Reduction of Energy Consumption by Means of an Efficient Building Envelope in the Mexican Caribbean

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ABSTRACT

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ABSTRACT

The purpose of this thesis was to determine how much energy and money can be saved by implementing thermal insulation on the most common housing projects in Mexico, which stands for most of the population of the country.

The research problem is that the housing projects for the average family households, which stands for up to 44.7% of the residential industry, does not include thermal insulation in its design and due to the warm temperatures, air conditioning systems have to be used in order to provide its inhabitants the comfort people need. This leads to high costs and poor sustainability.

This thesis analyses the building materials and their thermal conductive properties that are currently used in the housing industry in Mexico and the theoretical application of thermal insulation based on Finnish standards to determine the energy required and its cost to achieve the comfort temperature for the residents of a household to live in.

The results of the thesis show that up to 50 % of the energy can be saved if thermal insulation is considered in the design, which means much less energy costs and better building sustainability.

Keywords Thermal transmittance, u-value, thermal load, heat, solar radiation, thermal insulation, energy cost

Pages 34 p. + appendices 17 p.

CONTENTS

1 INTRODUCTION

1.1 Problem

Energy consumption in residential dwellings in Mexico represents 16% of the country's energy consumption. Mexico is in a warm climate region, making the use of air conditioning systems in residential houses the best solution to achieve a thermal comfort zone for its inhabitants. (Griego, 2012, 1)

Single family houses are built according to the National Building Code regulations, which satisfy the structural and ergonomic design. Nevertheless, such Building Code does not consider energy efficiency requirements; therefore, houses are built without thermal insulation design nor U-values requirements, regardless of the climate conditions of the area, making this a potential energy waste.

1.2 Research questions

How much energy can be saved in residential households in Mexico´s most common housing projects, if those were built meeting European energy efficiency requirements? In other words, would the use of thermal insulation in the building design reduce considerably the energy consumption?

1.3 Objectives

The objective of this thesis is to determine the amount of energy and money that can be saved by implementing thermal insulation in the design of single family houses in Mexico and to design an insulated dry wall to prevent moisture and condensation problems within the structure. These factors are not considered in Mexico at the moment in the construction design, making a large amount of energy being wasted in cooling the households. The partial objectives in this project are the following: determination of the U-value, making a condensation check, determination of the thermal loads, determination of the cooling capacity of the air-conditioning system, determination of energy cost and the results with comparison.

The thermal transmittance, also known as U-value, is the capacity of a structure to regulate the heat flow density. The U-value of the whole building envelope will be determined by the correlation between the thermal conductivity λ, of each of the building materials, the thickness of each layer, the area of the surface in question and the difference in air temperatures inside and outside of the structure. For this project, three different U-values will be used, one without considering the thermal insulation on the structure and the two others, with two different kinds of thermal insulation.

Since there are high temperatures and high levels of moisture in the circumstances of the study case, it is necessary to do a revision whether or not there could occur condensation due to the cold air from the air conditioning and the warm and humid conditions from the outside. The thermal load is the amount of heat gains through the structure, which without a cooling mechanism will produce high temperatures, making feel the occupants with thermal discomfort. The thermal loads to be considered in this project are the thermal load due to solar radiation, the occupants and the difference between outside and inside air temperatures.

The cooling capacity of an air-conditioning system is what will counter rest the thermal load in the structure, and will provide with the thermal comfort necessary for the occupants. The cooling capacity will help to determine the yearly energy costs of using the air-conditioning.

In order to determine the yearly cost of electricity, different calculations will be made depending on the average temperature of each month and the amount of energy that will be required to cool the structure with the air-conditioning system.

A comparison of the results will be made when the different costs of cooling the structure with the three different insulated properties are achieved.

1.4 Methods

To achieve the objectives, a basic house structure is analyzed by considering different characteristics of the structure. For example, the geographical locations of the structure, the climate in which it is located, its building materials, its thermal properties, such as conductivity, transmittance and resistance, the total thermal load into the structure at the most critical time of the year and the cooling capacity of the air conditioning systems. All these characteristics have to be considered in order to be able to supply the thermal comfort zone to the household.

2 CHARACTERISTICS OF STUDY CASE

2.1 Geographical description of the study case

The structure to be analyzed is theoretically located on the Yucatan peninsula on the south-east of Mexico, along the Caribbean coastal town of Tulum, in the state of Quintana Roo, shown in Figure 1, with the following coordinates 20.1373° N, 87.4633° W. This location was chosen due to the weather conditions, around the year humidity is high and temperatures can be around 30 °C at some point of the day, even in winter time. Mornings can be a chilly but at noon it can be warm. Such conditions make this study case gather crucial information to obtain the expected results.

Figure 1 State of Quintana Roo in Mexico

2.2 Climate in the location

According to the Köppen climate classification, the climate at the Yucatán peninsula in Mexico, is classified as Tropical wet and dry savannah, Aw type, as seen in Figure 2.

“Aw category has a pronounced dry season. The dry winter months typically get less than 40 mm of rain, compared to over 150 mm in each of the summer months. Much of coastal Mexico, stretching from Nayarit along the Pacific coast all the way to Guatemala, is in this category.” (Geo-Mexico)

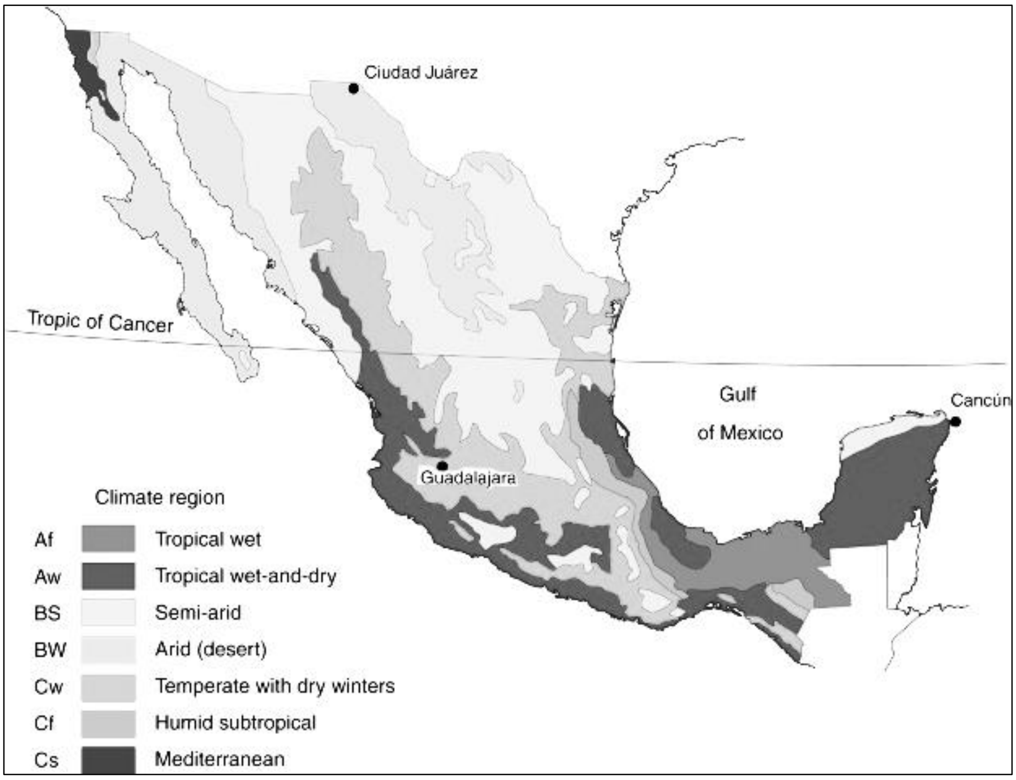

Figure 2 Köppen Climate classification in Mexico

The Köppen climate classication was developed based on the relationship between climate and vegetation. This type of climate classication scheme provides an efficient way to describe climatic conditions and multiple variables in their seasonalities with a single metric. The table classification can be seen in Table 1. (Chen, 2013, 1)

Table 1 Köppen clasification

Main characteristic of the Köppen climate major groups and sub-types.

Major group	Sub-types
A: Tropical	Tropical rain forest: Af Tropical monsoon: Am Tropical wet and dry savanna: Aw (Sometimes As is used in place of Aw if the dry season occurs during the time of higher sun and longer days)
B: Dry	Desert (arid): BWh, BWk Steppe (semi-arid): BSh, BSk
C: Mild temperate	Mediterranean: Csa, Csb, Csc Humid subtropical: Cfa, Cwa Oceanic: Cfb, Cfc, Cwb, Cwc
D: Snow	Humid: Dfa, Dwa, Dfb, Dwb, Dsa, Dsb Subarctic: Dfc, Dwc, Dfd, Dwd, Dsc, Dsd
E: Polar	Tundra: ET Ice cap: EF

2.3 Building legislation and norms in Mexico

Houses in Mexico are built according to the National Building Code, “Código de Edificación de Vivienda” CEV, in Spanish language, which is regulated by the National Building Commission, “Comisión Nacional de Vivienda”. (Código de Edificación de Vivienda)

This project used certain requirements in the Building Code in order to achieve the most reliable information and characteristics of the study case structure. However, the energy efficiency requirements are taken from the European Codes, since in Mexico those parameters are not considered when building residential households.

3 THEORETICAL CONCEPTS

3.1 Building envelope

A building envelope is defined as the set of components working as a unit, being capable of separating the exterior environment from the interior environment. Each system and its components are expected to have certain performance requirements to satisfy their functions as part of the building envelope.

The components are often made up of dissimilar materials that have dissimilar properties, which must be accommodated in the design and assembly of the system. An understanding of the properties of the individual materials, and of the system, is essential in the assessment of the performance of the building envelope." (American society of Engineers 2014, 5)

3.2 Heat transfer mechanisms

Energy in terms of heat is a fundamental factor for the study and analysis of this project, because the amount of heat in a house will determine the energy needed to provide a comfort zone for its dwellers. On the other hand, moisture content in the air can move from one place to another within a structure due to the thermodynamics phenomena.

Heat and water vapour that transfers within a structure, are the direct consequence of changes in temperature, air pressure and moisture content, and are linked to each other.

"The process by which energy is transported within and between building components of different temperature is known as *heat transfer*. The science of heat transfer seeks to predict the rate at which the energy exchange will take place." (Hagentoft, 2001,4)

Heat transfer can be defined as the transmission of energy from one region to another as a result of a temperature difference between them. Three modes of heat transfer can be identified: conduction, radiation and convection.

In *conduction,* the energy is transmitted due to internal vibrations of molecules, without a net displacement of the molecules themselves. All bodies emit radiant heat continuously. *Thermal radiation* is a type of electromagnetic radiation which is propagated as a result of temperature difference between bodies. Heat transfer due to radiation is not dependent on material medium. Heat may be transferred, even when a vacuum exists between the considered bodies of different temperatures. *Convection* is an important mechanism for heat transfer, which is due to the flow of fluid, generally in building physics it is air or sometimes water. The heat is carried by the heat capacity of the fluid, from one point to another."

