



Assessing prefabrication processes in house building systems

Titulación:	Grado en Arquitectura Técnica
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Fecha presentación:	14/06/2013
Modilidad:	Intercambio

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I. INTRODUCTION

The world is facing with an economic and an environmental crisis. Prefabricated building technology lately has come to the focus as a way to fight against the economic crisis, and contributing to sustainability. Therefore it is a method for taking in consideration, representing a lot of promising opportunities regarding the building sector in the future.

ECONOMY

The economical crisis caused huge drop in the building sector. Economic efficiency is more important than ever. The number of clients are very low, showing them the advantages, and the differences between the different methods are important. *The economic advantages* of prefabricated building method lies in the technology: the construction is faster, thanks to the offsite manufacturing process, and their independence from weather conditions. The quality of the elements is better, they are always checked following the current regulations. It also saves money on the site: less labour is needed. There are also disadvantages, such as less flexibility, assembly issues, the transportation costs, and that use of heavy equipment is required. On the other hand, most of these can be decreased by good design and well chosen schedule and organisation.

Regarding the **sustainability**, it is environmentally friendly, because it produces less waste. Regarding the reduction of the impact on the environment, the prefabricated systems give a big advantage in the production phase. However, transportation causes negative effect to environmental perspective. The other important key point is recycling. Creating a closed material cycle is almost exclusively possible using prefabrication technology, because in this case the building process is built similar principles. Life Cycle Analyses (LCA) have already given proof to this matter.

The main prefabricating technologies are based on heavy and lightweight technologies. The heavy technology contains the precast concrete systems. The most often used elements are frames, hollow core slabs and facade panels. Lightweight technologies are the steel and timber structures. The steel system uses frame structures, the timber system offers timber panels, room modules and slabs.

Different possibilities of prefabrication are shown in a review of the basic building processes.

Those are the following:

Review the basic building processes can help us to see the possibilities for improving the systems. These are the following:

- Design

Architects and technical staff cooperates in order to define the final production drawings

- Production

Varies for each technology. They produce high quality components in the factory

- Assembly

On site. Fabricating joints and connections

- Disassembly

Dry (fastened) and reversible joints can be disassembled

Methodologies

In the field of prefabrication there are a lot of methodologies to be applied, as there are many aspects to examine the subject. In the area of environmental impacts, the common used is **Life Cycle Analysis** (LCA). LCA is about calculating the total resources conception and a waste generation during each life cycle phase.

The LCA phases are:

1. Material fabrication
2. Transportation
3. Assembly
4. Use (50 years)
5. Maintenance
6. Demolition

Indicators in analysis: materials weight (kg/m²), energy (MJ/m²), CO₂ emissions (kgCO₂/m²), environment toxicity, human toxicity, material intensity, water used (m³/m²), solid waste (kg/m²), recycled material (%)

The LCA methodology is regulated in ISO 14040:2006 and ISO 14043:2006, although the building sector uses a simplified version based on one agreement.

Another useful methodology to make a good decision while choosing the building method, is using the **Construction method selection model (CMSM)**. Despite of the advantages of the prefabricated construction method, nowadays it is used in a low percentage. This method helps to evaluate the feasibility of prefabrication and explore an optional strategy to apply the method.

Prefabrication in house building

Prefabricated building is an easy and fast method to build. The area of house building has different requirements than constructing industrial equipment. The use of building centered into residential purpose and the durability of construction are strong conditions for choosing a specific system. The history of using prefabricated methods in house building goes back to the industrial revolution in the late nineteenth century.

Modular houses. Experiments.

After the second world war in Hungary, there was a huge shortage of dwelling buildings. The government tried to fill this gap with erecting 8-10 story buildings using prefabricated concrete panels. Nowadays they generate many problems, because the construction quality was not appropriate. These problems has to be solved within a short time, this is one important task of the engineers of our time. On the other hand we can learn of these experiences avoiding the mistakes by redesigning the different solutions.

ENVIRONMENT

The change of our climate is a very serious, threatening danger, which is caused by human activity. The effects, such as global warming, natural disasters, the attenuate ozone layer, etc. are nowadays well known. It is a problem affecting the whole planet, that is why international councils are needed. There has been international agreements on this matter, for example the Kyoto protocol. The European Union treat the question of protecting our environment seriously, and introduced directives and long term goals for the Member states.

The building sector is an energy intensive sector, with great potential to reduce energy needs and environmental pollution. Several measures are being taken to increase the energy efficiency and avoid energy consumption in this sector. Several standards has been set up in the last decade, in accordance with the international energy awareness. For example, the European Performance of Building Directive which is establishing goals what has to be reached by the EU member states by 2020. In addition, by 2020 new houses in member states has to be nearly zero energy buildings. Due to the strict quality control in prefabrication methods, and the less possibility of mistakes on the work site, prefabrication could be an easier way to observe the new rules.

In my thesis, I will overview the regulations, apply the calculations on a prefabricated example, defined by the national rules. After analysing the methods, I can make suggestions for improving the thermal behaviour of the structure to improve the energy efficiency, using energy and environment conscious solutions.

II. STATE OF THE ART

1. European Performance of Building Directive (EPBD)

The European Union is committed to the reduction of energy consumption and encouraging the use of renewable energy sources in the building sector. This intention is in accordance with the Kyoto Protocol, and its commitment to reduce greenhouse gas emissions by 20 % of the level in 1990, by 2020. The building sector accounts for 40 % of the total energy consumption, therefore to reduce the CO₂ emission, the buildings energy efficiency must be improved. EPBD establishes requirements and mile stones to reach that goal. The Directive was introduced in 2002, and has been modified on various times.

The most important principles of the *2002/91/EK*:

1. The protection of environment has to be part of the common politics
3. Increasing the energy efficiency, following the Kyoto Protocol
4. Handling the energy need
6. Dwelling sector is responsible for 40 % of energy usage, this tendency increases the CO₂ emission
7. Legal regulation is important to achieve concrete goals
8. The heating and cooling system of the building has to be designed to keep the energy consumption on a minimum level
10. The method of calculation the energy performance requirements has to live space for regional differentiation
12. Preparing a survey about the effects of possible alternative energy usage
16. Energy performance certification must be widely spread
18. Improving of passive cooling systems
19. Regular maintenance of boilers and climates

In the execution, the local climate must be take into account, therefore the member states establish the requirements about:

- a. general method in calculation of minimum energy performance requirements
- b. applying the minimum requirements for evaluating new buildings energy performance
- c. applying the minimum requirements for buildings before major renovations and existing buildings energy performance
- d. the energy performance certificate
- e. regular maintenance of boilers and climates, and supervision of boilers older than 15 years.

The countries can deal with the new and already built buildings separately. Buildings with more than 1000 square metres are in also a different category, in their case, it is obligatory to examine the methods of alternative energy-supply, such as co-generation, heat recovery and solar heating systems.

EC 2009/28 Directive

- renewable energy sources in the regional and local energy production
- new technologies and support of education

EC 2010/31 Directive

The main newest version of the directives. Its goal is to make the regulations more clear and organised.

- decreasing the energy use of EU with 20 % by 2020.
- until the end of 2020, every new building has to be nearly zero energy building
- until the end of 2020, every public owned building has to be nearly zero energy building

The definition of nearly zero energy building is established by the member states.

The general requirements for the nearly zero energy building is, that it must be highly energy efficient. The used –zero or very low- energy has to gained mainly from renewable energy resources.

There are various options for achieve the nearly zero energy building, but it is very important, that the environmental effects of the buildings have to be the lowest in their full lifetime, and provide the best possible convenience.

2. Hungarian national regulation

The current building energy regulation is built on three statutory rules:

7/2006 regulation: calculation and requirements

176/2008 : Energy Performance Certificate

264/2008 : supervision of boilers and ventilation systems

The *7/2006. regulation* details the national calculation method, and setting the energetic requirements for new buildings, and existing buildings before great renovations. The scope of the regulation affects to the buildings containing for long residence, and the designing building which use energy for ventilation specified by law. Major renovation means that the total expense of renovation exceeds 25% of the average value of rest of the buildings.

Regarding the calculation methods, the buildings can be divided to two groups:

- general buildings
- multiple complex energy system buildings

General buildings: regarding the calculations, all buildings are general, which are not under the terms of multiple complex energy system buildings, or complete maximum one term. Calculating their energy performance, following the simple or particular calculation method of the 7/2006 regulation is sufficient, computer simulation can be applied as well.

Multiple complex energy system buildings: the buildings, which have more than 1000 square metres of heated place, and at least two of the following terms are true:

- the specific efficiency of the lighting and the technological equipments exceed 20 W/m³ at least 100 days of the year 8 hours per day.
- the glass ratio of the building envelope is higher than 40 %
- the air holes of the building envelope is part of the ventilation system
- the cooling in the building is power-operated at least 100 days per in a year 8 hours per day.

For the energetic calculations of the multiple complex energy system buildings, computer simulations with capability of determining changing heat convection, and databases containing the weather conditions must be used.

