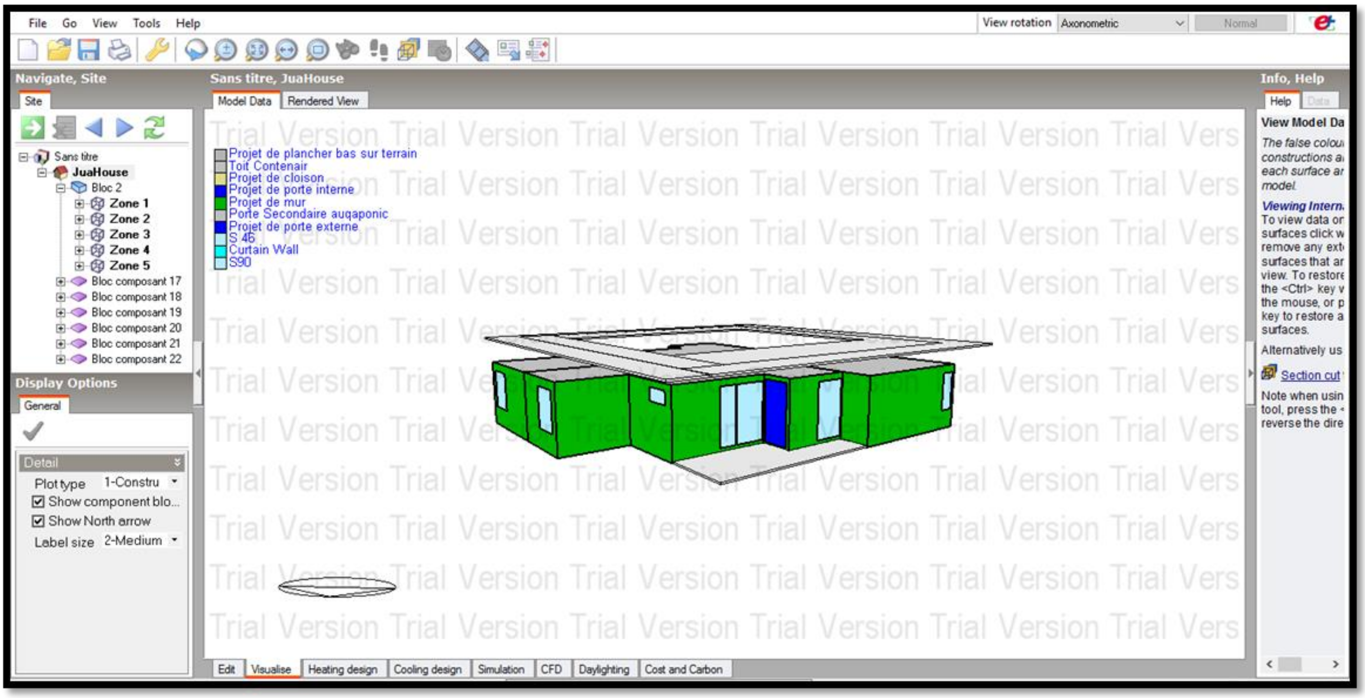


Figure 39: Design Builder Interface

3.2. Thermal Simulations:

We do thermal simulations for each material with different thicknesses defined according to, market availability and architectural design. Afterwards, we follow a comparative approach between the thermal heating and cooling loads results.

This phase is based on the below parameters and criteria's related to JuaHouse thermal performance:

- Parameters that contributes on the building thermal performance including: Building design, climate, metabolic heat, equipment, envelops components, openings characteristics, human behaviours.
- House heating and cooling loads without insulation.
- Insulation thickness.
- The minimum heating and cooling loads required for Marrakech region

PS: Bridging parameter will not be included in the simulations as it is really linked to the building construction phase and may impact the materials comparative analysis.

3.3. JuaHouse Design:

Is a single house designed for a maximum of 6 persons, it has one Living Room, two Bedroom's, Kitchen, Bathroom, Aquaponics, Gallery, Corridor and Technical Room as interior functions (Figure 40)