3.3 Thermal comfort

Thermal comfort is defined as the range of climatic conditions within which the majority of people would not feel thermal discomfort, either of heat or cold. Thermal comfort studies are either based on field surveys or controlled climatic chambers. (Gallo, 1988, 3)

3.4 Thermal load

"The cooling load is the amount of heat energy that would need to be removed from a space (cooling) to maintain the temperature in an acceptable range (BASIX).

According to BASIX the thermal loads take into account the dwelling's construction and insulation; including floors, walls, ceilings, roof, windows and doors. The dwelling's glazing and skylights; based on size, performance, shading and overshadowing.

3.5 Thermal transmittance

According to the Finnish national building code, "Thermal transmittance indicates the heat flow density which permeates a building component in steady-state when the temperature difference between the environment on different sides of the building component is the unit of temperature." This is also knows as the U-value, its units are $W/(m^2 \cdot K)$. (National building code of Finland, C4)

3.6 Thermal conductivity

The ability of a material to transfer heat between two surfaces with a temperature difference. "The thermal conductivity is the heat energy transferred per unit time and per unit surface area, divided by the temperature difference. It is measured in watts per degree Kelvin." This term is often referred as *lambda (λ).* Its units are $W/(m \cdot K)$. (The American Heritage Science Dictionary)

The thermal conductivity values used in this project can be found in Table 2. (Chadderton, 2007, 63)

Table 2 Thermal conductivity values

Material	Thermal conductivity λ, W/mK
Cement decking	0,36
Brickwork	0,84
Plasterboard / gypsum	0,16
Timber flooring	0,14
Polyuerthane	0,035
Extruded polystyrene	0,035
Concrete	1,4
Sand	0,58
Air	0,024
Glass	0,81
Bitumen	0,5
Mineral wool	0,036
Termafoam	0,0248

3.7 Thermal resistance

"Thermal resistance of a material layer of a uniform thickness or a layered structure in the thermal steady-state indicates the temperature difference between the isothermal surfaces on both sides of the structure divided by the heat flow density through the material layer." This is known as R and its units are $(m^2 \cdot K)/W$ (National building code of Finland, C4)

Tables 3 and 4 show the surface resistances used in this project. (Chadderton, 2007, 63)

Table 3 Inside surface resistances R_{si}

Building elemnt	Heat flow	R_{si} (m^2K/W)
Wall	Horizontal	0,12
Ceiling, floor	Upward	0,1
Ceiling, roof	Downward	0,14

Table 4 Outside surface resistances R_{so}

Building element	Surface emissivity	R_{so} (m^2K/W)		
		Sheltered	Nor-mal	Se-vere
Wall	High	0,08	0,06	0,03
Wall	Low	0,11	0,07	0,03
Roof	High	0,07	0,04	0,02
Roof	Low	0,09	0,05	0,02

3.8 Moisture

“Water can exist in three states of matter: solid, liquid and gas. In the physical conditions that buildings are operated, all these three states of moisture may exist.”

Water and moisture are essential for life but when it comes to buildings, moisture can bring about deterioration and disintegration of its materials. The interaction of moisture with building materials and components of the building envelope may significantly affect the thermal performance of buildings. (Hagentoft, 2001,87)

3.9 Air conditioning systems

Air conditioning is the tool with which an internal environment can be controlled to achieve the desired thermal comfort. “The term air conditioning may be used to describe an air-cooling system that reduces excessive temperatures but does not guarantee precise conditions, to minimize capital and operational costs. This is better defined as comfort cooling”. (Chadderton, 1993, 1)

3.10 Air tightness

In order to have a healthy building envelope, without significant damages, it is highly recommended to make it as airtight as possible. There are many disadvantages of air flowing in through joints and gaps in the building envelope. A large percentage of building damage is caused by leaks in the building envelope such as low sound insulation, draughts that cause discomfort for occupants and high heat losses. In general, airtightness has the following advantages:

- Prevention of moisture-related building damage
- Prevention of draughts and discomfort
- Prevention of high heat losses or gains due to infiltration
- Improvement of sound insulation
- Improvement of indoor air quality

(Troi, 2015, 131)

4 APPLIED BUILDING PHYSICS

4.1 Process description

In this section, a detailed description on how the results for all the calculations were obtained, will be provided to give the reader a guide and a better understanding of the analysis.

The objective of this project is to calculate the so-called *Thermal Load* of the structure, to determine the yearly electricity cost of the use of an air-conditioning system, needed to counter rest the thermal load.

The *Thermal Load* measure unit is kilowatts kW, which is the amount of energy in terms of heat into the structure; coming from radiation from the sun through windows, heat from temperature difference on the outside and inside air. Thermal load is obtained from the correlation between the *Thermal Transmittance, U-value,* the thickness of each layer of material, difference in temperatures between the outside and the inside air and the area of the *building envelope.*

The building envelope in this project was analyzed in three different ways:

The control analysis was to calculate the U-value of all the building envelope components without thermal insulation in the walls, roof, floor, nor windows. The second analysis was using mineral wool as thermal insulation on the structure, and double glazed windows. Finally, considering Termafoam as thermal insulation on the building envelope and double glazed windows.

Once the total Thermal Load is obtained in kW, it needs to be converted into *British Thermal Unit/hour (BTU/h)* to determine the right air-conditioning system needed to counter rest the thermal load, and provide with the desired comfort temperature. It has to be changed into BTU since air-conditioning systems are stated in British Thermal Unit for its cooling capacity in the Mexican market.

British Thermal Unit BTU is the measure unit in air condition systems. There are many different options on the market, but for this project, Daikin McQauy systems were analyzed for narrower results. (Daikin McQuay)

An air-conditioning system will have a different inlet power depending on its cooling capacity; therefore, once these values are determined, the cost of that energy, can be finally obtained. In this project, *energy costs* were determined in a monthly basis to achieve better yearly results, by using each month the average temperature values, provided by the National Meteorological Service SMN and the Federal Electricity Comission CFE. (Servicio Meteorológico Nacional), (Comisión Federal de Electricidad)

Detailed information on all the calculations and expressions in this section, can be found in Appendix 1.

4.2 Building envelope

The house is an example of the so-called "social interest houses", it is a single family house with two bedrooms, one bathroom with a laundry room, a kitchen and living room with dining room, one of the most commonly built in Mexico. Its dimensions are shown in the floor plan in Figure 3.

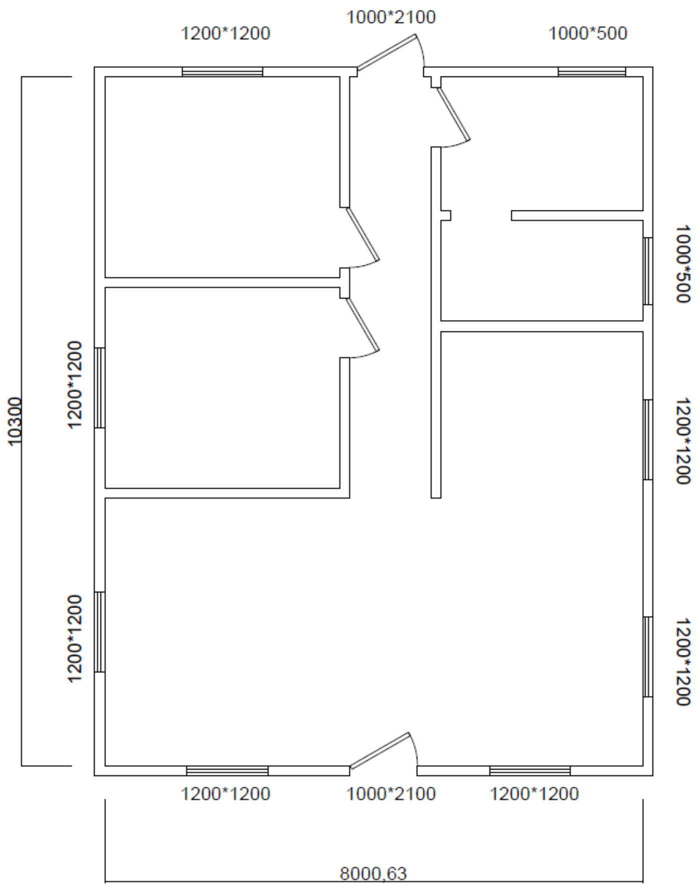

Figure 3 Floor plan

The structure is comprised of floor and roof area of 82.4 m^2, structural walls of 91.5 m^2, 11.08 m^2 of single-glazed windows and two doors of 4.2 m^2

Since there is no regulation in Mexico regarding the requirement of a U-value for energy efficiency purpose, three different U-values will be determined. First, as it is currently build, without thermal insulation, secondly using mineral wool as insulation on walls, roof, and double-glazed windows; and at last using the so-called Termafoam as insulation on the structure and using double-glazed windows.

4.3 U-value without thermal insulation

In this section, the U-value of the structure is calculated, considering the lack of thermal insulation. It can be seen how inefficient the building envelope components are, based on the high U-values.

4.3.1 External walls

The structure of the external walls, shown in Figure 4, is comprised of 120 mm thick red brick and 10 mm thick layer of mortar on both external and internal surface, and 5 mm layer of gypsum on the inner side, with an U-value of 2.87 W/($m^2 \cdot K$). Calculations on how U-value, was obtained can be found in Appendix 1. In Table 5 it is shown how the U-value was obtained.

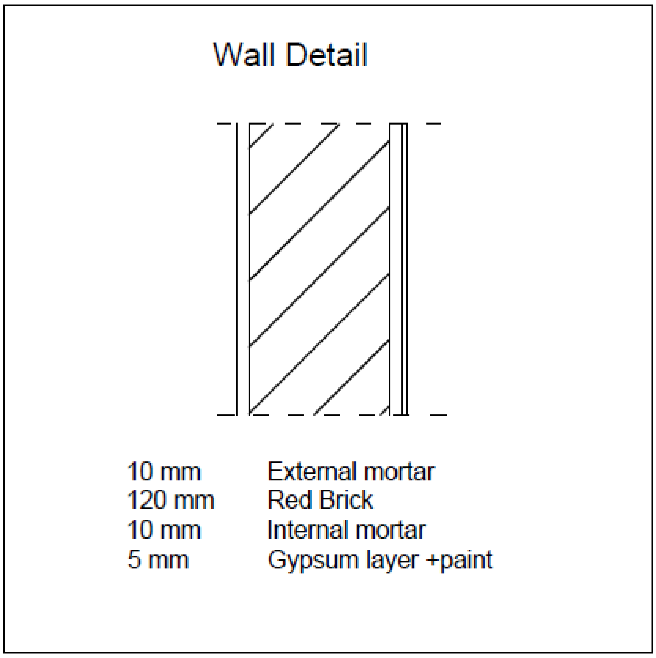

Figure 4 Wall detail

Table 5 U-value of external wall without insulation

Layer of wall	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m²*K/W]
Cement plaster	0.01	1.047	0.010
Brick	0.12	0.8	0.150
Cement plaster	0.01	1.047	0.010
Gypsum layer	0.005	0.58	0.009
	Horizontal internal surface resistance		0.120
	Horizontal external surface resistance		0.060
	Total thermal resistance		0.348
	U value= 1/Total thermal resistance		2.872

4.3.2 Roof

The roof consists of a 5 mm layer of bitumen on the external surface, 120 mm of reinforced concrete, 10 mm of internal mortar and 5 mm of a gypsum layer on the interior, as shown in figure 5. Its U-value is 4.31 W/(m$^2 \cdot$ K). In Table 6 it is shown how the U-value was obtained.