Levels and requirements of the 7/2006. regulation:

I. Heat transmission coefficient of building envelope ('U'-value)

II. Specific heat waste coefficient (q)

III. Cumulative energy quality (E_p)

Evaluation of the building based on the value of E_p/E_{pm}

A+	<55	Fokozottan energiatakarékos/Major energy saving
A	56-75	Energiatakarékos/Energy saving
B	76-95	Követelménynél jobb/Better than required
C	96-100	Követelménynek megfelelő/Sufficient to requirements
D	101-120	Követelményt megközelítő
E	121-150	Átlagosnál jobb/Better than average
F	151-190	Átlagos/Average
G	191-250	Átlagost megközelítő/Close to average
H	251-340	Gyenge/Weak
I	341<	Rossz/Bad

Table 1

3. Spanish national regulation

In Spain the revision of building envelope regulations started in 1995, in the frame of SAVE 76/93 they produced a full building technical code. Technical works finished by 2002, covering the European Performance Building Directive articles 4,5 and 6.

The following Royal Decrees are still in force that are in relation with EPBD:

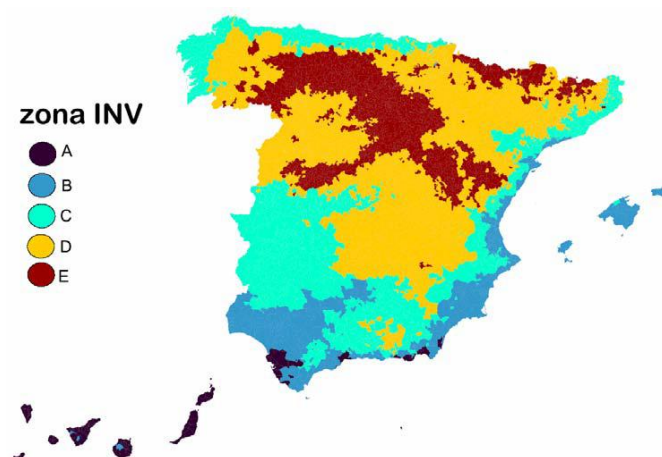
- Royal Decree 314/2006, of the 17th of March, approving the Technical Building Code

- Royal Decree 47/2007, of the 19th of January, approving the basic procedure for the energy certification of the new build (EPC)

- Royal Decree 1027/2007, of the 20th of July, approving the Thermal Building Regulations

-EPBD minimum requirements (Articles 4,5,6) are supposed to be fulfilled when the building complies with the requirements stated in the basic document about the building energy aspects in the new building technical code.

-Spain is divided in 5 climatic winter zones and 4 climatic summer regions, in total, 12 climatic zones. For every one of these zones, in addition to a minimum level of insulation for avoiding condensations and molds, prescriptive limits for thermal transmittances for opaque components and glazing are imposed. For summer conditions maximum values of modified solar factors of windows have been selected, depending on the internal gains of the buildings.



The winter climatic zones in Spain

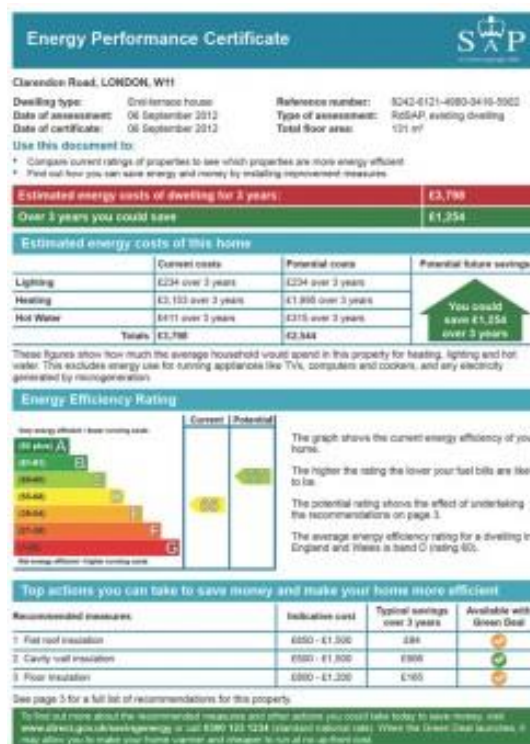
Figure 1

-Compliance of the regulation is obtained in two ways:

-Prescription: all the building elements are better than the maximum values;

-Performance: the calculated net energy demand is lower than that of a reference building built with the prescriptive elements.

The Spanish Energy Performance Certificate ranges from A –very high performance, involving a high contribution of renewable energies in the building consumption- to G, which represents low performance. Typically, a new building that follows the current regulations is rated on the limit between C and D. There are no certificates with the label F or G, because the minimum qualification that a new building can achieve is E.



Form of Energy Performance Certificate in Spain

Figure 2

Climatic zones and the 'U-value'

The Technical Building Code (Royal Decree 314/2006) introduced new regulations in the field of building energy efficiency. The basic standard consists of a Basic Document, made up in time by 5 documents with a specific objective each.

- CTE DB HE1: Limitation of energy demand
- CTE DB HE2: Performance of thermal installations (RITE)
- CTE DB HE3: Energy efficiency in lighting installations
- CTE DB HE4: Minimum solar contribution for hot sanitary water
- CTE DB HE5: Minimum photovoltaic contribution for electric power

The Document CTE DB HE1 is meant to replace the former regulation, based in the NBE-CT-79.

The new energy performance requirements established by CTE in section HE-1 and the procedure for certification of buildings are determined according to the climatic variability of 12 different climatic zones. Climatic zoning in Spain has been carried out in accordance with a variable expressly defined for such purpose which is known as climatic severity, calculated as the comparison between the heating/cooling demand of a certain building and that which the same building would have in a reference locality. Where the demand used in the calculation is heating demand, the variable calculated is characterised as winter climatic severity. Meanwhile, where the calculation uses the cooling demand, the variable calculated is characterised as summer climatic severity. In both cases, the reference locality used is Madrid. Following this procedure, the Spanish energy regulations classify the 52 provincial capitals into 12 climatic zones, identified by a letter from A to E and a number from 1 to 4. The letter refers to the winter climatic zoning, while the number refers to the summer climatic zoning.

Requirements are established in terms of U-values and solar factors, according to the climatic zone where the building is located.

The compliance with the requirements of HE-1 can be checked using either a simplified procedure, following a prescriptive approach (to be used in the case of dwellings and within certain limitations), or by a general performance approach, implemented by a software tool.

Element	Zone A	Zone B	Zone C	Zone D	Zone E
Facade walls	1,22	1,07	0,95	0,86	0,74
Floors	0,69	0,68	0,65	0,64	0,62
Roofs	0,65	0,59	0,53	0,49	0,46

Maximum U-values (W/m²K) of building envelope elements for winter climatic zones

Table 2

4. Overall heat transfer coefficient of building envelope (U-value)

The first level concerns the measure of heat loss in a specific building elements: the 'U' value. Knowledge of how to simply calculate U values is useful in the design process, It allows the designer to test the feasibility of their project at an early stage to ensure their suitability for the purpose according to regulatory frameworks. The higher U value is worse for the thermal performance of the building envelope. A low U value usually indicates high levels of insulation. Nearly every external building element has to comply with thermal standards that are expressed as a maximum U value.

The requirement of U_R (heat transfer coefficient of building elements) to all building elements terminating the heated volume of building: $U_R < U_M$, where U_M is required value of the examined building element.

Keeping the current limiting value is obligatory when choosing all the building elements. However following this regulation does not guarantee the compliance of specific heat waste coefficient for the whole building, because the $\sum A/V$ ratio has a major effect on it.

The U_R also contains a correction for the effect of thermal bridges. The length of the thermal bridges has to be summarized in all elements of the building envelope. Depending on the $\sum l / A_{\text{facade}}$ there are three types of building qualities regarding thermal bridges:

Elements of building envelope	Specific length of thermal bridges (fm/m ²)		
	Level of thermal bridges		
	<u>Weak</u>	<u>Moderate</u>	<u>Strong</u>
External walls	<0,8	0,8-1,0	1<
Flat roofs	<0,4	0,2-0,3	0,3<
B. elements of mansards	<0,2	0,4-0,5	0,5<

Table for choosing X efficient

Table 3

The corrected heat transfer coefficient reflecting the effect of thermal bridges, using the simple calculation method:

$$U_R = U (1+X)$$

Elements of building envelope			Coefficient reflecting the effect of thermal bridges 'X'
External walls	with uninterrupted insulation external position or inside the structure	weakly	0,15
		moderately	0,20
		strongly	0,30
	other external walls	weakly	0,25
		moderately	0,30
		strongly	0,40
Flat roofs		weakly	0,10
		moderately	0,15
		strongly	0,20
Building elements of manzards		weakly	0,10
		moderately	0,15
		strongly	0,20
Loft slabs			0,10
Arcade slabs			0,10
Basement slabs	insulation inside the structure		0,20
	insulation on the underside		0,10
Walls between heated and unheated rooms			0,05

Table 4

The building suits the requirements if:

$$U_R < U_M \quad [W/m^3K]$$

The following Table 5 includes the required values of U_M :

Element of building envelope	Required value of heat transfer coefficient 'U' (W/m ³ K)
External wall	0,45
Flat roof	0,25
Loft slab	0,30
Element terminating heated roof	0,25
Underside slab above arcade	0,25
Underside slab above unheated basement	0,50
Glassed window on facade (wooden or PVC)	1,60
Glassed window on facade (with steel frame)	2,00
Glassed window on facade, if $A < 0,5 \text{ m}^2$	2,50
Glass wall on facade	1,50
Skylight	1,70
Gate on facade without glass	3,00
Door on facade or between heated and unheated rooms	1,80
Wall between heated and unheated rooms	0,50
Wall between neighbouring heated buildings	1,50
Wall touching the ground between 0, and 1,0 m	0,45
Floor on ground, in 1,5 m zone at the perimeter	0,50

According to the *EC 2010/31 Directive* the Hungarian 7/006. regulation is being revised. The leading experts of the subject has worked out milestones to introduce in 2012, 2015 and 2019, to reach gradually the new energetic requirements of nearly zero energy buildings by 2020.