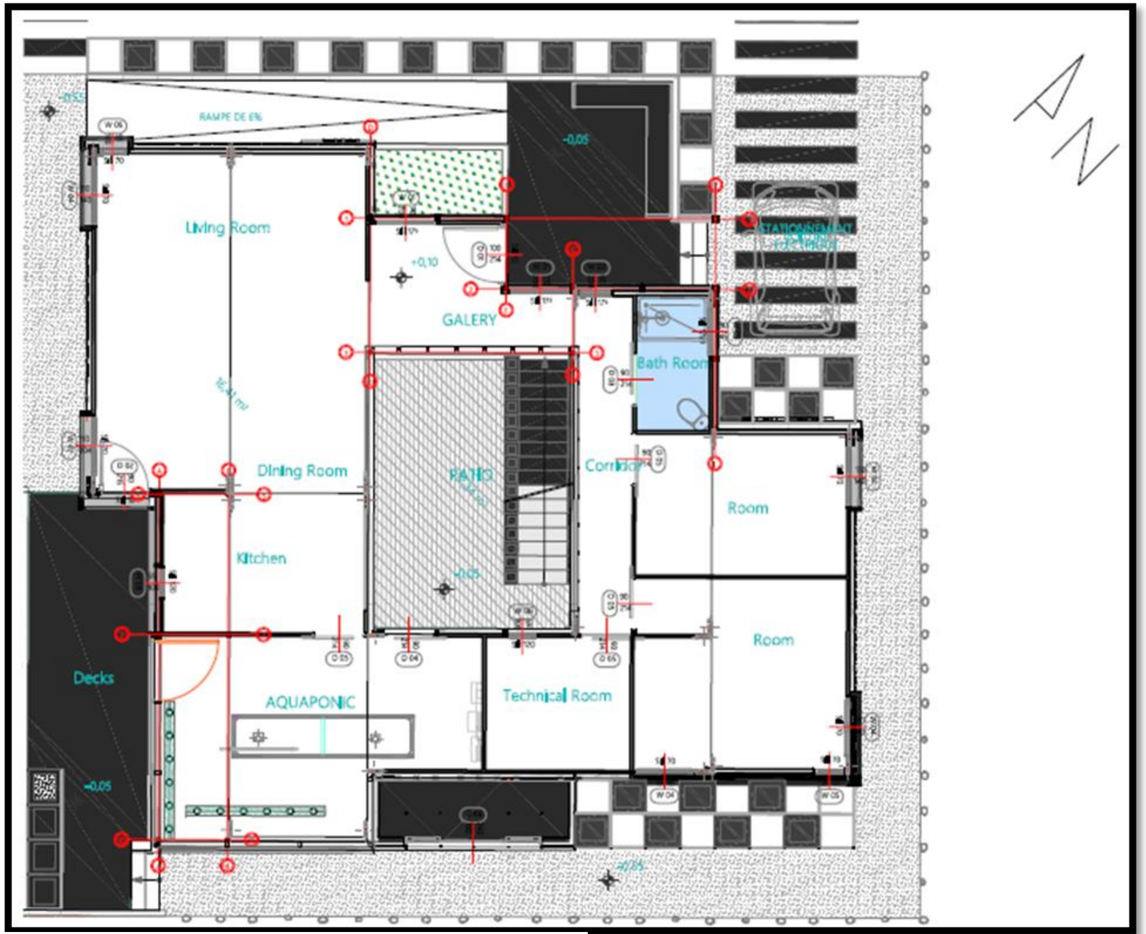


Figure 40: JuaHouse Floor Plan

Reference : JuaJamii

3.4. 3D of JuaHouse:

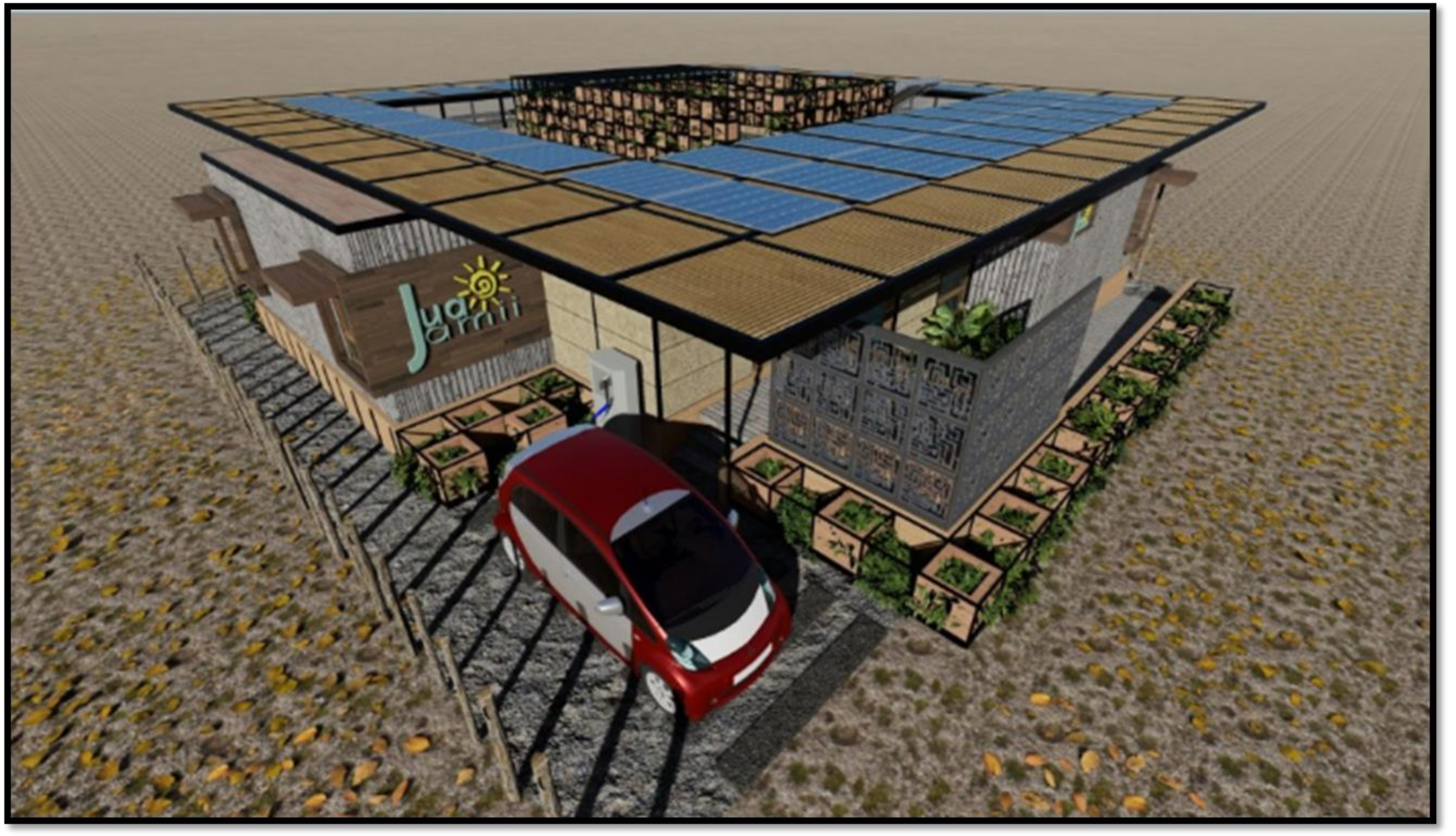


Figure 41: JuaHouse 3D.