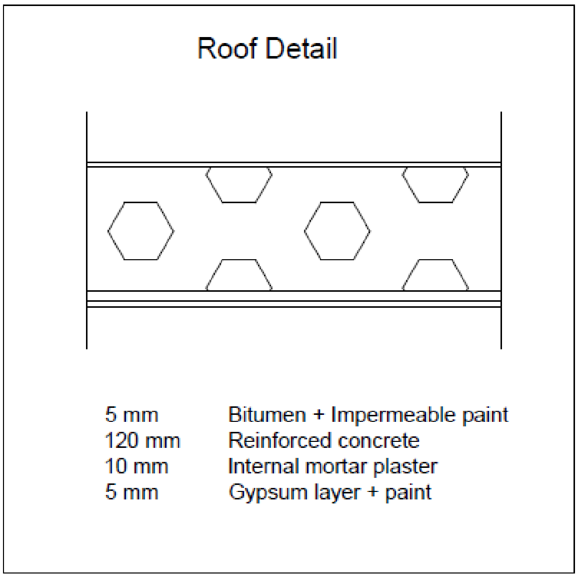

Figure 5 Roof detail

Table 6 U-value of roof without insulation.

Layer of Roof	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Bitumen paint	0.005	0.198	0.025
Reinforced concrete	0.12	1.4	0.009
Cement plaster	0.01	1.047	0.010
Gypsum layer	0.005	0.58	0.009
	Downwards internal surf. Resist.		0.14
	Vertical external surface resistance		0.04
	Total thermal resistance		0.2320
	U value= 1/Total thermal resistance		4.310

4.3.3 Floor

The floor is made of a 5 mm layer laminated floor, 10 mm of polyurethane, 120 mm of reinforced concrete, 50 mm of extruded polystyrene as insulation, the moisture barrier, 50 mm of sand and 50 mm of gravel, as shown in figure 6, with a U-value of 0.46 W/(m^2 · K). In Table 7 it is shown how the U-value was obtained.

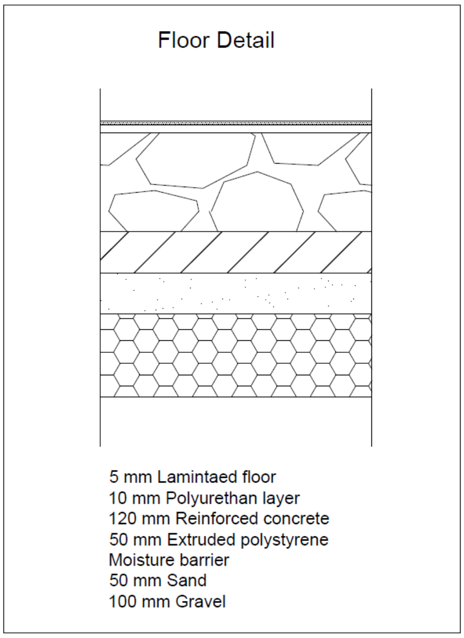

Figure 6 Floor detail

Table 7 U value of floor without insulation.

Layer of floor	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m²*K/w]
Laminated	0.005	0.047	0.106
Polyurethane	0.01	0.029	0.345
Reinforced concrete	0.12	1.4	0.086
Extruded polystyrene	0.05	0.035	1.429
Sand	0.05	0.58	0.086
	Upwards internal surf. resist.		0.10
	Total thermal resistance		2.157
	U value= 1/Total thermal resistance		0.465

4.3.4 Windows and doors

The windows are 6 mm thick single glazed windows with no polarization properties and a U-value of 5.33 W/($m^2 \cdot$ K). The doors are normal plywood doors and a U-value of 2.22 W/($m^2 \cdot$ K).

4.4 U-values considering mineral wool as insulation

In the following section, new building envelope's U-values will be determined taking into account mineral wool as a thermal insulating material. Mineral wool is considered to have a thermal conductivity value of 0.036 W/(m·K).

There are no specifications in the National Building Code of Mexico (Código Nacional de Vivienda) about the building's envelope U-value requirements; therefore the U-values in this section were calculated according to the values provided by the European Standards.

The values that were chosen for this calculation is from the south of Spain, as shown in Table 8, which are similar to the high temperatures that can occur in the Mexican Caribbean. (Eurima)

Table 8 U-values according to Eurima

U-values in Seville (W/m^2k)		
Wall	Roof	Floor
0.82	0.45	0.82

4.4.1 External walls

The structure of the external walls, as shown in Figure 7, is comprised of 10 mm layer of mortar, 120 mm of red brick, 30 mm of mineral wool as thermal insulation and 5 mm layer of gypsum on the inner side, with a U-value of 0.846 W/(m^2 · K).

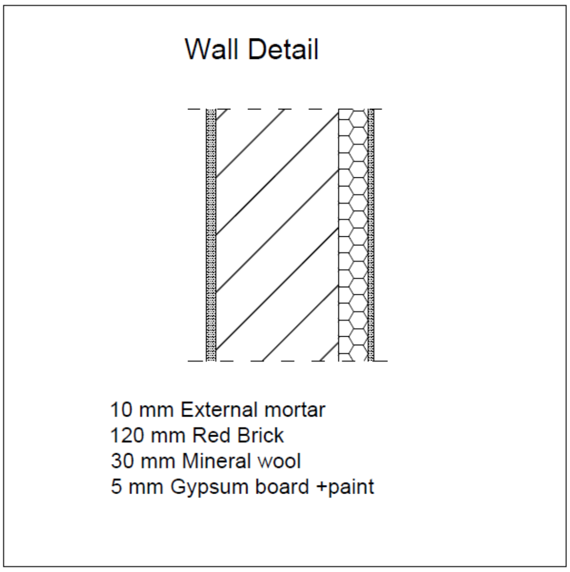

Figure 7 Wall detail

Since the U-value for the external wall has to be at least 0.82 W/(m^2 · K) according to the European standards, the thickness of the insulation layer has to be such that it will result in the total wall structure's desired value. In this case, the thickness of the insulating layer in addition to the other layers of the wall that lead into a U value of 0.846x W/(m^2 · K), was that of 30 millimeters.

The following table shows how the U-value was obtained for the external walls with mineral wool as thermal insulation.

Table 9 U-value of external wall with mineral wool.

Layer of wall	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Cement plaster	0.01	1.047	0.010
Brick	0.12	0.8	0.150
Mineral wool	0.03	0.036	0.833
Gypsum layer	0.005	0.58	0.009

Horizontal internal surf. Resist.	0.120
Horizontal external surface resistance	0.060
Total Thermal Resistance	1.182
U value= 1/Total thermal resistance	0.846

4.4.2 Roof

The roof consists of a 5 mm layer of bitumen on the external surface, 120 mm of reinforced concrete, 70 mm of mineral wool and 5 mm of a gypsum layer on the interior, as shown in Figure 8, its U-value is 0.44 W/(m^2 · K). In Table 10 it is shown how the U-value was obtained for the roof with mineral wool as thermal insulation.

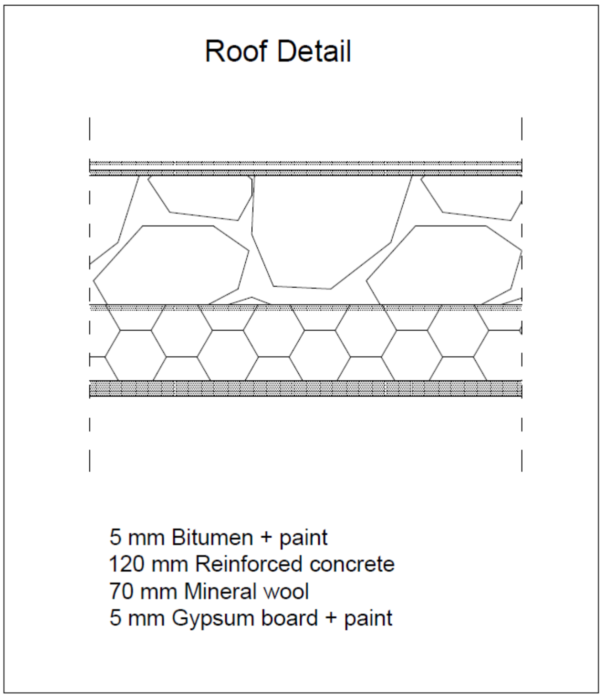

Figure 8 Roof detail

Table 10 U-value of roof with mineral wool.

Layer of Roof	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Bitumen paint	0.005	0.198	0.025
Reinforced concrete	0.12	1.4	0.086
Cement plaster	0.01	1.047	0.010
Mineral wool	0.07	0.036	1.944
Gypsum layer	0.005	0.58	0.009

Downwards internal surf. resist.	0.14
vertical external surface resistance	0.04
Total thermal resistance	2.2536
U value= 1/Total thermal resistance	0.444

4.4.3 Floor

The floor is made of 5 mm of laminated floor, 10 mm of polyurethane, 120 mm of reinforced concrete, 80 mm of extruded polystyrene as insulation, the moisture barrier, 50 mm of sand and 50 mm of gravel, as shown in Figure 9, with a U-value of 0.33 W/(m^2·K). The reason why in this floor element extruded polystyrene was used and not mineral wool, is because of the concrete poured over the insulation, and the increase in thickness compared to the previous example, is to obtain the U-values as in the European Regulations. In Table 11 it is shown how the U-value was obtained for the floor with mineral wool as thermal insulation.

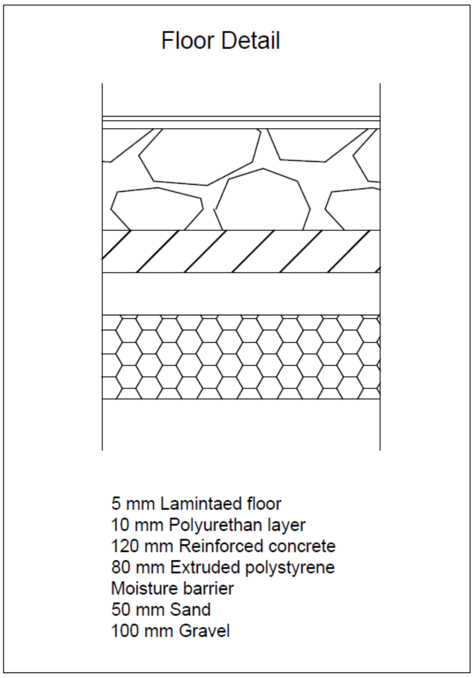

Figure 9 Floor detail

Table 11 U-value of floor with mineral wool.