The suggested values of 2012 and 2015 can be fulfilled with the current technologies and methods. One of the most important factor is the heat transfer of external walls. By 2019, the new value can be reached only with multi-layered wall structures. New regulations were introduced regarding the building engineering as well.

Element of building envelope	Required value of heat transfer coefficient 'U'(W/m ² K)		
	2012	2015	2019
External wall	0,30	0,26	0,22
Flat roof	0,20	0,18	0,15
Loft slab	0,20	0,18	0,15
Element terminating heated roof	0,20	0,18	0,15
Underside slab above arcade	0,20	0,18	0,15
Underside slab above unheated basement	0,30	0,28	0,25
Glassed window on facade (wooden or PVC)	1,30	1,15	1,00
Glassed window on facade (with steel frame)	1,60	1,45	1,40
Glassing	1,10	1,00	0,80
Special glassing	1,40	1,20	1,00
Glass wall on facade	1,60	1,45	1,30
Skylight	1,40	1,25	1,10
Door on facade or between heated and unheated rooms	1,60	1,45	1,30
Wall between heated and unheated rooms	0,33	0,30	0,25
Wall between eighbouring heated buildings	1,60	1,60	1,60
Wall touching the ground between 0, and 1,0 m	0,40	0,30	0,25
Floor on ground, in 1,5 m zone at the perimeter	0,40	0,30	0,25

Restrictions of required value of heat transfer coefficient between 2012 and 2020

Table 6

5. List of the possible ways to improve the thermal behaviour of this system, using sustainable solutions

I. Reducing the effect of thermal bridges

1. Types of thermal bridges and their effect
2. Thermal bridges of the specific prefabrication system
3. Possible ways to avoid thermal bridges

II. Applying thermal insulation

1. The heat transfer coefficient ('U'-value) for elements of the building envelope
2. Possible thermal insulations for each building element (floor, walls, flat roof)
 - Expanded or extruded plastic foam
 - Silicate stringy (stone wool, glass wool)
 - Expanded cork
 - Foamglass
 - Plastic foam (PIR)

III. Introducing passive solar systems

-
-
-
-

III. MY CONTRIBUTION

1. Calculations of overall heat transfer coefficient of building envelope (U)

Thermal bridges

The types of thermal bridges can be sorted by the geometric and structural shape of the building envelope.

Geometric thermal bridges are at the connection of surfaces meeting with an angle (wall-corners, wall-roof connections), and when elements connecting in plane, but their width is different.

Structural thermal bridges can be found at the connection of materials with different thermal conductivity, can be 'edgeline' thermal bridges, structures hangover from the facade, building engineering break-throughs, chimney, or the fixing elements of thermal insulation, as pointwise thermal bridge.

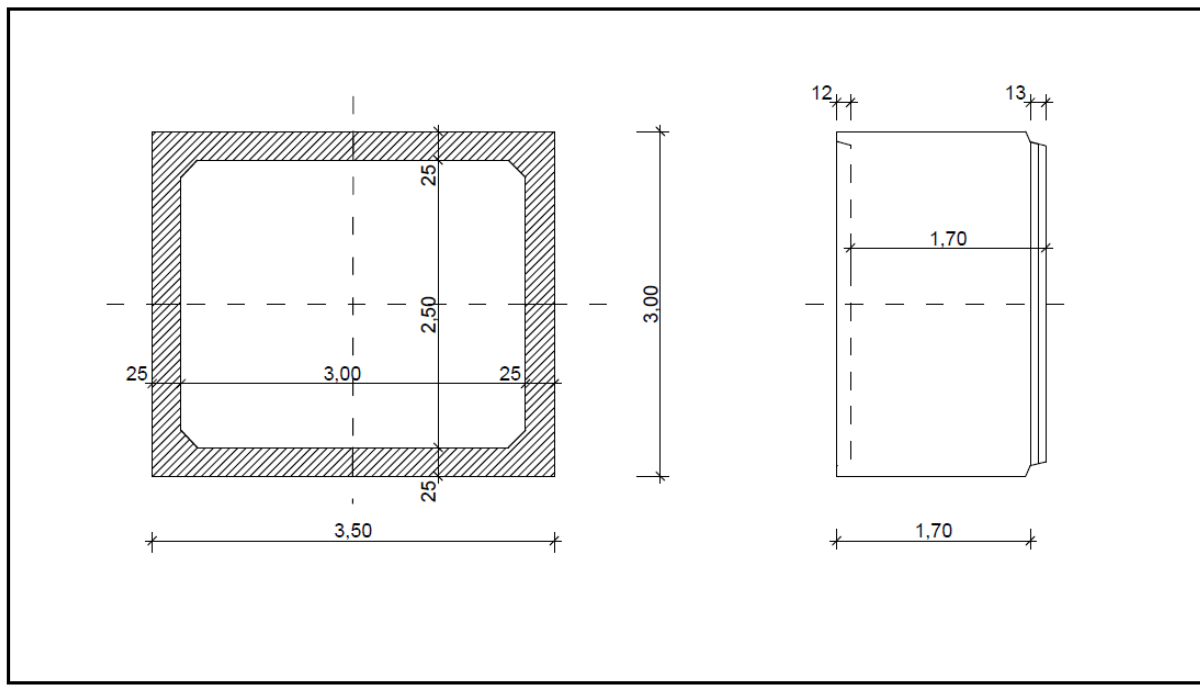


Figure 3

Regarding the prefabricated system of Marco 3000x2500 elements, it has advantages compared to the traditional systems. Figure 4 shows the prefabricated concrete element. The design of the element decreases the effect of the geometric thermal bridges occurred at the positive corner.

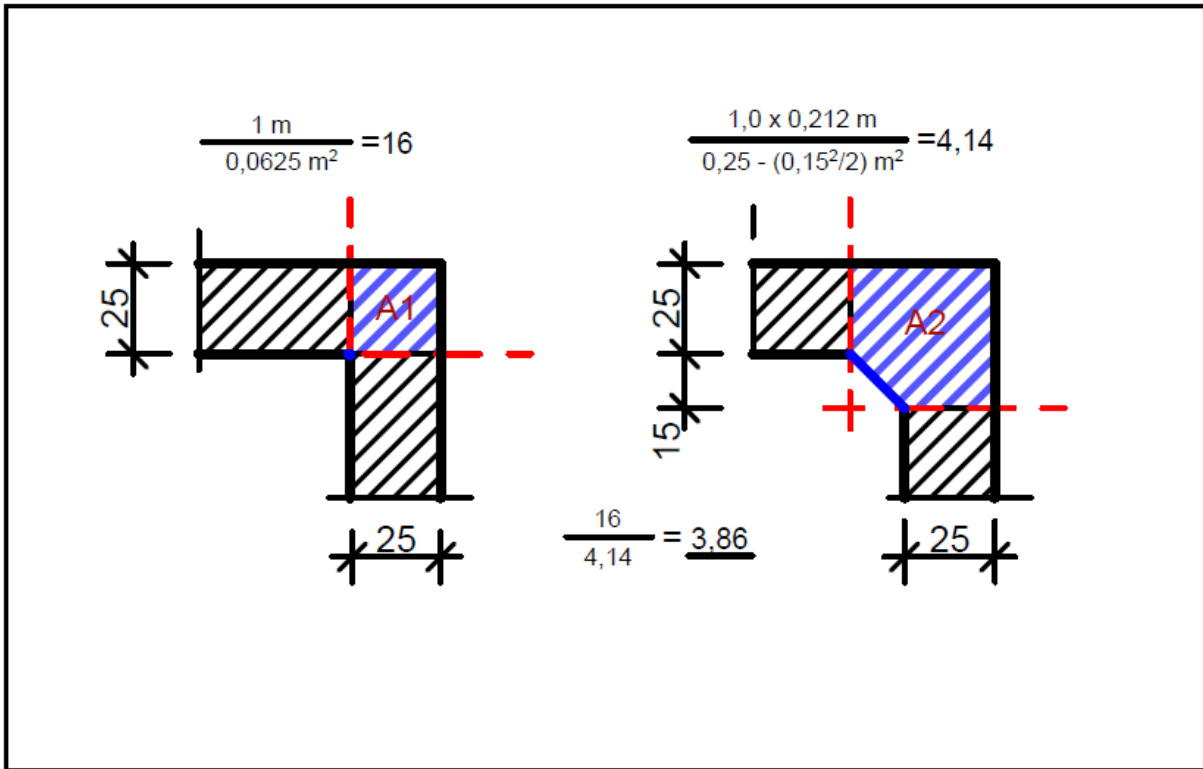


Figure 4

On the *Figure 3*, the picture shows the positive corner of a traditional building. The blue point represents 1 m of the wall, A1 is the cooling area belongs to that 1 m length line. As it is shown on the right side, with smoothing the corner, the line becomes a surface, providing much more heated area for the A2 cooling area.