Reference: JuaJamii

Figure 42: JuaHouse 3D.

Reference: JuaJamii

3.5. Informations related to parameters infulencing thermal performance of JuaHouse:

3.5.1. Climate data analysis of Benguerir:

We will use Benguerir climate data provided by Metronome software to do the thermal simulations. Furthermore, we have performed the below climate analysis with the aim of having a clear idea of Benguerir climate features.

a. Temperature:

Table 9: Climatic data of Benguerir region.

Reference: Green Park, 2018

	March 2015	April 2015	May 2015	June 2015	July 2015	August 2015	September 2015	October 2015	November 2015	December 2015	January 2016	February 2016
Tmax	29.1	32.7	42	39.2	44.7	43.7	36	37	31.1	26.8	26.1	25.1
Tmin	3.9	8.3	12	12.9	17	14.7	14	11.2	2.8	4.7	4.4	1.5
HRmax	100	100	96	95	92	94	97	98	100	100	100	99
HRmin	12	14	2	11	8	10	16	15	18	12	13	17

From (Table 9) we noticed that:

- The maximum value of the temperature reaches 44.70.
- The minimum value of the temperature is 1.50.
- Relative humidity up to 100% and 2% minimum

b. Wind

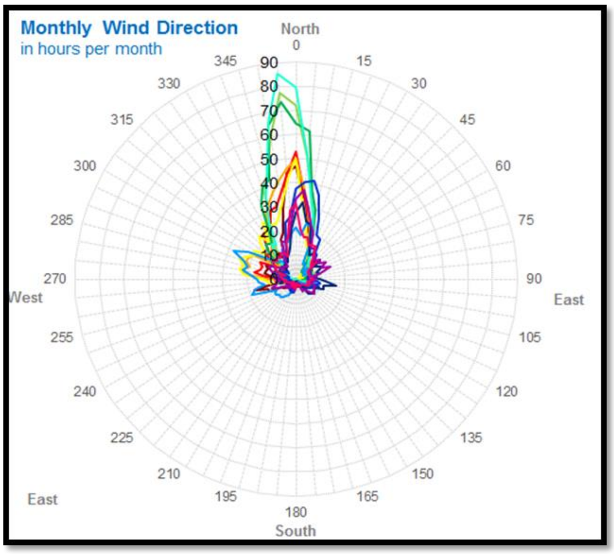


Figure 43: Wind Direction

Reference: Reference: Green Park, 2018

From this (Figure 43): we notice that the prevailing winds arrived from the North

PS: From the climate data we noticed that, Bengeurir is hot and humid climate which means that JuaHouse needs to be well insulated. The northern wind direction can also be used to passively cool the house.

3.5.2. Equipements used in JuaHouse:

Design builder requires the power density of each equipement used in the building as presented in following table:

Table 10: Power Density of the equipment used in JuaHouse.

Reference: JuaJamii

Colonne1	**Number of Equipement**	**Power (W)**	**Total Power (W)**	**Power Density (w/m2**
Hot Water System	1	2000	2000	23,14814815
Cooling and Heating device	3	840	2520	14,95076564
Fridge	1	40	40	0,462962963
Washing Machine	1	433	433	2,568921239
Clothes dryer	1	701	701	8,113425926
Dishwasher	1	1120	1120	6,644784728
Cooker/Stove/Oven	1	2000	2000	23,14814815
LED Bulbs Interior	13	5	65	0,385634828
Domestic Car Charger Socket	1	3300	3300	38,19444444
AC For Living Room	1	1640	1640	9,729863352
Water Pump (House)	1	100	100	1,157407407
Water Pump (Waste Water)	1	100	100	0,593284351

Water Pump (Aquaponic)	1	22	22	0,25462963
Air Pump (Aquaponic)	1	10	10	0,059328435
Phones	7	6	42	0,486111111
Computers	5	70	350	2,076495228
TV	1	40	40	0,462962963
LED Bulbs Exterior	8	10	80	0,474627481
Total Power (W)			**14563**	168,5532407
Area of House (m2)			**86,4**	

3.5.3. Interior Comfort Conditions:

We obtained these parameters from Solar Decathlon Africa's Rules and regulations (table….

Table 11: Interior Comfort Conditions

Reference: Solar Decathlon Africa, 2019

Temperature	22-25 C
Low heating limit temperature	19 C
Low cooling limit temperature	28 C
Humidity	45- 55 percent
Lighting tensity	300 Lux

3.5.4. Occupancy Schedules:

For this parameter we will use an international standard from American Society of Heating, Refrigerating and Air-Conditioning Engineers called "Residential Occupancy Schedule".

3.5.5. Openings characteristics:

The types of openings integrated into JuaHouse are: doors, windows and curten walls. Hasnaoui company supplied the house with these materials and they have the following features:

Table 12: Features of the Openings used in JuaHouse.