Layer of Floor	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Laminated	0.005	0.047	0.106
Polyurethane	0.01	0.029	0.345
Reinforced concrete	0.12	1.4	0.086
Extruded polystyrene	0.08	0.035	2.286
Sand	0.05	0.58	0.086

Upwards internal surf. Resist.	0.10
Total thermal resistance	3.008
U value= 1/Total thermal resistance	0.332

4.4.4 Windows and doors

The windows are 6 mm thick double-glazed windows with a 5 mm air layer between glasses and an U-value of 2.48 W/($m^2 \cdot$ K).

The doors are normal plywood doors and an U-value of 2.22 W/($m^2 \cdot$ K).

4.5 U-values considering termafoam as insulation

In this section, a new building envelope's U-vales will be determined using Termafoam as thermal insulating material. Termafoam is considered to have a thermal conductivity value of 0.0248 W/(m·K).

4.5.1 External walls

The external walls, as shown in Figure 10, are comprised of a 10 mm layer of mortar, 120 mm of red brick, 30 mm of Termafoam as thermal insulation and a 5 mm layer of gypsum on the inner side, with an U-value of 0.642 W/(m^2 · K). The reason why 30 millimeters of Termafoam was chosen is to decrease the U-value even more compared that to the mineral wool but using the same thickness. In Table 12 it is shown how the U-value was obtained for the external walls with Termafoam as thermal insulation.

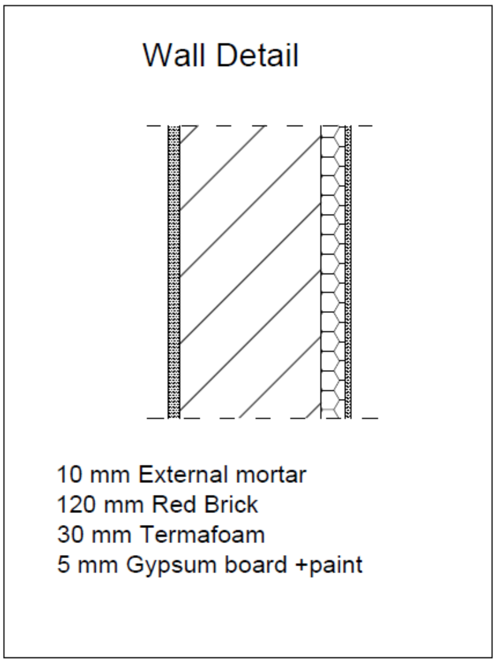

Figure 10 External wall detail

Table 12 U-value of external wall with Termafoam.

Layer of wall	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Cement plaster	0.01	1.047	0.010
Brick	0.12	0.8	0.150
Termafoam	0.03	0.0248	1.210
Gypsum layer	0.005	0.58	0.009
	Horizontal internal surf. resist.		0.120
	Horizontal external surface resistance		0.060
	Total thermal resistance		1.558
	U value= 1/Total thermal resistance		0.642

4.5.2 Roof

The roof consists of a 5 mm layer of bitumen on the external surface, 120 mm of reinforced concrete, 70 mm of Termafoam and 5 mm of a gypsum layer on the interior, as shown in Figure 11, its U-value is 0.319 W/($m^2 \cdot$ K). To decrease the U-value even more compared to the mineral wool by using the same thickness, a 70 mm layer of Termafoam was chosen. In Table 13 it is shown how the U-value was obtained for the roof with Termafoam as thermal insulation.

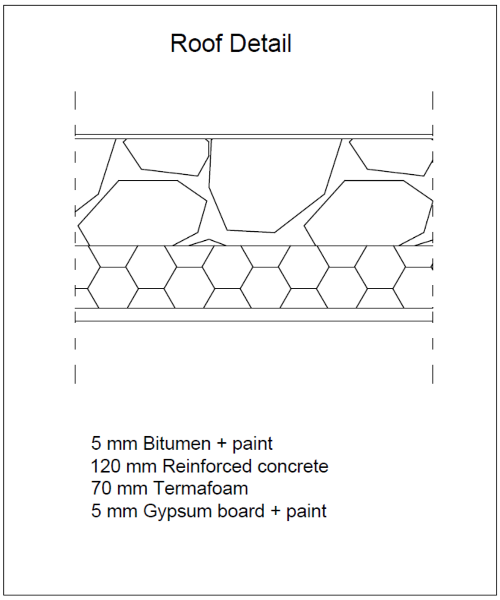

Figure 11 Roof detail

Table 13 U-value of roof with Termafoam.

Layer of Roof	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m²*K/w]
Bitumen paint	0.005	0.198	0.025
reinforced concrete	0.12	1.4	0.086
Cement plaster	0.01	1.047	0.010
Termafoam	0.07	0.0248	2.823
Gypsum layer	0.005	0.58	0.009
	Downwards internal surf. resist.		0.14
	vertical external surface resistance		0.04
	Total thermal resistance		3.131
	U value= 1/Total thermal resistance		0.319

4.5.3 Floor

The floor is made of 5 mm of laminated floor, 10 mm of polyurethane, 120 mm of reinforced concrete, 50 mm of Termafoam as insulation, the moisture barrier, 50 mm of sand and 50 mm of gravel, as shown in Figure n12, with a U-value of 0.365 W/(m^2 · K). In Table 14 it is shown how the U-value was obtained for the floor with Termafoam as thermal insulation.

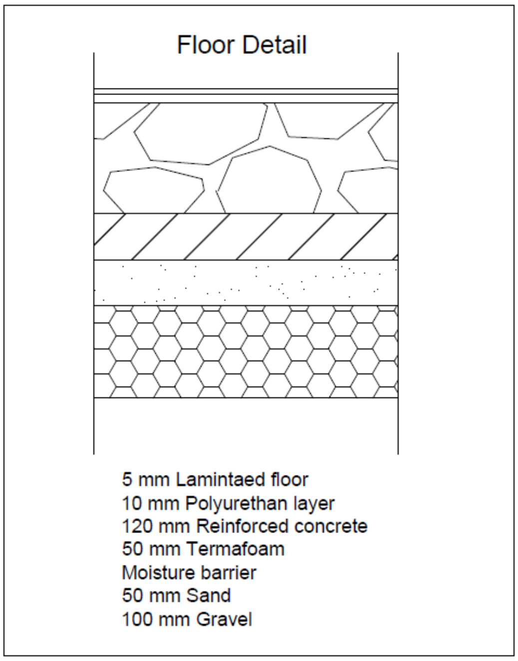

Figure 12 Floor detail

Table 14 U-value of floor with Termafoam.

Layer of Floor	Thickness [m]	Thermal conductivity λ [w/mK]	Thermal resistance R [m^2*K/w]
Laminated	0.005	0.047	0.106
Polyurethane	0.01	0.029	0.345
Reinforced concrete	0.12	1.4	0.086
Termafoam	0.05	0.0248	2.016
Sand	0.05	0.58	0.086

Upwards internal surf. resist.	0.10
Total thermal resistance	2.739
U value= 1/Total thermal resistance	0.365

4.5.4 Windows and doors

The U-value for windows and doors are the same as in the previous part. For windows, the U-value of 2.48 W/($m^2 \cdot$ K) and doors 2.22 W/($m^2 \cdot$ K).

4.6 Condensation check

Given the climate circumstances of the location of the study case, using thermal insulation where condensation can occur is an analysis that can be done to prevent future damage in the structure. Certain characteristics of the external wall structure are considered in this calculation, such as the difference in temperature in each layer, air partial pressure, moisture content and volume at saturation. The pressure at saturation on different temperatures can be seen in Table 15. (Sensors and Transducers)

Table 15 Water vapour: temperature and partial pressure table

Temp. (°C)	Pressure (kPa)	Temp. (°C)	Pressure (kPa)
−20	0.10	30	4.24
−10	0.26	40	7.38
−8	0.31	50	12.33
−6	0.37	60	19.92
−4	0.44	70	31.16
−2	0.52	80	47.36
0	0.61	90	70.11
1	0.66	95	84.53
2	0.71	96	87.67
3	0.76	97	90.94
4	0.81	98	94.3
5	0.87	98.5	96.00
6	0.93	99.0	97.75
7	1.00	99.2	98.45
8	1.07	99.4	99.16
9	1.15	99.6	99.88
10	1.23	99.8	100.60
11	1.31	100.0	101.32
12	1.40	100.2	102.04
13	1.50	100.4	102.78
14	1.60	100.6	103.52
15	1.71	100.8	104.26
16	1.82	101	105.00
17	1.94	102	108.78
18	2.06	103	112.67
19	2.20	104	116.67
20	2.34	105	120.8
21	2.49	110	143.2
22	2.64	120	198.5
23	2.81	130	270.1
24	2.98	140	361.4
25	3.17	150	476.0
26	3.36	170	792.0
27	3.56	200	1555
28	3.78	250	3978
29	4.00	300	8592

Table 16 below shows the theoretical pressure when it is at 100 % of moisture content at every layer along the external wall with the difference in temperature of the inside air and the outside, considering that it is 35 °C on the outside air and 21 °C on the inside air of the structure.

Table 16 Saturated pressure values

Layer	d (m)	λ (w/mC)	R (m^2C/W)	Temp (C)	ΔT (C)	P sat (Pa)
				35		5622
Outside air	35	0	0.06		0.61	
				34.39		5439
Cement plaster	0.01	1.047	0.0096		0.10	
				34.29		5408
Brick	0.12	0.8	0.15		1.54	
				32.75		4944
Termofoam	0.02	0.0248	1.008		10.33	
				22.42		2706
Cement plaster	0.01	1.047	0.0096		0.10	
				22.32		2690
Gypsum layer	0.01	0.58	0.009		0.09	
				22.23		2673
Inside air	21	0	0.12		1.23	
				21.00		2484
Totals			1.366		14.00	
				$\Delta P = Psat_{out} - Psat_{ins} =$		3138

The actual pressure values on the structure, can be seen in Table 17.

Table 17 Actual pressure values

	δp (kg/smPa)	Zp (m^2sPa/Kg)	ΔP (Pa)	P act (Pa)
Outside air	35	0	0	4216.50
Cement plaster	4.00E-12	2.50E+09	143.25	4216.50
Brick	6.46E-12	1.86E+10	1064.43	4073.25
Termofoam	8.00E-13	2.50E+10	1432.55	3008.81
Cement plaster	4.00E-12	2.50E+09	1064.43	1576.26
Gypsum layer	1.50E-12	3.33E+09	1064.43	1433.01
Inside air	21	0		1242.00
				1242.00
Totals		5.19E+10		

In order to determine whether or not condensation will take place, the pressure has to be analyzed, comparing the pressure at certain points. If at some point the actual pressure *(Pact)* is larger than pressure at saturation *(Psat)*, there will be condensation at that point.

In this case, the following comparison in Table 18 shows that within every layer, P_{sat} is always greater than P_{act}. There will not be need to place a water vapour barrier between any of the layers within the structure.