The effect of the smoothing the corner with expressed in numbers shows, that the thermal bridge is almost four times weaker. Therefore that is an effective method of avoiding a geometric thermal bridge. Although this method is available using prefabrication technology.

In the case of using prefabricated systems, the chance of thermal bridges caused by material changes is low, the structures are mostly homogenous. Although the connection of the elements can be a problematic area, especially, when those are not correctly solved. The connection must be airtight, to prevent uncontrolled ventilation.

Attention must be drawn to the terrace between the two modules. In the case of covering that area with a structure connected to the concrete modules, the connection must be designed with taking into account the possibility of creating a new thermal bridge, by adding a new cooling surface.

Peripheral thermal bridges are also important. They have to be summarized to calculate the 'length of thermal bridges', and determine the Building's level of thermal bridges to know the X modification coefficient. The X coefficient is used for reducing the U_R value of the building due to the thermal bridges.

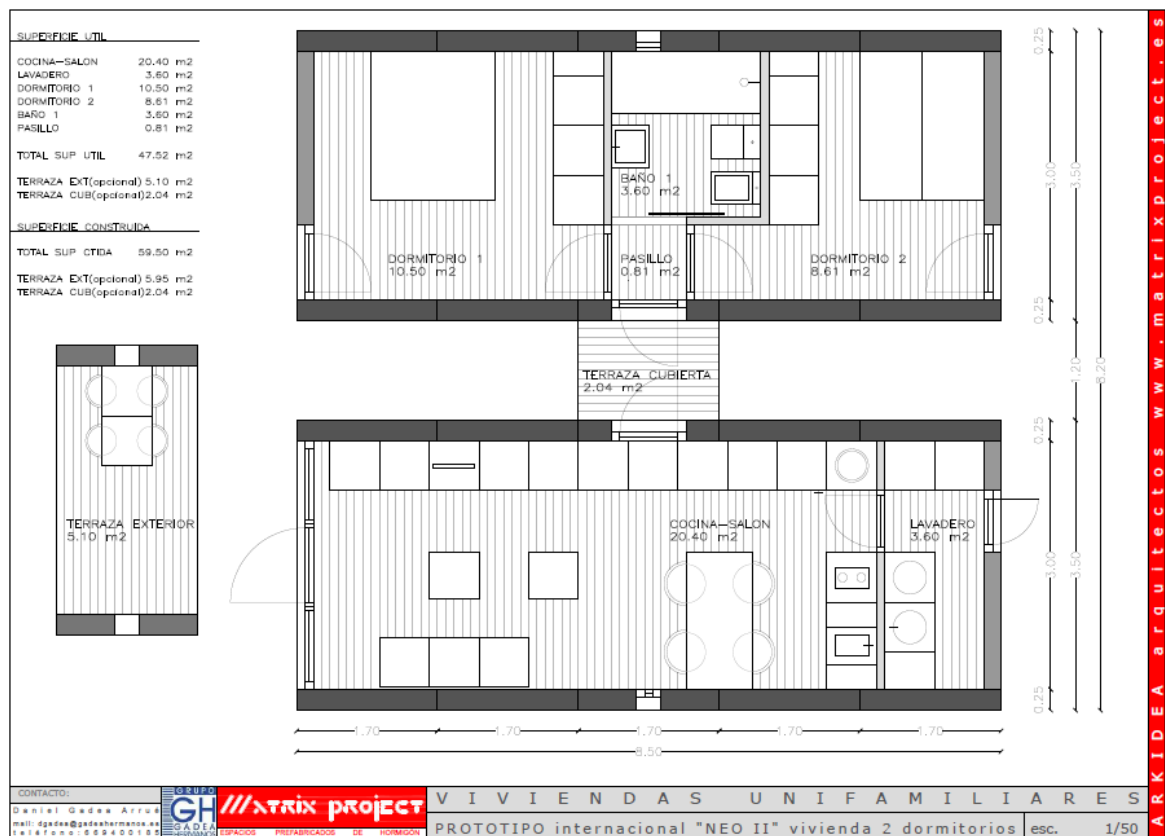


Figure 5

Elements	Height (m)	Lenght (m)	Pieces	Σ (m)
Vertical corner edges	2,40		6	14,40
Horizontal corner edges		3,00	2	10,14
		8,00	2	
Openings	2,20	0,90	1	27,50
	2,20	0,30	1	
	2,20	0,75	1	
	2,20	3,00	1	

$A_{\text{facade}} = 2(8,50 \times 3,0) + 2(3,5 \times 3,0) - (2,2 \times 0,9) - (3 \times 2,2) - (0,75 \times 2,2) = 61,77 \text{ m}^2$

Table 7

$$\Sigma I/A_{\text{facade}} = 52,04/61,77 = \mathbf{0,8425}$$

Elements of building envelope	Specific lenght of thermal bridges (fm/m²)		
	Level of thermal bridges		
	<u>Weak</u>	<u>Moderate</u>	<u>Strong</u>
External walls	<0,8	0,8-1,0	1<
Flat roofs	<0,4	0,2-0,3	0,3<
B. elements of manzards	<0,2	0,4-0,5	0,5<

Table 8 – for choosing X efficient

The corrected heat transfer coefficient reflecting the effect of thermal bridges, using the simple calculation method:

$$U_R = U (1+X)$$

The building's level of thermal bridges for external wall is 'moderate', but regarding the flat roofs, the level is 'strong'.

2. Calculation of original U-value

The overall heat transfer coefficient of building envelope (U-value) express the heat transfer on 1 m² of the building envelope, in one second, if the temperature difference of air between the outside and inside is 1K.

$$U = 1 / (1/\alpha_e + \sum d/\lambda + 1/\alpha_i) \text{ [W/m}^2\text{K]}$$

The ' α ' heat transfer shows the how much heat (J) 1 m² of the building element transfers to the air in 1 second, when the heat difference is 1 K.

The design values of α are given in the regulations:

	α_e [W/m ² K]	α_i [W/m ² K]
External walls	24	8
Flat roof	24	10
Internal slab	8	6

Table 9

First of all, I perform the calculations for the painted concrete elements, without using any insulation, or plastering layers, to see how far are their thermal behaviour from the requirements. The prototype of the system has been constructed this way, without using additional layers.