Reference : Alumix

	Number of items	Number layers	U value (w/m2 k)
Windows type S46	6	Double Glazing	2.81
Window type S70	1	Double Glazing	2,60
Window type S90	2	Double Glazing	2,75
Curten Wall type S52	48 m^2	Double Glazing	2,61
Door type S46	1	Double Glazing	2.81
Doors made of wood	2	One layer	0.64

3.5.6. Insulation Scenarios to perform simulation:

These scenarios relate to the thickness and positioning of the materials within the design. We have therefore been able to identify these scenarios on the basis of the architectural criteria and the thickness available in the Moroccan market.

a. The maximum insulation thickness that can be integrated to the architectural design:

Interior: Due to the small dimensions of the containers, aiming to have a confortable interior design proportions. 8 cm is the maximum value of interior thickness that can be reached. Additionally, according to the competition rules, the construction has two phases in two different sites which imply that the interior insulation reduces the assembly and transportation between the two sites.

Exterior: with the proposed assembly and disassembly system, the insulation outside cannot exceed 10 cm.

b. Available thickness in the Moroccan Market:

After the market analysis of Glass Wool, Stone Wool and Melamine Foam we found that the most available thickness is 5 cm for the three materials. Thus, the proposed thicknesses for simulations are a scaling up in the same thickness dimension.

c. Conclusion:

We conclude from the above circumstances with three scenarios (Table 13), which include the insulation thickness and positioning that we will use for the simulations:

Table 13 : Scenarios for Simulations

Priorities that should be taken in consideration.	**I5**	**I5E5**	**I5E10**
First priority: The first simulation will start from the interior side because of the time gain, we could get.	5cm Interior	5 cm interior. 5 cm exterior.	5 cm interior 10 exterior
Second Priority: 8 cm as the maximum thickness for the interior			
Third Priority: Scaling up with 5 cm when defining the thicknesses			
4th Priority: Maximum of thickness from outside is 10 cm.			

3.6. Simulation results and discussion:

3.6.1. Thermal simulation of JuaHouse without Insulation:

We will perform thermal simulation of JuaHouse without insulation as a reference to facilitate the comparative analysis between the proposed materials.

a. The envelop composition without insulation material:

According to the design reflection, the envelop will be composed of the layers presented in (Table 14)

Table 14: Proposed Composition of the building envelop without insulation.

Reference: JuaJamii

	Wall	Roof	Floor
Layers	Outer Surface Plywood 20 mm Container Metal 4 mm Plywood 20 mm Timber Flooring 2 mm Inner Surface	Outer Surface Plywood 20 mm Roofing Felt 2 mm Container Metal 4 mm Air Gap 50 mm Plasterboard 12,5 mm Inner Surface	Outer Surface Plywood 20 mm Container Metal 4 mm Plasterboard 12,5 mm Inner Surface

All the interior and exterior coatings of fabric building envelop are having the features presented in the (Table 15):

Table 15: Thermal Conductivity of the Interior and Exterior Coatings.

Reference: Design Builder Library

Material	Thermal Conductivity (w/m k)
Plywood	0,15
Timber Flooring	0,14
Container	205
Roofing Felt	0,19
Plasterboard	0,25

a. Results:

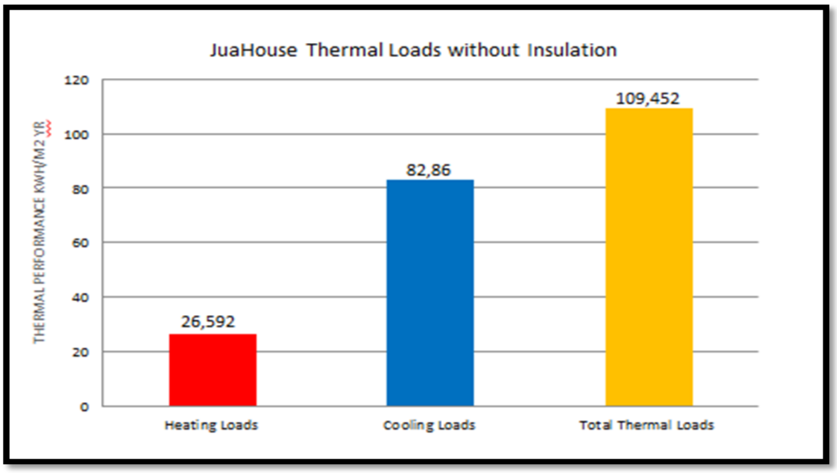


Figure 44: JuaHouse Thermal Loads Without Insulation

3.6.2. Thermal Simulations of each Scenario:

The results of the three simulation scenarios are presented according to each scenario as below:

a. Interior with 5 cm (I5):

The envelop layers composition and dimensions for this scenario are presented in the following table:

Table 16: Envelop Layers composition of I5 Scenario

	Walls	Roof	Floor
Layers	Outer Surface Plywood – 20 mm Container Metal – 4 mm Insulation Material – 50 mm Plaster board – 12,5 mm Inner Surface	Outer Surface Plywood – 20 mm Roofing Felt – 2 mm Container Metal – 4 mm Insulation Material – 50 mm Air Gap – 50 mm Plaster board – 12,5 mm Inner Surface	Outer Surface Container Metal – 4 mm Insulation Material – 50 mm Plywood – 20 mm Timber Flooring – 3 mm Inner Surface