Table 18 Pressure comparison within layers

Layer	P act [Pa]	P sat [Pa]
Outside air	4216.50	5622
Cement plaster	4216.50	5439
Termofoam	4073.25	5408
Brick	3008.81	4944
Cement plaster	1576.26	2706
Gypsum layer	1433.01	2690
Inside air	1242.00	2673

No condensation will take place within the external wall due to pressure, temperature and humidity differences.

4.7 Thermal loads

In this section, the thermal loads into the structure will be established based on the location, latitude, weather conditions and time of the year. The five loads that are considered in this project are, the thermal load through the structure, load due to radiation, load due to the occupants, the thermal load due to ventilation, which also takes into account air leakages, and the thermal bridges. The kitchen thermal load due to cooking and the one caused by electrical equipment are not taken into account in these calculations.

4.7.1 Thermal load through the structure

Based on the information gathered from the National Meteorological Institute, calculations were done considering the average temperature in each month in order to have a more accurate yearly energy consumption. Nevertheless, the thermal insulation design was based on the warmest conditions.

The structural thermal load is the total amount of energy in *kilowatts kW* that goes through the building envelope. To calculate this, it is necessary to know the U-value and the area of each building envelope component, the total amount of air changes per hour and the difference in inside and outside air temperatures, using the following equation. (Chedderton, Dave. 1995, 69)

$$Q := \left(f_1 \cdot \Sigma_{AU} + f_2 \cdot \eta_1 \cdot N_1 \cdot vol_1\right) \cdot \Delta T$$

4.7.2 Thermal load due to solar radiation

In order to calculate the thermal load due to solar radiation, many different factors were taken into account, such as the latitude of the location of the structure, the solar radiation in each time of the year, either summer, winter or the equinoxes, angle of incidence of the sun and the structure, the thickness of the glass of the windows, and the outside and inside air temperature.

The total thermal load due to solar radiation is calculated by the input of the total incident radiation, which is comprised of the Direct Radiation, Diffuse Radiation and the Reflected radiation; into the heat flow rate into the room through the glass. The following equation are considered. (Chedderton, David, 1995, 99)

Direct radiation

$$I_{DN.w} := A_w \cdot \exp\left(\frac{-B_w}{\sin(\beta_w)}\right)$$

$$I_{DT.w} := I_{DN.w} \cdot \cos(\theta_w)$$

Diffuse radiation

$$F_{ws.w} := \frac{(1 + \cos(\Sigma_w))}{2}$$

$$I_{d.w} := C_w \cdot I_{DN.w} \cdot F_{ws.w}$$

Reflected radiation

$$I_{r.w} := (I_{DN.w} + I_{d.w}) \cdot \rho_w \cdot F_{ws.w}$$

Heat flow rate through the glass

$$temp_g := \frac{(A_g \cdot I_t + t_{out} \cdot h_{so} + h_{si} \cdot t_{in})}{25}$$

Total heat by radiation

$$Q_1 := h_{si} \cdot (temp_g - t_{in}) + T_g \cdot I_t$$

4.7.3 Thermal load due to ventilation

In air tight structures, ventilation has to occur to provide with new air. This thermal ventilation load has to be considered as the amount of heat that is introduced into the structure as warm air comes from the outside due to the ventilation. In order to calculate this, it is necessary to know the volume of the structure, the infiltration and ventilation rate, and the difference in temperatures outside and inside the structure. This is determined by the following equation. (Hall, F. 2015, 63)

$$Q_{vent} := N_{air} \cdot V_{build} \cdot C_{air} \cdot (T_{outs} - T_{ins})$$

4.7.4 Thermal load due to occupants

The thermal load from the occupants of the building is determined by an average value of 90 Watts per occupant in a resting state. In this project, four occupants were assumed for each of the cases, with and without insulation. (Chedderton, David. 1995, 103)

4 sedentary occupants $$Q_{TO} := 4 \cdot Q_{oc} = 360\,W$$

4.7.5 Thermal bridges

For this project, the thermal bridges, were considered as 10 % of the total heat load into the building.

4.8 Cooling energy needed and energy cost in Mexico

Since the total thermal load is in kilowatts kW, a conversion into BTU/h has to be done. According to the Mexican Electricity Federal Commission, CFE Comisión Federal de Electricidad in Spanish language, the cost of the kilowatt/hour is in average 1.52 pesos or 0.08 Euros. (CFE Comisión Federal de Electricidad)

The energy unit in air-conditioning systems is the Brittish Thermal Unit per hour (BTU/h); therefore, our calculations had to be converted from kilowatts to BTU/h.
1 kW = 3413.56 BTU/h.

5 RESULTS

The total load in each month, can be seen divided into five different loads, structural load, the load from solar radiation, load from occupants, load due to ventilation, which takes air leakage into account, and thermal bridges load. In this study, electrical and kitchen thermal loads are not considered. It is also shown the season of the year in relation to the solar radiation load.

There are no results in the months of January and December due to the average temperature which is below 22 degrees Celsius, which is less than the comfort temperature inside of the structure. The temperature of 22 degrees was chosen as a comfort temperature for the colder months of the year and 24 degrees, for the warmest months, in order to reduce the energy needed. The loads from the three building envelopes can be seen in Table 19.

Table 19 Building envelope without insulation thermal loads

Control		Av. Temp [°C]	Comf. Temp [°C]	Structural load	Radiation load	Ocupants load	Ventilation load	Pre-Total load	Thermal bridges	Total load [kW]	Total load [BTU/h]
Win	Jan	19.5									
Win	Dec	21.0									
Win	Feb	24.0	22	1.42 kW	2.21 kW	0.36 kW	0.28 kW	4.27 kW	0.43 kW	4.70 kW	16026.82 BTU/h
Equ	Nov	25.4	22	2.424 kW	1.76 kW	0.36 kW	0.47 kW	5.01 kW	0.50 kW	5.52 kW	18819.32 BTU/h
Equ	Mar	27.1	23	2.923 kW	1.81 kW	0.36 kW	0.57 kW	5.66 kW	0.57 kW	6.23 kW	21255.24 BTU/h
Equ	Oct	27.5	23	3.208 kW	1.81 kW	0.36 kW	0.63 kW	6.01 kW	0.60 kW	6.61 kW	22550.15 BTU/h
Sum	Jun	28.6	24	3.279 kW	1.14 kW	0.36 kW	0.64 kW	5.42 kW	0.54 kW	5.96 kW	20339.43 BTU/h
Equ	Sep	29.0	24	3.565 kW	1.81 kW	0.36 kW	0.71 kW	6.45 kW	0.64 kW	7.09 kW	24190.37 BTU/h
Equ	May	29.3	24	3.779 kW	1.82 kW	0.36 kW	0.74 kW	6.70 kW	0.67 kW	7.37 kW	25143.72 BTU/h
Equ	Apr	29.5	24	3.921 kW	1.82 kW	0.36 kW	0.77 kW	6.87 kW	0.69 kW	7.56 kW	25789.30 BTU/h
Sum	Aug	32.6	24	6.131 kW	1.21 kW	0.36 kW	1.21 kW	8.91 kW	0.89 kW	9.80 kW	33446.14 BTU/h
Sum	Jul	34.0	24	7.12 kW	1.22 kW	0.36 kW	1.40 kW	10.10 kW	1.01 kW	11.11 kW	37908.88 BTU/h

Table 20 Building envelope with mineral wool loads

Min wool		Av. Temp [°C]	Comf. Temp [°C]	Structural load	Ra-diation load	Ocupants load	Ventila-tion load	Pre-Total load	Thermal bridges	Total load [kW]	Total load [BTU/h]
Win	Jan	19.5									
Win	Dec	21.0									
Win	Feb	24.0	22	0.393 kW	2.21 kW	0.36 kW	0.28 kW	3.24 kW	0.32 kW	3.57 kW	12172.13 BTU/h
Equ	Nov	25.4	22	0.667 kW	1.76 kW	0.36 kW	0.47 kW	3.26 kW	0.33 kW	3.58 kW	12224.67 BTU/h
Equ	Mar	27.1	23	0.805 kW	1.81 kW	0.36 kW	0.57 kW	3.55 kW	0.35 kW	3.90 kW	13305.64 BTU/h
Equ	Oct	27.5	23	0.883 kW	1.81 kW	0.36 kW	0.63 kW	3.68 kW	0.37 kW	4.05 kW	13823.60 BTU/h
Sum	Jun	28.6	24	0.903 kW	1.14 kW	0.36 kW	0.64 kW	3.04 kW	0.30 kW	3.35 kW	11421.46 BTU/h
Equ	Sep	29.0	24	0.982 kW	1.81 kW	0.36 kW	0.71 kW	3.86 kW	0.39 kW	4.25 kW	14495.45 BTU/h
Equ	May	29.3	24	1.04 kW	1.82 kW	0.36 kW	0.74 kW	3.96 kW	0.40 kW	4.36 kW	14863.28 BTU/h
Equ	Apr	29.5	24	1.08 kW	1.82 kW	0.36 kW	0.77 kW	4.03 kW	0.40 kW	4.43 kW	15126.02 BTU/h
Sum	Aug	32.6	24	1.688 kW	1.21 kW	0.36 kW	1.21 kW	4.47 kW	0.45 kW	4.91 kW	16769.99 BTU/h
Sum	Jul	34.0	24	1.963 kW	1.22 kW	0.36 kW	1.40 kW	4.94 kW	0.49 kW	5.44 kW	18552.83 BTU/h

Table 21 Building envelope with Termafoam loads

Ter-mafoam		Av. Temp [°C]	Comf. Temp [°C]	Structural load	Ra-diation load	Ocupants load	Ventila-tion load	Pre-Total load	Thermal bridges	Total load [kW]	Total load [BTU/h]
Win	Jan	19.5									
Win	Dec	21.0									
Win	Feb	24.0	22	0.343 kW	2.21 kW	0.36 kW	0.28 kW	3.19 kW	0.32 kW	3.51 kW	11984.46 BTU/h
Equ	Nov	25.4	22	0.584 kW	1.76 kW	0.36 kW	0.47 kW	3.17 kW	0.32 kW	3.49 kW	11913.15 BTU/h
Equ	Mar	27.1	23	0.704 kW	1.81 kW	0.36 kW	0.57 kW	3.44 kW	0.34 kW	3.79 kW	12926.55 BTU/h
Equ	Oct	27.5	23	0.773 kW	1.81 kW	0.36 kW	0.63 kW	3.57 kW	0.36 kW	3.93 kW	13410.73 BTU/h
Sum	Jun	28.6	24	0.79 kW	1.14 kW	0.36 kW	0.64 kW	2.93 kW	0.29 kW	3.22 kW	10997.33 BTU/h
Equ	Sep	29.0	24	0.858 kW	1.81 kW	0.36 kW	0.71 kW	3.74 kW	0.37 kW	4.11 kW	14030.04 BTU/h
Equ	May	29.3	24	0.91 kW	1.82 kW	0.36 kW	0.74 kW	3.83 kW	0.38 kW	4.21 kW	14375.35 BTU/h
Equ	Apr	29.5	24	0.944 kW	1.82 kW	0.36 kW	0.77 kW	3.89 kW	0.39 kW	4.28 kW	14615.56 BTU/h
Sum	Aug	32.6	24	1.476 kW	1.21 kW	0.36 kW	1.21 kW	4.26 kW	0.43 kW	4.68 kW	15974.27 BTU/h
Sum	Jul	34.0	24	1.717 kW	1.22 kW	0.36 kW	1.40 kW	4.70 kW	0.47 kW	5.17 kW	17629.50 BTU/h

Table 22 below shows the annual energy cost of the building envelope without thermal insulation. The price of the kilowatt hour in Mexico is 0.08 Euros. Since the highest load is 37908.88 BTU/h, the air-conditioning system that corresponds to this load is the one with a cooling capacity of 33600 BTU/h or 9.8 kW. During the day, 15 hours of usage of the air-conditioning system were chosen due to the time that people would stay at home, since it is considered 8 hours away to be at work.