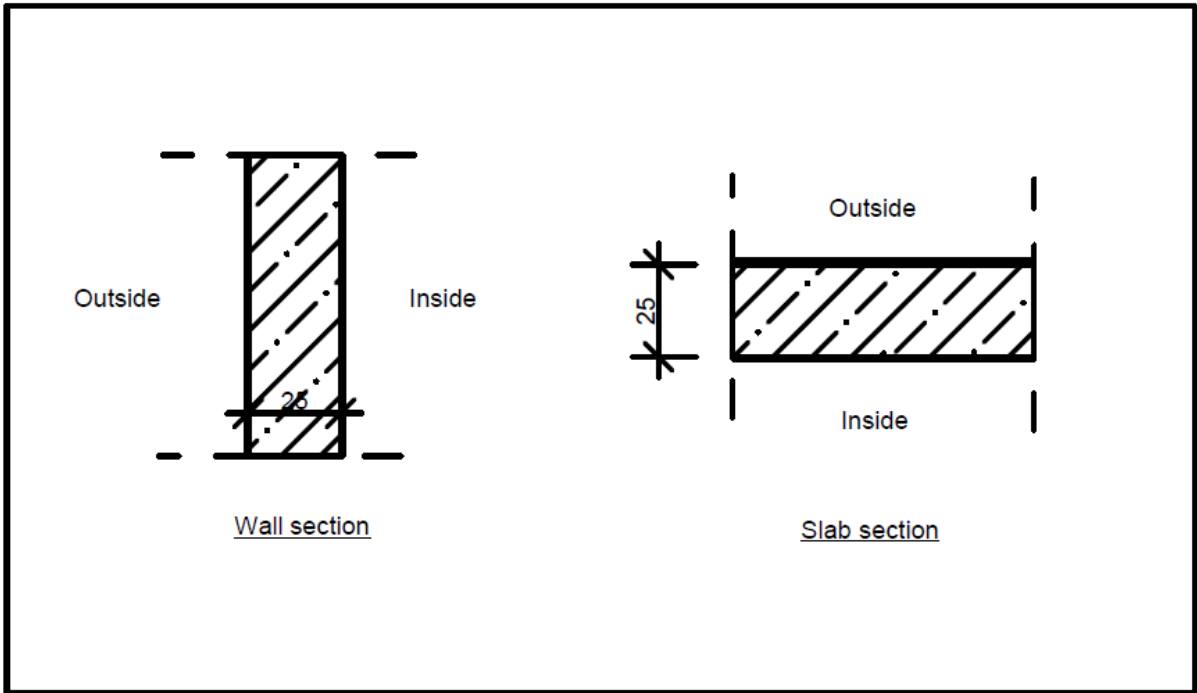


Figure 6

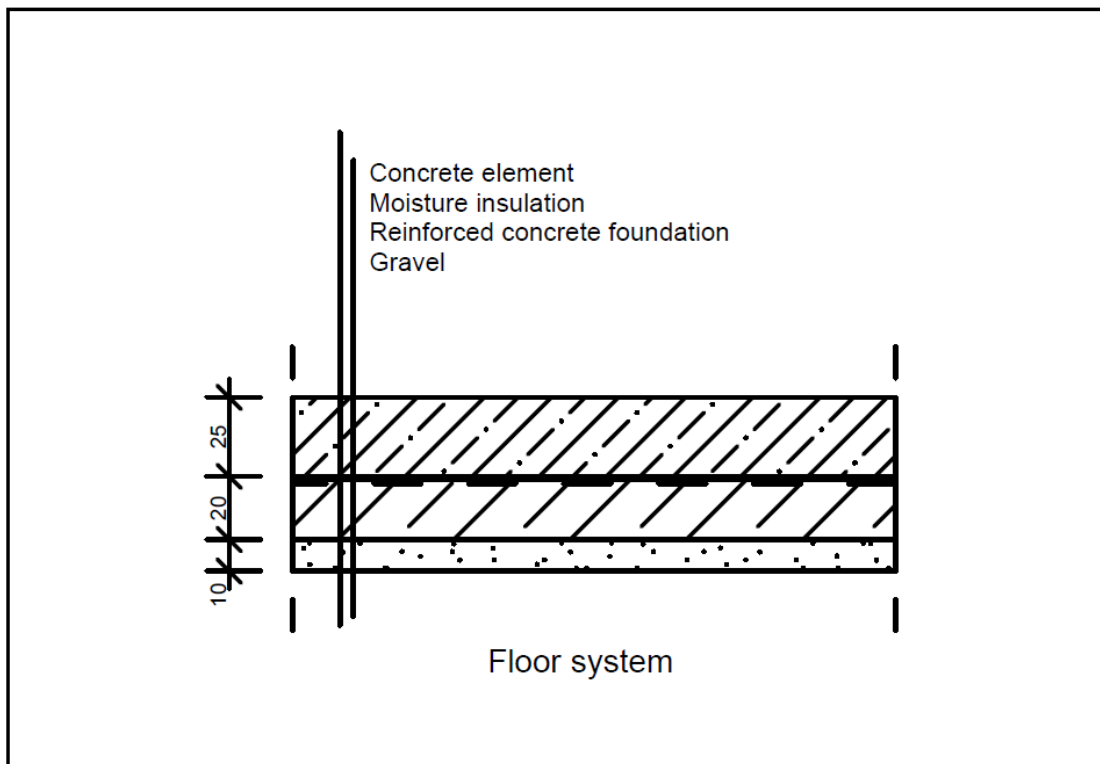


Figure 7

$$U_{\text{wall}} = 1 / (1/24 + 0,25 / 1,55 + 1/8) = \underline{3,05} \text{ [W/m}^2\text{K]}$$

$$U_{\text{roof}} = 1 / (1/24 + 0,25 / 1,55 + 1/10) = \underline{3,30} \text{ [W/m}^2\text{K]}$$

$$U_{\text{floor}} = 1 / (1/8 + 0,25 / 1,55 + 0,20 / 1,55 + 0,10 / 0,35 + 1/6) = \underline{1,15} \text{ [W/m}^2\text{K]}$$

Element	Actual value	Spain Zone B	Hungary	2019
Facade wall	3,05	1,07	0,45	0,22
Roof	3,30	0,68	0,25	0,15
Floor*	1,15	0,59	0,50	0,25

Comparison with maximum U-values in [W/m²K] of building envelope elements

Table 9

*In the case of the floor, the applied system has to be considered with the actual layers for the U-value calculations. Especially as the thermal insulation of floors has another important function: the acoustic insulation. For noise protection, the inorganic and natural organic insulations are better choice, because of their material structure: these are compressible and more flexible, than synthetical materials.

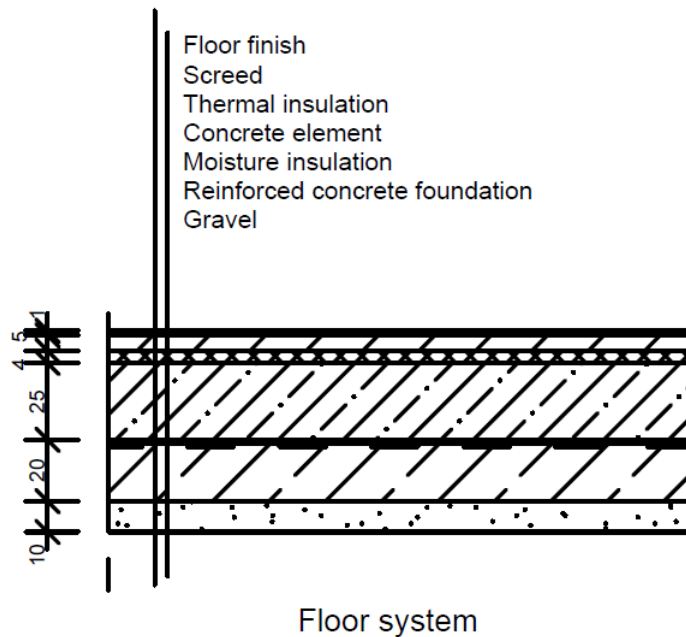


Figure 8

The *Figure 8* shows the basic layers of the floor. Ceramic tiling has been applied with a thin adhesive layer. The thermal insulation layer is under the floor screed and above the prefabricated concrete element. In the calculation only the type of the thermal insulation has been changed. I used current data of products from the website of the manufacturing companies.

Quality	Thermal conductivity	Thickness required/applied	Surface	Price/m2	Actual price
Measurement	W/mK	cm	m2	EUR	EUR
Austrotherm EPS	0,044	4/4	48	3,53	169,4
Styrofoam XPS	0,028	3/4	48	7,04	337,9
ISOVER TDPS	0,033	3/3	48	6,07	291,4
Rockwool Steprock	0,038	3/3	48	4,11	197,3
AMORIM Acousticork	0,038	3/3	48	14,83	711,8
FOAMGLAS Floor Board	0,041	4/4	48	14,80	710,4

Compliance of spanish regulations (Zone B)

Table 10

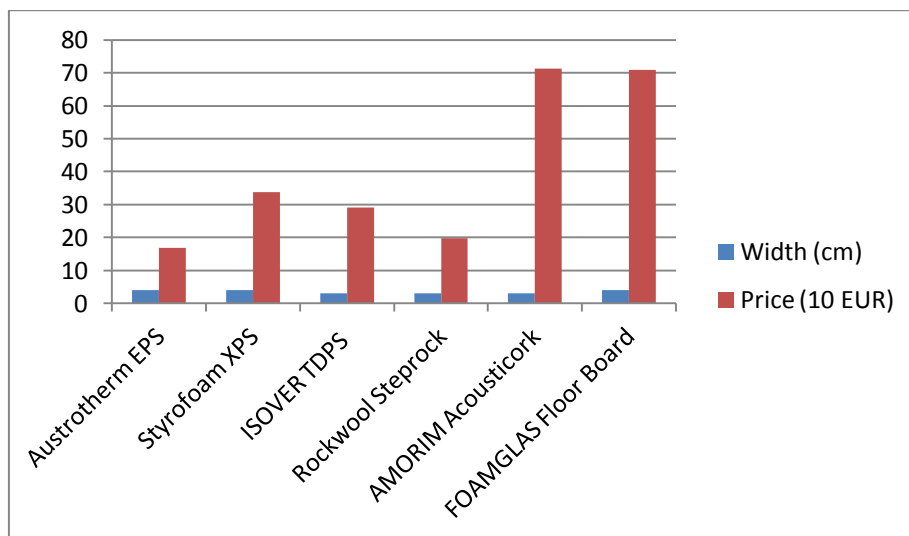


Figure 9

Table 10 shows the results of thermal calculations regarding the floor. The requirements has to fulfilled in the 1,5 metre area of the side territory. The 3-4 cm average is a usual data, this width is used for the internal slabs also for sound insulation. Although there is a leap in the price, considering the expanded cork and the foamglass insulation, it it showed in the *Figure 9*. The regulations can be fulfilled with cheap solutions as well, but if we take notice of sustainability, I recommend expanded cork to use. It is one of the most environmentally friendly insulation, due to the its natural origin, and it is produced very close, so the transportation does not debase this advantage. On the other hand, it has to be point out, that the cost is almost double, as the regularly used foam or silicate stringy materials. The foamglass insulation also worth to mention. It has almost the same price as expanded cork, and also environmentally friendly, it is in the group of inorganic thermal insulations. Although the main advantage of foamglass is the high compressive strenght, which makes it appropriate for carrying the weight of even the whole structure. This is an aspect worth consideration: if the thermal insulation can be located below the concrete module, the created configuration allow less thermal bridges at the connection of the floor and the external wall.

To come to a conclusion, I would recommend the installing of expanded cork insulation, due to its long life term, its highly efficient insulating qualities, and the very low environmental effect.