➢ **Results:**

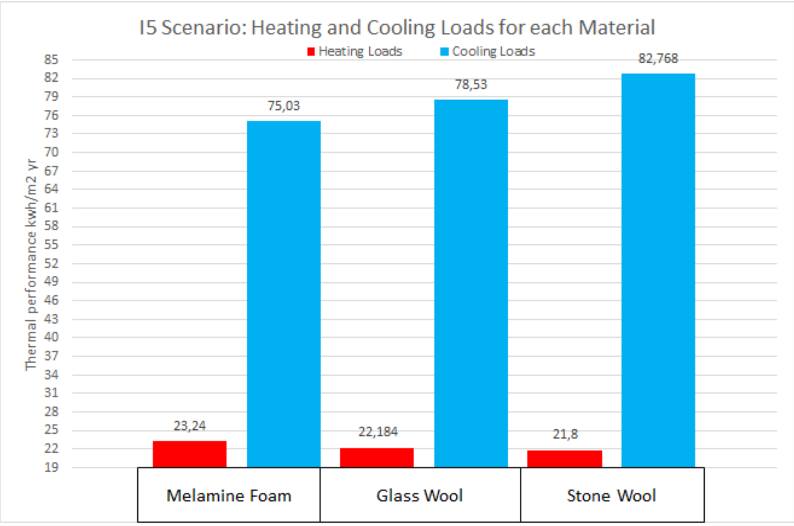


Figure 46 : I5 Scenario: Heating and Cooling Loads for Each Material

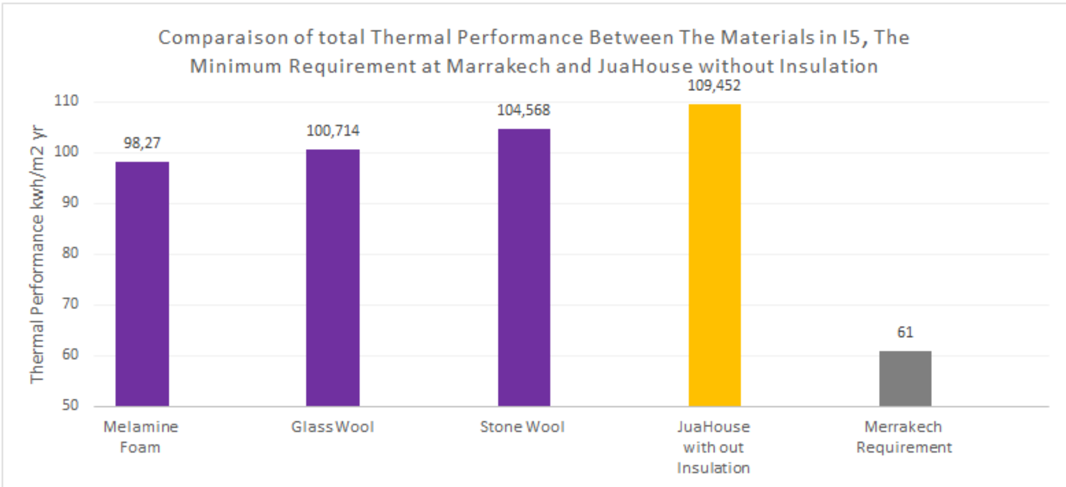
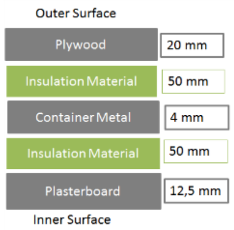
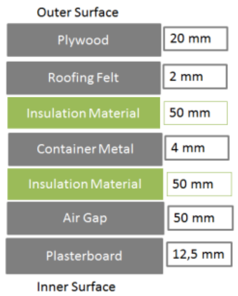


Figure 45: Comparison of Total Performance Between The Materials in I5, The Minimum Requirement at Marrakech and JuaHouse without Insulation.

b. Interior 5 and Exterior 5 (I5E5):

The envelop layers composition and dimensions for this scenario are presented in the following table:

Table 17 : Envelop Layers composition of I5E5 Scenario

	Walls	Roof	Floor
Layers			

➢ **Results:**

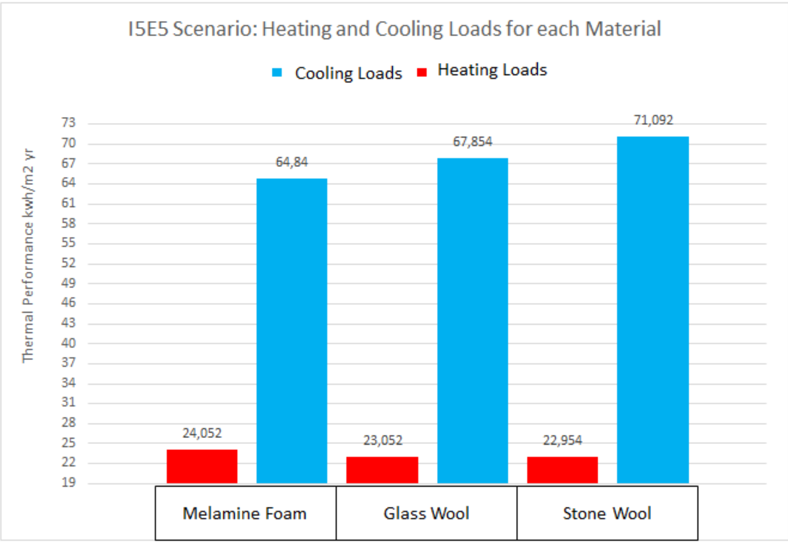


Figure 48 : I5E5 Scenario: Heating and Cooling Loads for Each Material

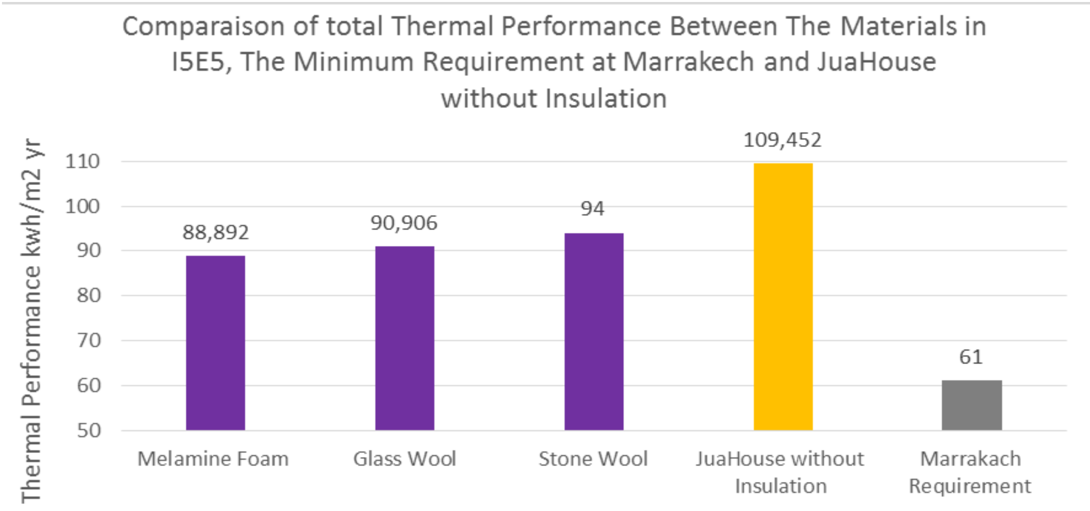


Figure 47: Comparison of Total Performance Between The Materials in I5E5, The Minimum Requirement at Marrakech and JuaHouse without Insulation.

c. Interior 5 and Exterior 10 (I5E10):

The envelop layers composition and dimensions for this scenario are presented in the following table:

Table 18: Envelop Layers composition of I5E10 Scenario

	Walls	Roof	Floor
Layers	Outer Surface Plywood — 20 mm Insulation Material — 100 mm Container Metal — 4 mm Insulation Material — 50 mm Plasterboard — 12,5 mm Inner Surface	Outer Surface Plywood — 20 mm Roofing Felt — 2 mm Insulation Material — 100 mm Container Metal — 4 mm Insulation Material — 50 mm Air Gap — 50 mm Plasterboard — 12,5 mm Inner Surface	Outer Surface Plywood — 20 mm Insulation Material — 100 mm Container Metal — 4 mm Insulation Material — 50 mm Plywood — 20 mm Timber Flooring — 2 mm Inner Surface