The chosen air-conditioning system has the following properties:

Model	Capacity	Input power
MQIS-164036-CWF216A	33600 BTU/h	3.6 kW

Table 22 Cost without thermal insulation

Total load [kW]		Total load [BTU/h]		Hours	Energy needed [kWh]		Energy needed [BTU]		Ratio con-sum.	Energy consum.		Cost
4.70	kW	16026.82	BTU/h	15	1972.74	kWh	6731265.06	BTU	2.7	730.64	kWh	58.45 €
5.52	kW	18819.32	BTU/h	15	2481.93	kWh	8468692.63	BTU	2.7	919.23	kWh	73.54 €
6.23	kW	21255.24	BTU/h	15	2896.62	kWh	9883688.32	BTU	2.7	107.82	kWh	85.83 €
6.61	kW	22550.15	BTU/h	15	3073.09	kWh	10485820.14	BTU	2.7	1138.18	kWh	91.05 €
5.96	kW	20339.43	BTU/h	15	2682.41	kWh	9152741.40	BTU	2.7	993.48	kWh	79.48 €
7.09	kW	24190.37	BTU/h	15	3190.28	kWh	10885664.94	BTU	2.7	1181.58	kWh	94.53 €
7.37	kW	25143.72	BTU/h	15	3426.54	kWh	11691829.08	BTU	2.7	1269.09	kWh	101.53 €
7.56	kW	25789.30	BTU/h	15	3401.15	kWh	11605182.90	BTU	2.7	1259.68	kWh	100.77 €
9.80	kW	33446.14	BTU/h	15	4557.98	kWh	15552453.93	BTU	2.7	1688.14	kWh	135.05 €
11.11	kW	37908.88	BTU/h	15	5166.15	kWh	17627627.06	BTU	2.7	1913.39	kWh	153.07 €
										Yearly cost		973.30 €

Table 23 below shows the annual energy cost of the building envelope with Mineral wool as thermal insulation. Since the highest load is 18552.83 BTU/h, the air-conditioning system that corresponds to this load is the one with a cooling capacity of 22000 BTU/h or 6.44 kW.

The chosen air-conditioning system has the following properties:

Model	Capacity	Input power
MQIS-164024-CWF216A	22000 BTU/h	2.2 kW

Table 23 Cost with mineral wool as insulation

Total load [kW]		Total load [BTU/h]		Hours	Energy needed [kWh]		Energy needed [BTU]		Ratio con-sum.	Energy consum.		Cost
3.57	kW	12172.13	BTU/h	15	1498.27	kWh	5112293.35	BTU	3	499.42	kWh	39.95 €
3.58	kW	12224.67	BTU/h	15	1612.22	kWh	5501103.29	BTU	3	537.41	kWh	42.99 €
3.90	kW	13305.64	BTU/h	15	1813.27	kWh	6187122.57	BTU	3	604.42	kWh	48.35 €
4.05	kW	13823.60	BTU/h	15	1883.85	kWh	6427975.29	BTU	3	627.95	kWh	50.24 €
3.35	kW	11421.46	BTU/h	15	1506.29	kWh	5139655.30	BTU	3	502.10	kWh	40.17 €
4.25	kW	14495.45	BTU/h	15	1911.69	kWh	6522953.92	BTU	3	637.23	kWh	50.98 €
4.36	kW	14863.28	BTU/h	15	2025.54	kWh	6911426.06	BTU	3	675.18	kWh	54.01 €
4.43	kW	15126.02	BTU/h	15	1994.85	kWh	6806707.48	BTU	3	664.95	kWh	53.20 €
4.91	kW	16769.99	BTU/h	15	2285.38	kWh	7798043.34	BTU	3	761.79	kWh	60.94 €
5.44	kW	18552.83	BTU/h	15	2528.34	kWh	8627065.40	BTU	3	842.78	kWh	67.42 €
										Yearly Cost		508.26 €

Table 24 below shows the annual energy cost of the building envelope with Mineral wool as thermal insulation. Since the highest load is 17629.50 BTU/h, the air-conditioning system that corresponds to this load is the one with a cooling capacity of 18000 BTU/h or 5.27 kW.

The chosen air-conditioning system has the following properties:

Model	Capacity	Input power
MQIS-164018-CWF216A	18000 BTU/h	1,6 kW

Table 24 Cost with Termafoam as insulation

Total load [kW]		Total load [BTU/h]		Hours	Energy needed [kWh]		Energy needed [BTU]		Ratio con-sum.	Energy consum.		Cost
3.51	kW	11984.46	BTU/h	15	1475.17	kWh	5033472.92	BTU	3	491.72	kWh	39.34 €
3.49	kW	11913.15	BTU/h	15	1571.13	kWh	5360915.52	BTU	3	523.71	kWh	41.90 €
3.79	kW	12926.55	BTU/h	15	1761.61	kWh	6010846.30	BTU	3	587.20	kWh	46.98 €
3.93	kW	13410.73	BTU/h	15	1827.59	kWh	6235991.24	BTU	3	609.20	kWh	48.74 €
3.22	kW	10997.33	BTU/h	15	1450.35	kWh	4948797.25	BTU	3	483.45	kWh	38.68 €
4.11	kW	14030.04	BTU/h	15	1850.31	kWh	6313516.76	BTU	3	616.77	kWh	49.34 €
4.21	kW	14375.35	BTU/h	15	1959.05	kWh	6684535.81	BTU	3	653.02	kWh	52.24 €
4.28	kW	14615.56	BTU/h	15	1927.53	kWh	6577002.21	BTU	3	642.51	kWh	51.40 €
4.68	kW	15974.27	BTU/h	15	2176.94	kWh	7428037.70	BTU	3	725.65	kWh	58.05 €
5.17	kW	17629.50	BTU/h	15	2402.52	kWh	8197719.24	BTU	3	800.84	kWh	64.07 €
										Yearly cost		490.72 €

The percentage of energy costs compared to the building envelope in control, are expressed in Table 25.

Table 25 Comparison of energy costs

Building envelope	Yearly cost	Saving
Control	973.30 €	
Mineral wool	508.26 €	47.78 %
Termafoam	490.72 €	49.58 %

6 CONCLUSION

Based on the results, it is clear that up to 47.78 % of energy cost can be saved by using Mineral Wool and 49.58 % Termafoam in the structure of external walls and roof, as well as implementing double-glazed windows, comparing to not using thermal insulation in countries where the climate conditions are very warm during the summer and a large amount of energy is used for cooling purposes. The results show that a different air conditioning system can be used on a structure which has been built with thermal insulation, in this case an air conditioning system with a capacity of 18000 BTU/h or 5.27 kW can be used since the maximum load in the warmest month is 17629.50 BTU/h or 5.17kW.

The cost of such system, MQIS-16408-CWF216A with a capacity of 18000 BTU/h is 105 euros. Comparing to building without thermal insulation, in less than a year its payed back, since without thermal insulation the yearly energy cost is 973.30 euros and with Termafoam only 498.66 euros.

The cost of the square meter of Termafoam in Mexico is 3.4 euros, since the area of roof, walls, and floor using Termafoam is 245.22 m^2, the total cost of Termafoam would be 833.74 euros. The cost of installation work is not considered in this project since the corporations that build this type of housing projects are so large and the installation is already in their budget. (Avicultura)

The annual energy cost without thermal insulation is 973.30 and with Termafoam it is 490.72, which saves up to 49.58 % therefore, in two years, the amount of money that can be saved in energy is 965.16 euros. Since the cost of Termafoam is 833.74 euros and the air-conditioning system costs 105 euros, this gives a total of 938.74 euros as an initial investment; hence, in less than two years, the investment will be paid back, and moving forward each year up to nearly 50% of energy costs can be saved.

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Troi, Alexandra and Zeno, Bastian Energy Efficiency Solutions 2015

Appendix 1

APPENDIX, CALCULATIONS DONE IN MATHCAD

In this section of Appendix 1, all the calculations done in MathCad are shown with a brief description of what they stand for.

The following are the dimensions of the structure.

$$v := 10.3\cdot m\cdot 8\cdot m\cdot 2.5\cdot m = 206\cdot m^3$$

$$walls := [(10300\cdot mm\cdot 2500\cdot mm)\cdot 2] + [(8000\cdot mm\cdot 2500\cdot mm)\cdot 2] = 91.5\,m^2$$

$$windows := [(1200\cdot mm\cdot 1200\cdot mm)\cdot 7] + [(1000\cdot mm\cdot 500\cdot mm)\cdot 2] = 11.08\,m^2$$

$$doors := (1000\cdot mm\cdot 2100\cdot mm)\cdot 2 = 4.2\,m^2$$

$$floor := 10300\cdot mm\cdot 8000\cdot mm = 82.4\,m^2$$

Area of building envelope components.

$$Walls_{T.A} := 91.5\cdot m^2 - 11.08\cdot m^2 = 80.42\,m^2$$

$$Windows_{T.A} := 11.08\cdot m^2$$

$$Roof_{TA} := 82.4\cdot m^2$$

$$Floor_{TA} := 82.4\cdot m^2$$

Thermal conductivity of the layers that comprise the building envelope components.

Walls.

cement plaster $\lambda_{cem} := 1.047 \cdot \frac{W}{m \cdot K}$

brick $\lambda_{br} := 0.8 \cdot \frac{W}{m \cdot K}$

gypsum layer $\lambda_{gyp} := 0.58 \cdot \frac{W}{m \cdot K}$

Floor.

Laminatec $\lambda_{lam} := 0.047 \cdot \frac{W}{m \cdot K}$

Polyurethane $\lambda_{pol} := 0.029 \cdot \frac{W}{m \cdot K}$

Reinforced concrete $\lambda_{con} := 1.4 \cdot \frac{W}{m \cdot K}$

Extruded polystyrene $\lambda_{ext} := 0.035 \cdot \frac{W}{m \cdot K}$

Sand $\lambda_{sand.fl} := 0.58 \cdot \frac{W}{m \cdot K}$

Roof.

Bitumen paint $\lambda_{bit} := 0.198 \cdot \frac{W}{m \cdot K}$

Cement plaster $\lambda_{cem} = 1.047 \cdot \frac{W}{m \cdot K}$

Reinforced concrete $\lambda_{con} = 1.4 \cdot \frac{W}{m \cdot K}$

Gypsum layer $\lambda_{gyp} = 0.58 \cdot \frac{W}{m \cdot K}$

Windows.