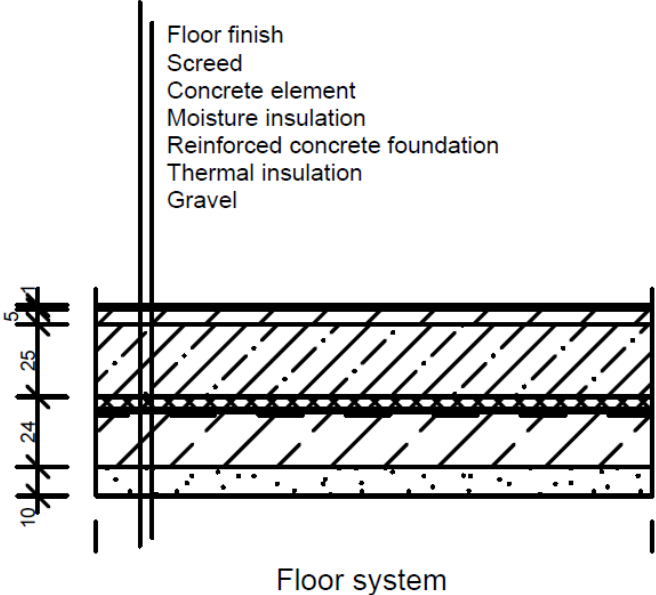


Figure 10

3. Types of thermal insulations

The increasing requirements of heat protection lead to the inevitable use of multilayered building structures in the not too far future. The most common solution to suit the requirements is made by applying an insulation layer on the external surface of the wall. The main property of this layer is the very low heat conductivity ($\lambda=0,00350-00400$ W/mK), due to their low weight/cubic capacity ratio.

Widely spreaded are the boarded systems. Several different system is available, based on different materials and the production process.

The general order of layers from the inside is:

- thin layer of adhesive
- insulation boards or sheets
- specially structured fiberglass
- primer layer of thin-plastering
- colour-plastering of facade

The width of the layers is variant from a few mm to the wide of the insulation layer, which can be up to 6-12 cm.

The panels are fastened to the wall also with mechanical connection, using special plastic dowels improved for this purpose.

The insulated panels can be sorted by the their structural build-up, or the origin of their basic element. I will use the second method, because it has an environmental effect as well.

- | | |
|-----------------------|--|
| -Inorganic: | -Silicate stringy (stone wool, glass wool) |
| | -Foamglass |
| | -Perlite products |
| | -Concrete with gas or foam |
| | -Clay products |
| -Natural organic: | -Expanded cork |
| | -Excelsior sheet |
| -Synthetical organic: | -Expanded or extruded plastic foam |
| | -Plastic foam, expansion on site |

Quality / Type	Silicate stringy insulations	Foams, insulations with pores
Basic material	inorganic	organic
Material structure	open	mostly closed EPS: temporarily closed XPS: closed
Chemical resistance	strong	varies (solvents)
Vapour diffusion resistance	low	high
Flameability	non-flammable	flammable
Sound proofing	poor	poor
Sound absorption	very good	poor
Handling	hard (stubbly)	easy
Installing on cold side	forbidden	can be used

Table 11

The two most common used types of insulation are the Silicate stringy and the Foam thermal insulations. They differ in their basic material, and technology, for that reason the comparison is relevant. In the most important qualities, silicate stringy insulations behave better, than the foams. Contractors prefer the foam materials because of their lower price, and they are easier to handle. Although the proper placement and supervision is very important for avoiding the fire hazard, these materials are flammable. The protection is solved by observing strict rules of placement. Another quality worth consideration is the high vapour diffusion resistance, ignoring this fact could cause serious problems inside the structure, due to the danger of increasing moisture content. Necessarily installing the silicate stringy materials also need punctuality and extra attention.

The main question about thermal insulation materials is the lifetime, and what is going to happen with them after they lose their qualities. This could be a problem especially in the case of foam insulations, we don't know how these building materials can be stored or used again. The building sector is using an increasing number of this type of thermal insulation as the easiest way. The regulations indicate the usage of wider and wider insulations, causing the production of more and more foams, without knowing how this leads in the future. For this reason I would recommend to choose silicate stringy insulations, despite of their slightly higher prices.

4. Effect of different plastering on external walls

Inside plastering improves the conveniences of the inner space, and provides a more aesthetic, smooth surface. Regarding the materials, the internal plastering is usually thicker, generally used are the grout (thick white wash) and gypsum boards, around one or two (1,25 cm thick) layers.

Applying outside plastering may hide the concrete structure, but at the same time provide some protection against the environment, and may slightly improve the thermal behaviour of the element.

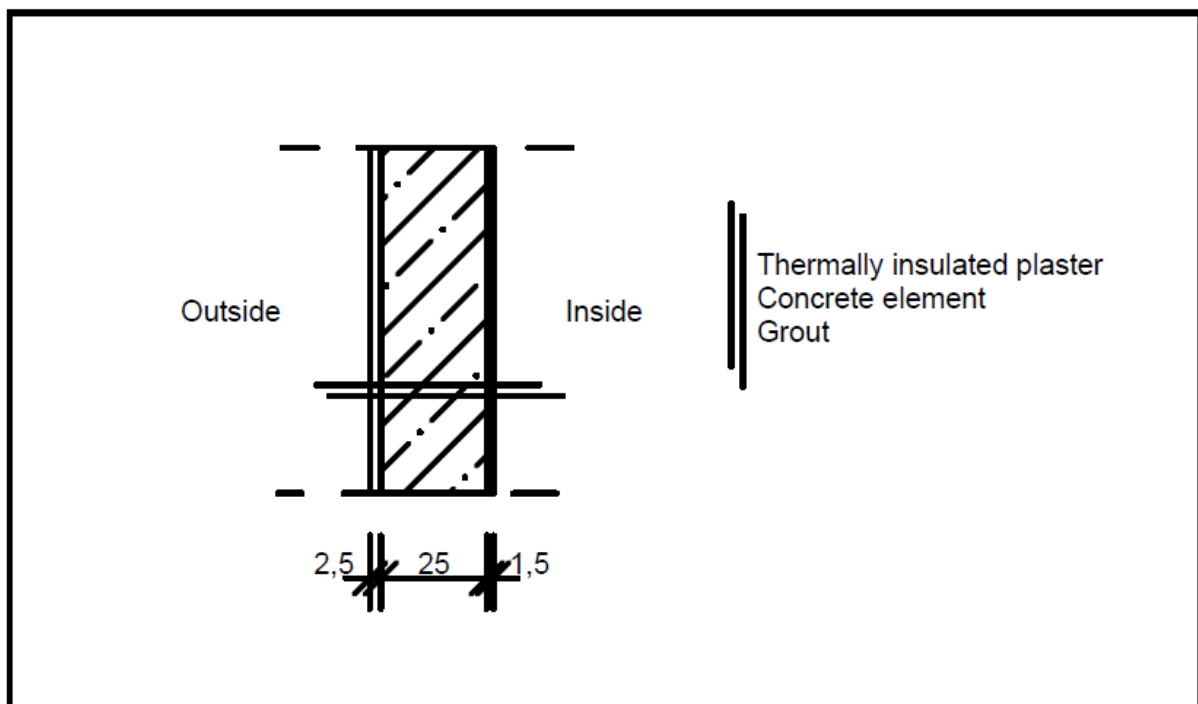


Figure 11

The external plastering has been modified in the last decades, in order to improve its thermal behaviour. The cement based plaster is made up of three parts sand plaster and one part cement. It is used on the buildings exterior to waterproof the walls. Grout can also be used as external plasterwork.

Thermally insulated plasters contain EPS pearls or mineral additive materials. It is lightweight, which causes reduction in substance, for that reason the final layer has to be tougher. A vapour barrier layer and checking of the moisture behaviour of the building elements is also necessary. Lately the improvements enables the plasterwork behave as a highly effective thermally insulating plaster, which can substitute the insulation in some cases.

Element: Facade wall				
Type of external plastering	Type of internal plastering	λ_1 [W/mK]	λ_2 [W/mK]	U_{wall} [W/m ² K]
Cement based plaster(2 cm)	Grout (1,5 cm)	0,93	0,81	2,72
	Gypsum board (1,25 cm)	0,93	0,25	2,50
Grout (1,5 cm)	Grout (1,5 cm)	0,81	0,81	2,74
	Gypsum board (1,25 cm)	0,81	0,25	2,52
Thermally insulated plaster (2,5 cm)	Grout (1,5 cm)	0,14	0,81	1,90
	Gypsum board (1,25 cm)	0,14	0,25	1,79
Highly effective thermally insulated plaster (3 cm)	Grout (1,5 cm)	0,058	0,81	1,16
	Gypsum board (1,25 cm)	0,058	0,25	1,12
Highly effective thermally insulated plaster (4 cm!)	Grout (1,5 cm)	0,058	0,81	0,97
	Gypsum board (1,25 cm)	0,058	0,25	0,94

Table 12

The table shows the effects of combination of different plasterworks. Using more effective plasterwork can dramatically improve the thermal behaviour. As can be seen, the highly effective thermally insulated plaster, applied as a 4 cm layer is very close to satisfy the current spanish regulation for facade walls. Although the hungarian rules are almost twice stricter, and the spanish rules are going to be tougher during the next years as well. *Table 9* shows the comparison of the 'U'-values.