- **Results:**

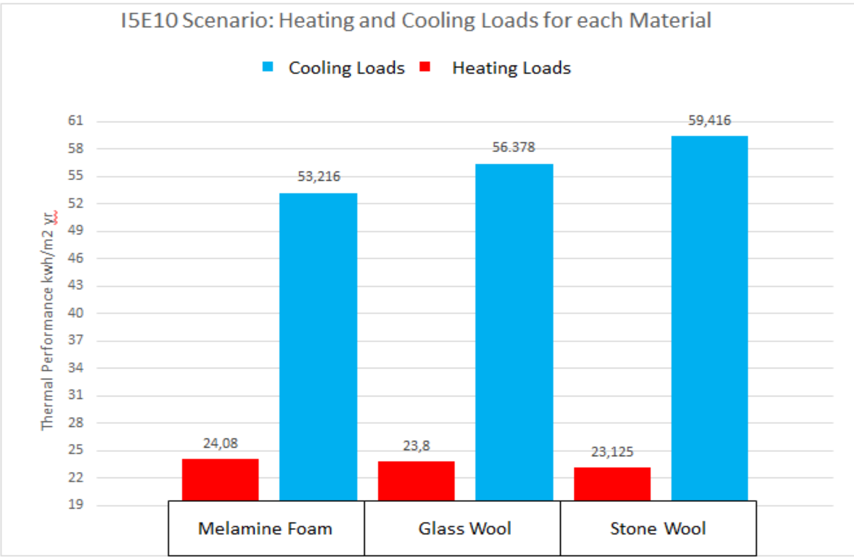


Figure 49: I5E10 Scenario: Heating and Cooling Loads for Each Material

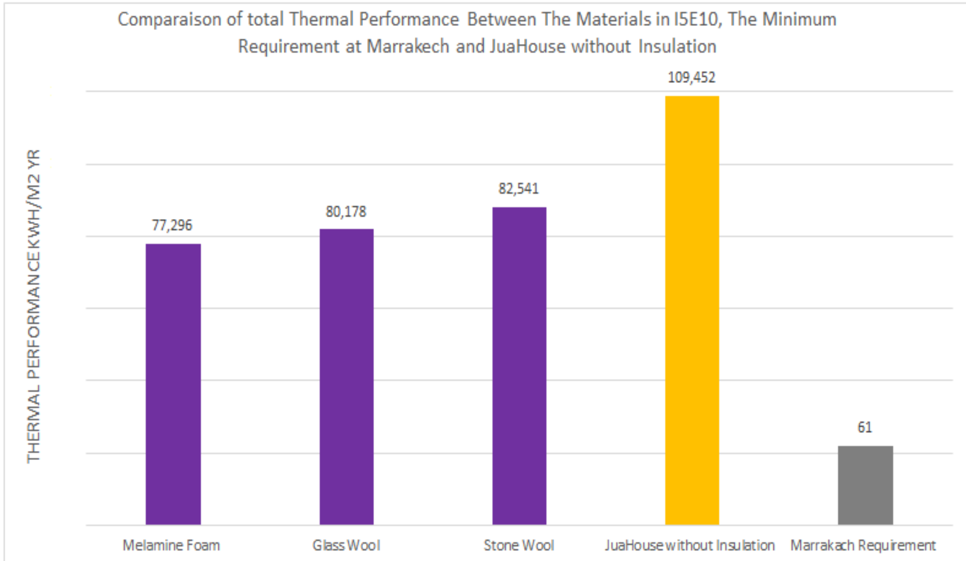


Figure 50: Comparison of Total Performance Between The Materials in I5E10, The Minimum Requirement at Marrakech and JuaHouse without Insulation.

3.6.3. Discussion:

For all the results, the cooling loads are four times much greater than the heating loads which confirm that Benguerir climate is very hot and the JuaHouse thermal design reflection is highly needed.

From the three scenarios we distinguish the following points:

- Melamine Foam's shows the best cooling loads which are the smallest followed by Glass Wool and Stone Wool that has the biggest loads, the result shows the inverse representation for the heating loads. However, the distinction in heating is not as important as the Cooling (Figure 46, 48, 50)
- We can also check (Figure 45, 47, 49) which shows a ranking of total thermal loads between the three different materials starting with stone wool as being the highest in thermal performance followed by Glass Wool and Melamine Foam.
- In this regard and in the three scenarios, Melamine foam is the best insulation material in terms of thermal performance followed by Glass wool and Stone Wool.
- Increasing insulation material thickness result with more improvement in thermal performance (Figure45, 47, 49)
- Between the three scenarios and for the three materials, the best thermal performance has been reached in I5E10 scenario (Figure 49). However, its results don't match the minimum thermal building requirement of Marrakech region, which implies that JuaHouse still needs more thermal performance improvement.
- As the Melamine is having the best U value, it shows best thermal performance among the other materials followed by Glass Wool which has the second U value also.
- With the insulation parameter, in this research we couldn't reach the thermal performance required by the Moroccan thermal regulations because of the architectural limitation related to material thicknesses. Therefore, enhancing the thermal performance of the House require including more passive solutions to the design.

3.7. Economic analysis of each material:

In this point, we are going to make cost and benefit calculations for each material in each scenario with aim to help in the choice of the best approach to achieving economic benefit while ensuring energy savings for JuaHouse. Thus, we are going to calculate the following factors:

- The initial investments of each material, as the amount required to start a business or a project
- The Projected Annual Energy Cost Savings of each material: energy cost savings occurring in a single year from the energy efficiency measures implemented.
- Payback of each material: the time it takes for the energy savings to payback the initial cost of the project.

3.7.1. The initial investments of each material:

To calculate the investments, we include the implementation price which is 20 percent from the material price. Therefore we are going to use the following formula:

Investment = Total Surface to be insulated * (Material Cost/m^2 + Implementation Cost/m^2)

By taking in consideration that the total surface to be insulated of the house is: 251.68 m^2, the results are presented in (Table 19)

Table 19: Initial Investments of Each Material.

	Melamine			Glass Wool			Stone Wool		
	I5	I5E5	I5E10	I5	I5E5	I5E10	I5	I5E5	I5E10
The price (Euros/ m^2)	4.89	9.78	14.67	3.46	6.92	10.38	6.94	13.94	20.88
The material price in each Scenario including	5.87	11.74	17.61	4.16	8.32	12.48	8.33	16.66	24.99

the Implementation Euros/ m^2									
Initial Investment (Euros)	1477,36	2954.7232	4432.08	1047	2093.9	3140.9	2095.98	4191.97	6289.4

3.7.2. Annual Projected Annual Energy Cost Savings:

We use the following formula in order to do the necessary calculations:

The Projected Annual Energy Cost Savings = Annual Energy Savings * Price of Kwh in Morocco

Table 20 : Annual Projected Annual Energy Cost Savings

	Melamine			Glass Wool			Stone Wool		
	I5	I5E5	I5E10	I5	I5E5	I5E10	I5	I5E5	I5E10
Total Thermal performance ($Kwh/m^2.yr$)	98.27	88.892	77.296	100.714	90.906	80.178	104.568	94	82.541
Annual Energy Savings (Kwh/yr)	2814.28	5174.54	8093.02	2199.17	4667.6	7367.6	1229.2	3888.4	6772.9
The price of kWh in Morocco	0,094	0,095	0,095	0,11	0,095	0,095	0,11	0,095	0,095

Euros / kwh									
The Projected Annual Energy Cost Savings (Euros/yr)	264.54	491.58	768.8	241.9	443.4	699.9	135.2	369.4	643.43

3.7.3. Payback of each material:

To make the required calculations, we use the formula below:

Simple Payback = Energy Saving Investment/ The Projected Annual Energy Cost Savings.