Glass $\lambda_{gl} := 0.81 \cdot \frac{W}{m \cdot K}$

Air $\lambda_{air} := 0.024 \cdot \frac{W}{m \cdot K}$

Doors.

plywood $\lambda_{ply} := 0.13 \cdot \frac{W}{m \cdot K}$

The following shows the thickness and the thermal resistance of each layer within the structure component.

Walls.

cement plaster $d_{cem.wall} := 0.01 \cdot m$ $R_{cem.wall} := \frac{d_{cem.wall}}{\lambda_{cem}} = 0.0096 \cdot m^2 \frac{K}{W}$

Brick $d_{br} := 0.12 \cdot m$ $R_{br} := \frac{d_{br}}{\lambda_{br}} = 0.15 \cdot m^2 \frac{K}{W}$

Gypsum layer $d_{gyp.wall} := 0.005 \cdot m$ $R_{gyp} := \frac{d_{gyp.wall}}{\lambda_{gyp}} = 0.009 \cdot m^2 \cdot \frac{K}{W}$

Floor.

Lamintaec $d_{lam} := 0.005 \cdot m$ $R_{lam} := \frac{d_{lam}}{\lambda_{lam}} = 0.106 \cdot m^2 \cdot \frac{K}{W}$

Polyurethan $d_{pol} := 0.01 \cdot m$ $R_{pol} := \frac{d_{pol}}{\lambda_{pol}} = 0.345 \cdot m^2 \cdot \frac{K}{W}$

Reinforced concrete $d_{con.fl} := 0.12 \cdot m$ $R_{con.fl} := \frac{d_{con.fl}}{\lambda_{con}} = 0.086 \cdot m^2 \cdot \frac{K}{W}$

Extruded polystyrene $d_{ext.fl} := 0.05 \cdot m$ $R_{ext.fl} := \frac{d_{ext.fl}}{\lambda_{ext}} = 1.429 \cdot m^2 \cdot \frac{K}{W}$

Sand $d_{sand.fl} := 0.05 \cdot m$ $R_{sand.fl} := \frac{d_{sand.fl}}{\lambda_{sand.fl}} = 0.086 \frac{s^3 \cdot K}{kg}$

Roof.

Bitumen paint $d_{bit} := 0.005 \cdot m$ $R_{bit} := \frac{d_{bit}}{\lambda_{bit}} = 0.025 \cdot m^2 \cdot \frac{K}{W}$

reinforced concrete $d_{con.rf} := 0.012 \cdot m$ $R_{con.rf} := \frac{d_{con.rf}}{\lambda_{con}} = 0.009 \cdot m^2 \cdot \frac{K}{W}$

cement plaster $d_{cem.rf} := 0.01 \cdot m$ $R_{cem.rf} := \frac{d_{cem.rf}}{\lambda_{cem}} = 0.01 \cdot m^2 \cdot \frac{K}{W}$

gypsum layer $d_{gyp.rf} := 0.005 \cdot m$ $R_{gyp.rf} := \frac{d_{gyp.rf}}{\lambda_{gyp}} = 0.009 \cdot m^2 \cdot \frac{K}{W}$

Windows.

Glass $d_{gl} := 0.006 \cdot m$ $R_{gl} := \frac{d_{gl}}{\lambda_{gl}} = 0.00741 \cdot m^2 \cdot \frac{K}{W}$

Air $d_{air} := 0.005 \cdot m$ $R_{air} := \frac{d_{air}}{\lambda_{air}} = 0.208 \cdot m^2 \cdot \frac{K}{W}$

Doors.

Plywood $d_{ply} := 0.035 \cdot m$ $R_{ply} := \frac{d_{ply}}{\lambda_{ply}} = 0.269 \cdot m^2 \cdot \frac{K}{W}$

The following are the surface resistances of the building envelope components.

Internal surface resistance horizontal $R_{si.hor} := 0.12 \cdot m^2 \cdot \frac{K}{W}$

External surface resistance wall $R_{se.hor} := 0.06 \cdot m^2 \frac{K}{W}$

Internal surface resis. downward $R_{si.down} := 0.14 \cdot m^2 \cdot \frac{K}{W}$

External surface res. roof $R_{se.roof} := 0.04 \cdot m^2 \cdot \frac{K}{W}$

Internal surf. res. floor upward $R_{si.up} := 0.10 \cdot m^2 \cdot \frac{K}{W}$

The total thermal resistance and the U-value of each component without thermal insulation is shown as follows.

Thermal Resistances of walls, roof and floor without thermal insulation

$$R_{wall} := 2 \cdot R_{cem.wall} + R_{br} + R_{gyp} + R_{si.hor} + R_{se.hor} = 0.358 \cdot m^2 \frac{K}{W}$$

$$R_{floor} := R_{si.up} + R_{lam} + R_{pol} + R_{con.fl} + R_{ext.fl} + R_{sand.fl} = 2.152 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{roof} := R_{si.down} + R_{se.roof} + R_{bit} + R_{cem.rf} + R_{gyp} + R_{con.rf} = 0.232 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{window} := R_{si.hor} + R_{se.hor} + R_{gl} = 0.187 \cdot m^2 \frac{K}{W}$$

$$R_{door} := R_{si.hor} + R_{se.hor} + R_{ply} = 0.449 \cdot m^2 \cdot \frac{K}{W}$$

U-values of walls, roof and floor without thermal insulation.

$$U_{wall} := \frac{1}{R_{wall}} = 2.8 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{roof} := \frac{1}{R_{roof}} = 4.31 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{floor} := \frac{1}{R_{floor}} = 0.465 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{window} := \frac{1}{R_{window}} = 5.34 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{door} := \frac{1}{R_{door}} = 2.23 \cdot \frac{W}{m^2 \cdot K}$$

The following presents the thermal resistance and U-value of the components using mineral wool as thermal insulation, the thermal conductivity and thickness of the mineral wool layer.

Thermal Conductivity of mineral wool.

Mineral wool $\lambda_{min} := 0.036 \cdot \frac{W}{m \cdot K}$

Thickness of walls, roof and floor using mineral wool.

$d_{min.wl} := 0.03 \cdot m$ $R_{min.wl} := \frac{d_{min.wl}}{\lambda_{min}} = 0.833 \cdot m^2 \cdot \frac{K}{W}$

$d_{min.fl} := 0.02 \cdot m$ $R_{min.fl} := \frac{d_{min.fl}}{\lambda_{min}} = 0.556 \cdot m^2 \cdot \frac{K}{W}$

$d_{min.rf} := 0.07 \cdot m$ $R_{min.rf} := \frac{d_{min.rf}}{\lambda_{min}} = 1.944 \cdot m^2 \cdot \frac{K}{W}$

$d_{ext.fl1} := 0.08 \cdot m$ $R_{ext.fl1} := \frac{d_{ext.fl1}}{\lambda_{ext}} = 2.286 \cdot m^2 \cdot \frac{K}{W}$

Thermal Resistances of walls, roof and floor using mineral wool.

$$R_{wall2} := R_{cem.wall} + R_{br} + R_{gyp} + R_{min.wl} + R_{si.hor} + R_{se.hor} = 1.182 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{floor2} := R_{si.up} + R_{lam} + R_{pol} + R_{con.fl} + R_{ext.fl1} + R_{sand.fl} = 3.009 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{roof2} := R_{si.down} + R_{se.roof} + R_{bit} + R_{cem.rf} + R_{gyp} + R_{con.rf} + R_{min.rf} = 2.176 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{window2} := R_{si.hor} + R_{se.hor} + 2R_{gl} + R_{air} = 0.403 \cdot m^2 \cdot \frac{K}{W}$$

U-values of walls, roof and floor using mineral wool.

$$U_{wall2} := \frac{1}{R_{wall2}} = 0.846 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{roof2} := \frac{1}{R_{roof2}} = 0.459 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{floor2} := \frac{1}{R_{floor2}} = 0.332 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{window2} := \frac{1}{R_{window2}} = 2.48 \cdot \frac{W}{m^2 \cdot K}$$

The following presents the thermal resistance and U-value of the components using Termafoam as thermal insulation as well as the thermal conductivity and thickness of the Termafoam layer.

Thermal Conductivity of Termafoam.

Termofoam $\lambda_{termo} := 0.0248 \cdot \frac{W}{m \cdot K}$

Thickness of walls, roof and floor using Termafoam.

$d_{termo.wl} := 0.03 \cdot m$ $\quad R_{termo.wl} := \frac{d_{termo.wl}}{\lambda_{termo}} = 1.21 \cdot m^2 \cdot \frac{K}{W}$

$d_{termo.fl} := 0.05 \cdot m$ $\quad R_{termo.fl} := \frac{d_{termo.fl}}{\lambda_{termo}} = 2.016 \cdot m^2 \cdot \frac{K}{W}$

$d_{termo.rf} := 0.07 \cdot m$ $\quad R_{termo.rf} := \frac{d_{termo.rf}}{\lambda_{termo}} = 2.823 \cdot m^2 \cdot \frac{K}{W}$

Thermal Resistances of walls, roof and floor using Termafoam.

$$R_{wall3} := R_{termo.wl} + R_{si.hor} + R_{se.hor} + R_{cem.wall} + R_{br} + R_{gyp} = 1.558 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{floor3} := R_{termo.fl} + R_{si.up} + R_{lam} + R_{pol} + R_{con.fl} + R_{sand.fl} = 2.739 \cdot m^2 \cdot \frac{K}{W}$$

$$R_{roof3} := R_{termo.rf} + R_{si.down} + R_{se.roof} + R_{bit} + R_{cem.rf} + R_{gyp} + R_{con.rf} = 3.055 \cdot m^2 \cdot \frac{K}{W}$$

U-values of walls, roof and floor using Termafoam.

$$U_{wall3} := \frac{1}{R_{wall3}} = 0.642 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{roof3} := \frac{1}{R_{roof3}} = 0.327 \cdot \frac{W}{m^2 \cdot K}$$

$$U_{floor3} := \frac{1}{R_{floor3}} = 0.365 \cdot \frac{W}{m^2 \cdot K}$$

The following calculations show how the thermal load through the structure was achieved, as an example it is considered using the difference in temperature of 10 °C, between 34 °C on the outside air and 24 °C on the inside air, and during the summer time, which has an effect on the thermal load due to radiation from the sun. The following examples covers the three different building envelope components without thermal insulation.