For that reason, applying a thermal insulation layer is inevitable. After examining *Table 11*, in the following thermally insulated plasterwork is used outside, and grout on the inside surface of the wall.

Element	Actual value	Spain Zone B	Hungary	2019
Facade wall	0,94	0,82	0,45	0,22

Comparison with maximum U-values in [W/m²K] of facade walls

Table 13

5. Effect of different type of insulation on external walls

The increasing requirements of heat protection are causing that nowadays one-layered wall system are not sufficient multilayered external walls need to be used for achieve the new values. The most common solution to suit the requirements is applying an insulation layer on the external surface of the wall. There are many types of thermal insulation with different basic materials, qualities and prices provided by different brands. As the technology evolves, the value of heat conductivity is lower and lower, but in the not too far future, extreme width of layers has to be used.

In the following, the analysis can be found about the effect of using different type of insulation material, comparing the prices in this specific prefabricated house system, and looking forward the 'U'-values of 2019.

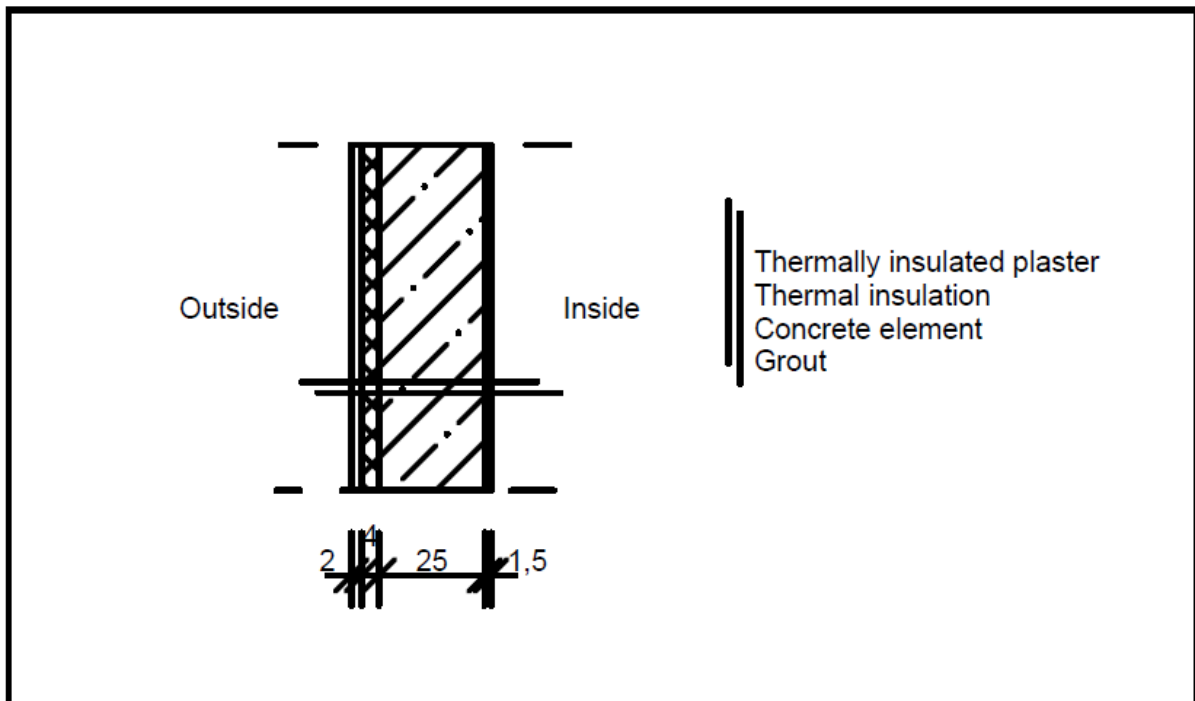


Figure 12

Figure 10 shows the general layers of the external wall. The 25 cm wide reinforced concrete is the core. On the inside the calculations have been performed with grout plastering layer, because it is the most common used and it helps creating a healthy atmosphere inside. The plasterwork outside is thermally insulated plaster, because it has been proved the most effective solution, and it is widely used as well.

In the following, the different types of thermal insulations are summarized, considering their basic materials, the production process, and their environmental impact.

-Synthetical organic: polystyrene thermal insulations

Polystyrene products are made of organic cellular plastic. Nowadays they are the most common insulations, for the entire building envelope.

There is two main type: -Expanded polystyrene foam (EPS)
 -Extruded polystyrene foam (XPS)

Expanded polystyrene(EPS) foam is a closed-cell insulation that's manufactured by "expanding" a polystyrene polymer; the appearance is typically a white foam plastic insulation material. Extruded polystyrene (XPS) foam is a rigid insulation that's also formed with polystyrene polymer, but manufactured using an extrusion process, and is often manufactured with a distinctive color to identify product brand. Polystyrene insulation is manufactured in a variety of board sizes, usually a minimum of 1-inch thick. Tapered units are also manufactured for use in roofing assemblies where the insulation is used to create slope for positive drainage.

While EPS and XPS are two different products, they do have some similar characteristics and fall under the same manufacturing standard: *ASTM C578 Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*. This particular specification covers the different types and physical properties of cellular polystyrene intended for use as thermal insulation.

-Expanded polystyrene foam (EPS)

Expanded Polystyrene is a lightweight, rigid, plastic foam insulation material produced from solid beads of polystyrene (with a diameter of 0,2 to 0,3 mm). Expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production. The gas expands under the action of heat, applied as steam, to form perfectly closed cells of EPS. These cells occupy up to 50 times the volume of the original polystyrene bead. The EPS beads are then moulded into appropriate forms suited to their application.

There are 5 manufacturing stages:

1. Pre-expansion: polystyrene granules are expanded by free exposure to steam to form larger beads, each consisting of a series of non-interconnecting cells.
2. Conditioning: after expansion, the beads still contain small quantities of both condensed steam and pentane gas. As they cool, air gradually diffuses into the pores, replacing, in part, the other components.
3. Moulding: the beads are moulded to form boards, blocks or customised products. The mould serves to shape and retain the pre-foam, and steam is again used to promote expansion. During moulding, the steam causes fusion of each bead to its neighbours, thus forming a homogeneous product.

4. Shaping: following a short cooling period, the moulded block is removed from the machine, and after further conditioning, may be cut or shaped as required using hot wire elements or other appropriate techniques.
5. Post-production processing: the finished product can be laminated with foils, plastics, roofing felt, fibreboard or other facings such as roof or wall cladding material.

Expanded polystyrene foam (EPS) is usually white. Some new innovative EPS products are grey due to the inclusion of graphite, which substantially increases the insulation performance. EPS is considered safe, non-toxic and inert. At any time of his life cycle does it contain any Chlorofluorocarbons (CFCs) or Hydrofluorocarbons (HCFCs).

The most important properties of EPS are :

- excellent thermal performance (λ between 0.038 and 0.030W/m.K)
- high compressive strength
- outstanding impact absorption
- low weight
- imperviousness to moisture
- 100% recyclable

-Extruded polystyrene foam (XPS)

Extruded polystyrene is produced by a continuous extrusion process: blowing-agent-free polystyrene granules are melted in an extruder and a blowing agent is injected into the extruder under high pressure where it dissolves into the polystyrene melt. This blowing-agent containing melt exits the extruder via a slot die. The blowing agent expands due to the drop in pressure which causes the polystyrene to foam into the form of a board with homogeneous and closed cell structure. The main used blowing agent is CO₂. For some special applications requiring a very low thermal conductivity HFC's are the preferred blowing agent.

Variations in the slot die allow board thicknesses between 20 mm and 200 mm. After passing through a cooling zone, the boards' edges are trimmed. The variation of process parameters during production allows the modification of the XPS product characteristics in order to satisfy the various application requirements. With foam densities between 20 and 50 kg/m³ compressive strength values can be achieved from 150 to 700 kPa. This corresponds to loading capacities between 15 and 70 tons per square metre. XPS's rated thermal conductivity values currently range from 0.029 to 0.045 W/mK. The closed cell structure of the XPS foam makes capillary water absorption impossible. But water vapour movement is possible through XPS foam.

EPS and XPS are resistant to moisture; however, XPS is more common for below-grade waterproofing and roof systems where insulation is placed over the roof membrane (IRMA, or inverted roof membrane assembly). The IRMA concept is also utilized for insulating building walls, where polystyrene insulation is placed over a barrier membrane, with the siding or cladding system installed over the insulation layer.

Advantages	Disadvantages
long-term, stable R-value	exposure to sun will deteriorate the product
can be placed below grade	solvent materias cause irreversible damage
can be utilized for inverted assemblies	high temperature will „melt” polytsyrene
do not support mold or mildew growth	polystyrene is flammable, requireing proper placement in any assembly

Table 14

Table 13 shows the advantages and disadvantages of EPS and XPS polystyrol thermal insulations.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m3	W/mK	mm	mm	level
Austrotherm EPS	30-45	0,031	1000x500	60-400	B1
Neopor	16	0,032			B1

Table 15 - **Austrotherm EPS F-PLUS Facade Insulaton Board**

For the calculations, I selected actual products of manufactorors, to inform about the real state to get relevant results.