Table 21: Payback of Each Material

	Melamine			Glass Wool			Stone Wool		
	I5	I5E5	I5E10	I5	I5E5	I5E10	I5	I5E5	I5E10
Simple Payback	5 years and 7 months	6 years	5 years and 10 months	4 years and 4 months	4 years and 9 months	4 years and 6 months	15 years and 5 months	11 year and 4 months	9 years and 9 months

3.7.4. Discussion:

- Glass Wool with low price per m2, it shows the best investments with in the three scenarios, followed by Melamine foam.

- As melamine foam is having the high thermal performance, it shows the highest Projected Annual Energy Cost Savings, on contrary to the Stone Wool which has the thermal performance.
- The lowest payback appears on the scenarios of Glass Wool followed by Melamine foam and then Stone Wool.
- From the outcomes of the scenarios, increasing the thickness implies increasing the investments and, at the same time, improving the Projected Annual Energy Cost Savings. However, only the thickness does not improve the payback results.
- From literature review, the stone wool is having a good thermal cost. However, we found that the payback is very high for this material which implies that the available stone wool in Morocco may not be at effective in terms of investments.

4. Conclusion:

In this chapter we saw how the container house is sensitive to the hot climate especially, in our case study in Benguerire, having insulation will reduce the amount of energy consumed in the house and therefore the bill will be much more cheaper . Glass wool proved to be the more energy efficient material in insulating the JuaHouse since the result showed that it has the best outcomes in thermal performance against the other proposed materials.

Conclusion:

The current rates of demand cannot be met just with alternative sources of supply such as wind or solar power, but if demand can first be reduced, it then becomes possible to meet a greater proportion of it in this way, and therefore increase levels of both local and national energy security. The best way to reduce demand is through better use of insulation, because when defining the appropriate insulation material for a building helps significantly on saving money by reducing heating and cooling energy bills, freeing up income, helping to reduce fuel poverty and boosting the economy.

Building thermal simulations tools are very strong when it comes to evaluating a building's energy performance. It is suggested that the simulation be incorporated during a building's design stage. During this point, there are more chances to take critical decisions for the building design with a cheaper cost. Moreover, different scenarios can be simulated to achieve the best possible design, not only in terms of physical design, but also in terms of operational scenario.

In this research, comparative analyses were carried out to choose the best insulation material for Juahouse, by reporting the findings from literature review, thermal simulations and economic calculations. In this regards, Glass Wool is one of the best available insulation materials in Morocco, by showing an effective thermal price adding to the very small environmental impact throughout its life cycle which was shown from the state of art.

Recommandations:

In this study, the thermal simulation that we have done does not include thermal bridging which is linked to the stage of execution. In this regard, the implementation of the proposed solution in the real world requires a profound knowledge of thermal bridging and workers monitoring.

From the thermal performance results, the house didn’t reach minimum thermal performance required by Moroccan regulations despite the increasing on insulation materials thicknesses. That means, if thermal performance enhancement of the house, need to include other passive and active solutions, and from this study we propose the following points:

- Maximize the windows in the south facades to reduce the heating gains.

- Increasing the use of vegetation around the house
- Openings dimensions and positioning to renew the air inside the house.
- The use of Heating Ventilation and Air Conditioning system.

Life cycle analysis (LCA) as a method used to evaluate the environmental impact of a product through its life cycle which includes production, Transportation, Usage, End life. In this study, it has been taken directly from previous findings because of the luck of information related to: production, Transportation, End life of each material. Thus, developing a research study related to Life Cycle Analysis for each proposed material will help on having a clear idea about low environmental impact material for JuaHouse.

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Appendix:

1. **EPBD** (Directive on the energy performance of buildings): Established by the European Union and it contains several provisions to improve the energy efficiency of both new and existing buildings. Key provisions of the EPBD include the requirement for Member States to develop energy performance certificates to be included in all advertisements for the sale or rental of buildings; establish inspection schemes for heating and air-conditioning systems (or put in place measures with equivalent effect); set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements; and draw up lists of national financial measures to improve the energy efficiency of buildings. Perhaps the most demanding requirement of the EPBD is that all new buildings must be nearly zero-energy buildings ('nZEB') from 2021, and for this requirement to apply to all public buildings from 2019. Weaknesses in Member States' implementation of the EPBD, including the lack of a common definition of nZEB, are analysed in 2016. (Wilson. A.B, 2017)

2. **The Bbio (Besoin bioclimatique)**, or Bioclimatic Need of France Thermal Regulation (RT 2012), this coefficient represents the energy efficiency of a building.

Equation : "Bbio = 2 x Heating Requirement + 2 x Cooling Need + 5 x Lighting Need". Le ('Besoin Bioclimatique (Bbio)',n.d)

3. **Cpe: (**The primary energy consumption) is calculated by professional who carries out a thermal study of a building. It covers the consumption of heating, cooling, lighting, hot water and various auxiliaries (pumps, etc.).

Equation: "Cep = Consumption of primary energy per year of (Heating + Air Conditioning + Domestic Hot Water + Lighting + Auxiliary) - Photovoltaic production (limited to 12 kWhEp / (m^2.year)" ('Le Coefficient d'Energie Primaire (Cep)',n.d)**.**

4. **KFW** (Kreditanstalt für Wiederaufbau): promotional bank, it is a Group supports change and encourages forward-looking ideas in Germany, Europe and throughout the world(KFW,n.d).