volum($vol_1 := 10.3 \cdot 8 \cdot 2.5 = 206$

$$T_{airoutside1} := 34$$

$$T_{comfort1} := 24$$

$$\Delta T := T_{airoutside1} - T_{comfort1} = 10$$

Windows

$$A_{window1} := 11.08$$

$$U_{window1} := \frac{U_{window}}{1 \cdot \frac{W}{m^2 \cdot K}} = 5.336$$

$$AU_{window1} := A_{window1} \cdot U_{window1} = 59.123$$

Doors

$$A_{door1} := 4.2$$

$$U_{door1} := \frac{U_{door}}{1 \cdot \frac{W}{m^2 \cdot K}} = 2.226$$

$$AU_{door1} := A_{door1} \cdot U_{door1} = 9.349$$

Walls

$$A_{wall1} := 80.42$$

$$U_{wall1} := \frac{U_{wall}}{1 \cdot \frac{W}{m^2 \cdot K}} = 2.795$$

$$AU_{wall1} := A_{wall1} \cdot U_{wall1} = 224.811$$

Floor

$$A_{floor1} := 82.4$$

$$U_{floor1} := \frac{U_{floor}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.465$$

$$AU_{floor1} := A_{floor1} \cdot U_{floor1} = 38.295$$

Roof

$A_{roof1} := 82.4$

$U_{roof1} := \dfrac{U_{roof}}{1 \cdot \dfrac{W}{m^2 \cdot K}} = 4.31$

$AU_{roof1} := A_{roof1} \cdot U_{roof1} = 355.179$

Temperature ratio 1	$f_1 := 1$
Temperature ratio 2	$f_2 := 1.1$
Air change per hour	$N_1 := 0.35$
Constan	$\eta_1 := 0.33$

Total heat load through the structure

$\Sigma_{AU} := AU_{window1} + AU_{door1} + AU_{wall1} + AU_{roof1} + AU_{floor1} = 686.757$

$Q_p := \left(f_1 \cdot \Sigma_{AU} + f_2 \cdot \eta_1 \cdot N_1 \cdot vol_1\right) \cdot \Delta T = 7129.29211$

$Q_{TS} := \dfrac{Q_p}{\dfrac{1}{W}} = 7.129 \cdot kW$

The following calculations show how the thermal load through the structure was achieved, in the building envelope components without mineral wool.

Windows

$A_{window1} = 11.08$

$U_{window1.1} := 2.48$

$AU_{window2} := A_{window1} \cdot U_{window1.1} = 27.478$

Doors

$A_{door1} = 4.2$

$U_{door1} = 2.226$

$AU_{door1} = 9.349$

Walls with wool insulation

$A_{wall1} = 80.42$

$$U_{wall2.1} := \frac{U_{wall2}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.846$$

$AU_{wall2} := A_{wall1} \cdot U_{wall2.1} = 68.066$

Floors with wool insulation

$A_{floor1} = 82.4$

$$U_{floor2.1} := \frac{U_{floor2}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.332$$

$AU_{floor2} := A_{floor1} \cdot U_{floor2.1} = 27.386$

Roof with wool insulation

$$A_{roof1} = 82.4$$

$$U_{roof2.1} := \frac{U_{roof2}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.459$$

$$AU_{roof2} := A_{roof1} \cdot U_{roof2.1} = 37.86$$

Total heat load through the structure with mineral wool

$$\Sigma_{AU2} := AU_{window2} + AU_{door1} + AU_{wall2} + AU_{floor2} + AU_{roof2} = 170.139$$

$$Q_{p2} := \left(f_1 \cdot \Sigma_{AU2} + f_2 \cdot \eta_1 \cdot N_1 \cdot vol_1\right) \cdot \Delta T = 1963.116$$

$$Q_{TS2} := \frac{Q_{p2}}{\frac{1}{W}} = 1.963 \cdot kW$$

The following calculations show how the thermal load through the structure was achieved, in the building envelope components with Termafoam.

Windows

$$AU_{window1} = 59.123$$

$$A_{door1} = 4.2$$

Doors

$$U_{door1} = 2.226$$

$$AU_{door1} = 9.349$$

Walls with Termafoam insulation

$$A_{wall1} = 80.42$$

$$U_{wall3.1} := \frac{U_{wall3}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.642$$

$$AU_{wall3} := A_{wall1} \cdot U_{wall3.1} = 51.622$$

Floors with Termafoam insulation

$$A_{floor1} = 82.4$$

$$U_{floor3.1} := \frac{U_{floor3}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.365$$

$$AU_{floor3} := A_{floor1} \cdot U_{floor3.1} = 30.081$$

Roof with Termafoam insulation

$$A_{roof1} = 82.4$$

$$U_{roof3.1} := \frac{U_{roof3}}{1 \cdot \frac{W}{m^2 \cdot K}} = 0.327$$

$$AU_{roof3} := A_{roof1} \cdot U_{roof3.1} = 26.976$$

Total heat load through the structure

$$\Sigma_{AU3} := AU_{window2} + AU_{door1} + AU_{wall3} + AU_{floor3} + AU_{roof3} = 145.507$$

$$Q_{p3} := \left(f_1 \cdot \Sigma_{AU3} + f_2 \cdot \eta_1 \cdot N_1 \cdot vol_1\right) \cdot \Delta T = 1716.795$$

$$Q_{TS3} := \frac{Q_{p3}}{\frac{1}{W}} = 1.717 \cdot kW$$

The following calculations show how the thermal load due to solar radiation was obtained.

Atmospheric extintion coefficient $B_w := 0.21$

Constant of cloudlless sky $C_w := 0.135$

Apparent solar radiation $A_w := 1230 \cdot \frac{W}{m^2}$

radiant pi $\pi_1 := 180$

Vertical surface reflectivity $\Sigma_w := 90 \cdot °$

Reflectivity of ground $\rho_w := 0.6$

Surface azimuth angle $\zeta_w := 0 \cdot °$

Solar azimuth angle $\gamma_w := 0 \cdot °$

Wall azimuth angle $\alpha_w := 180 \cdot °$

Latitud $L_w := 20$

$d_w := 23.5$

Atmospheric coefficient B_w

atmos coeff in summer	0,21
atmos coeff in equinox	0,175
atmos coeff in winter	0,14

Cw cloud summer	0,135
Cw cloud equinox	0,096
Cw cloud winter	0,058

Solar radiation A_w

summe	1230
equino	1155
winte	1080

Incidence angle

summe	86,5
equino	66,5
winte	46,5

Solar noon

$$\beta_{w1} := \left(\frac{\pi}{2} 1\right) - \left(d_w + L_w\right) = 46.5$$

Solar noon $\beta_w := 86.5 \cdot °$

Incidence angle $\theta_w := 86.5 \cdot °$

Direct radiation

$$I_{DN.w} := A_w \cdot \exp\left(\frac{-B_w}{\sin\left(\beta_w\right)}\right) = 996.6274 \cdot \frac{W}{m^2}$$

$$I_{DT.w} := I_{DN.w} \cdot \cos\left(\theta_w\right) = 60.843 \cdot \frac{W}{m^2}$$

Diffuse radiation

$$F_{ws.w} := \frac{\left(1 + \cos\left(\Sigma_w\right)\right)}{2} = 0.5$$

$$I_{d.w} := C_w \cdot I_{DN.w} \cdot F_{ws.w} = 67.272 \cdot \frac{W}{m^2}$$

Reflected radiation

$$I_{r.w} := \left(I_{DN.w} + I_{d.w}\right) \cdot \rho_w \cdot F_{ws.w} = 319.17 \cdot \frac{W}{m^2}$$

Total incident radiation

$$I_{tot.w} := I_{DT.w} + I_{d.w} + I_{r.w} = 447.28 \cdot \frac{W}{m^2}$$

Heat transferred through single glazed window

temperature outside $t_{out} := 34$

temperature inside $t_{in} := 24$

total solar irradiance $I_t := \frac{I_{tot.w}}{\frac{W}{m^2}} = 447.285$

Absorptivity of glass $A_g := 0.15$

Transmissibility of glass $T_g := 0.78$

Thickness of window $d_g := 6$

inside surface heat transfer coefficient $h_{si} := 8.3$

outside surface heat transfer coefficient $h_{so} := 16.7$

Glass temperature

$$temp_g := \frac{\left(A_g \cdot I_t + t_{out} \cdot h_{so} + h_{si} \cdot t_{in}\right)}{25} = 33.364\ °C$$

Heat flow rate into the room through the glass

$$Q_1 := h_{si} \cdot \left(temp_g - t_{in}\right) + T_g \cdot I_t = 426.601$$

$$Q_{1.1} := \frac{Q_1}{\frac{1}{\frac{W}{m^2}}} = 426.601 \cdot \frac{W}{m^2}$$

Area of windows facing south

$A_{w1} := 1.2 \cdot m \cdot 1.2 \cdot m \cdot 2 = 2.88\,m^2$

Total heat through the southern window by solar radiation

$Q_{TR} := A_{w1} \cdot Q_{1.1} = 1.229 \cdot kW$

The following calculations show the thermal load due to the occupants.

4 sedentary occupants

$Q_{oc} := 90 \cdot W$

$Q_{TO} := 4 \cdot Q_{oc} = 360\,W$

The thermal load due to ventilation including air leakage, it is shown in the following calculations.

Air change per hour	$N_{air} := 2$	
Volume of building	$V_{build} := 206$	m^3
Temp outside	$T_{outs} := 34$	C
Temp inside	$T_{ins} := 24$	C
Heat capacity of air	$C_{air} := 0.34$	

$$Q_{vent} := N_{air} \cdot V_{build} \cdot C_{air} \cdot \left(T_{outs} - T_{ins}\right) = 1400.8$$

$$Q_{vent1} := \frac{Q_{vent}}{1000} = 1.401 \qquad kW$$

$$Q_V := \frac{Q_{vent1}}{\frac{1}{kW}} = 1.401 \cdot kW$$

The total thermal load into the structure without thermal insulations is the following.

Pre total load withouth insulation

$$Q_{PT} := Q_V + Q_{TR} + Q_{TS} + Q_{TO} = 10.119 \cdot kW$$

Load due to thermal bridges without insulation

$$Q_{TH} := 0.10 \cdot Q_{PT} = 1.012 \cdot kW$$

Total heat load withouth insulation

$$Q_{T.1} := Q_V + Q_{TR} + Q_{TS} + Q_{TO} + Q_{TH} = 11.131 \cdot kW$$

The total thermal load into the structure with mineral wool is the following.

Pre total load with mineral wool

$$Q_{PT2} := Q_V + Q_{TR} + Q_{TS2} + Q_{TO} = 4.953 \cdot kW$$

Load due to thermal bridges with mineral wool

$$Q_{TH2} := 0.10 \cdot Q_{PT2} = 0.495 \cdot kW$$

Total heat load with minerla wool

$$Q_{T2} := Q_V + Q_{TR} + Q_{TS2} + Q_{TO} + Q_{TH2} = 5.448 \cdot kW$$

The total thermal load into the structure with Termafoam is the following.

Pre total load with mineral wool

$$Q_{PT3} := Q_V + Q_{TR} + Q_{TS3} + Q_{TO} = 4.706 \cdot kW$$

Load due to thermal bridges with mineral wool

$$Q_{TH3} := 0.10 \cdot Q_{PT3} = 0.471 \cdot kW$$

Total heat load with minerla wool

$$Q_{T3} := Q_V + Q_{TR} + Q_{TS3} + Q_{TO} + Q_{TH3} = 5.177 \cdot kW$$