Austrotherm EPS F-PLUS Facade Insulaton Board is an extreme thermail insulation facade board, made of polystyrene hard foam with protection coating, improved by Austrotherm.

Neopor® expandable polystyrene (EPS) foams are silvery grey in colour due to the integrated graphite within the Neopor® cell structure. The graphite reflects and absorbs radiant heat and significantly improves insulation capacity.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m ³	W/mK	mm	mm	level
Styrofoam IB-A	32	0,035	1250x600	20-100	B1
Austrotherm XPS TOP 30	35	0,035	1250x600	30-200	B1

Table 16 - Styrofoam IB-A

XPS TOP 30 is usable for insulating flat roof with inverse order of layers, for floor with specially big load, for two-layered external walls, and for manzard roofs.

-Inorganic thermal insulations

These materials are mostly silicate based and inorganic materials. They have the advantage of low vapour diffusion resistance, due to their open material structure, they are non-flammable, and they have lower impact to the environment.

-Silicate stringy (mineral wool, glass wool)

The mineral (stone) wool uses 97 % of mineral materials – basalt, gabbro, recycled materials (stone wool briquettes, slag)- during the production process. The main raw material for these products is a renewable and plentiful natural resource. The earth's volcanoes and plate tectonics produce 38,000 times more stone material every year than is used to produce insulations. The remaining 3 % are binders and impregnating oil, a coating product that increases the water resistance.

Water drops hitting the surface of a stone wool slab will usually just flow down the surface without getting deeper into the product structure. This results in the products ability to only absorb very little amounts of water when exposed to water directly. Once removed from wet conditions the stone wool dries out easily and quickly so that virtually no water remains in the product.

Insulation products in general limit heat transfer, so that heat remains on the warmer side of the product with only a limited amount of heat being transferred to the colder side. In general, heat can be transferred via conduction, radiation and convection. In stone wool products conduction and radiation are the most important ones. Heat conduction is taking place when energy is transferred within a stone wool fibre, whereas radiation is occurring inside the air gaps between the stone wool fibres. Stone wool achieves its insulating properties by 'capturing' the air between the fibers,

so that virtually no convection takes place. Because this insulation only contains natural air and no other gases such as blowing agents, the thermal performance does not change due to gases diffusing from the products – not even if longer periods like the total lifetime of a building are considered.

Stone wool insulations can be used under extreme conditions. It retains its insulation properties in both very low (e.g. oxygen installations) and very high (up to 1000°C) temperatures.

Stone wool insulation is a major energy and CO₂ saver. Despite the fact that the stone melting process is energy consuming, the use of stone wool insulation ensures a positive energy balance through its lifetime. A typical 250 mm loft insulation product will save 128 times more primary energy and 162 times more CO₂ and acid rain components than what was used for its production, transport and disposal. Thus the positive energy balance begins at just 5 months after the installation of the product and the ecological balance connected with acid rain and the decrease of CO₂ is restored after 4 months from the moment of installing the insulation.

Over the years investments in recycling facilities have been significant, and today three quarters of the stone wool waste from production is recycled. By introducing the recycling technology, waste levels have been reduced considerably. Compared to 2001 the amount of waste to landfill has decreased by 13%, impressively since 2002 the improvements have actually been 38%. Stone wool residue is also used in other industries, for instance as raw material in bricks.

Numerous leaching analyses confirm that stone wool process waste and used products can be deposited without problems at ordinary landfill sites for mineral waste with low organic content.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m ³	W/mK	mm	mm	level
Rockwool Frontrock	135	0,039	1000x600	20-60	A1

Table 17 - Rockwool Frontrock (RP-PT)

The Frontrock (RP-PT) sheets are usable for insulating external walls as non-flammable, vapour-permeable thermal and acoustic insulation. It can be installed to buildings with any level of fire-resisting without limitations. Placing the sheets is happening using adhesive and dowels.

The glass wool thermal insulation

Glass wool is produced using the high-speed centrifugal rotary process that turns glass materials into fabrics after melting the raw materials for glass at a high temperature. It is a fabric insulation material made from an artificial inorganic mineral molded into a specific shape with a binder. It has excellent thermal insulation, heat resistance, and sound absorption since it is made of inorganic materials. It is smooth as cotton, maximizes the fiber collection volume per meter, and guarantees a semi-permanent service life. It can be easily cut with a knife and manufactured in various sizes.

Unlike organic insulation materials that refine and process petroleum multiple times, KCC's glass wool uses silica (sand) as the main ingredient and does not produce any pollutants, such as Freon gas and volatile organic composites. It is an eco-friendly product that contributes to conserving energy resources and curbing global warming since it consumes less energy than organic insulation materials through its lifecycle.

Fiberglass insulation is widely available in the form of batts or blankets, but newer forms are also available. Batts lined with vinyl can help reflect light or sunlight while increasing the insulating value of this material. Loose-fill fiberglass can be sprayed into inaccessible spaces, similarly to the use of cellulose insulation. Very dense fiberglass blankets are often used to line ductwork to reduce heat loss and minimize condensation.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m ³	W/mK	mm	mm	level
ISOVER FDPL 5	120	0,034	1200x600	20-400	A1

Table 18 - ISOVER FDPL 5

-Foamglass thermal insulation

Foamglass is a cellular glass insulation material that's impervious to moisture, inert, resistant to insects and vermin, strong, and reasonably well-insulating. It can be used for insulating roofs, walls, and below-grade applications, including beneath slabs. The high compressive strength makes it particularly appropriate for roof decks, green roofs, and parking decks.

Foamglass is 100% glass -manufactured primarily from sand, limestone, and soda ash-. These ingredients are melted into molten glass, which is cooled and crushed into a fine powder. The powdered glass is poured into molds and heated (below the melting point) in a "sintering" process that causes the particles to adhere to one another. Next, a small amount of finely ground carbon-black is added and the material is heated in a "cellulation" process. Here, the carbon reacts with oxygen, creating carbon dioxide, which creates the insulating bubbles in the foamglas, and it swells to 10-12 of its original size. CO₂ accounts for more than 99% of the gas in the cellular spaces.

One of the biggest advantage of foam glass is the small environmental impact: there are no blowing agents that deplete ozone or contribute to global warming. There are no flame retardants or other additives needed to improve fire resistance. As a 100% inorganic material, Foamglas is inert and fireproof. And it has enough compressive strength to be used under any concrete slab -an application where extruded polystyrene (XPS) currently dominates the market. It's better than XPS, because, in addition to the absence of those chemicals, foamglas is impervious to moisture (water and vapor), does not support mold growth, blocks radon, and keeps out termites and rodents. Keeps its size and shape, and resistant to fire.

Foamglas is more expensive than the other insulation materials we're used to using. According to datas can be found on manufactorors website, the price is roughly two-and a half times higher than of extruded polystyrene (XPS). That value can come back from replacing other layers in the construction system (vapour retarders, moisture barriers, radon-control components), from greater durability, from environmental attributes, and even from installing a thinner concrete slab: we can reduce the thickness of the concrete slab, because Foamglas is so rigid,

Foamglas is an inorganic, high-compressive-strength insulation with no need for flame retardants or other hazardous chemicals. It is one of the best solution for insulation of the current available options.

Quality	Density	Thermal conductivity	Format	Thickness	Tensile strenght	Flameability
Measurement	kg/m ³	W/mK	mm	mm	kPa	level
FOAMGLAS Wall Board	105	0,041	1200x600	40-180	0,40	A1

Table 19 - FOAMGLAS Wall Board

FOAMGLAS® cellular glass insulation is a lightweight, rigid insulating material composed of millions of completely sealed glass cells, each an insulating space. FOAMGLAS® cellular insulation's all-glass, closed-cell structure provides an efficient physical properties, it is impermeable to moisture in any form, cannot burn and it is non-combustible. FOAMGLAS products are safe in the event of flooding as well, as they are vapor-proof and do not absorb water, either in liquid form or through interior condensation.

-Perlite products

Hydrophobic expanded perlite is a naturally occurring siliceous volcanic rock that is moulded into pipe and block forms. Perlite 650 is a high temperature insulation which displays exceptional corrosion inhibiting properties. A negative charge is present within the sodium silicate binder which draws the positive charge from the pipe. This acts as a protection barrier against moisture, oxygen, chlorides and other corrosive elements. The normal density of perlite products is 220 kg/m³.

It is used in insulating refills, or producing perlite concrete. Useful for thermal insulation of reinforced concrete slabs and lofts. During the tenure, it has a moisture-equalizer effect. Its lifetime can be high (due to the mineral origin), and it can be reused as soil improving. On the down side, the transportation could be expensive and highly energy consuming.

Natural organic thermal insulations

The expanded cork thermal insulation

Cork is a natural product made from the outer bark of a species of oak tree that grows in the western Mediterranean region of Europe and North Africa. The bark is harvested after trees reach an age of 30-40 years and it regenerates, allowing harvesting every nine years over the tree's 200-year life.

In Portugal, the world's leading producer of cork, these oak trees are federally protected. Harvesting is done by hand, much as it has for over 2,000 years. While cork oak forests in Portugal are expanding, cork's market share for bottle stoppers is dropping as plastic stoppers and screw-off caps become more common, motivating the company to look for new markets.

Cork has been used for flooring, floor underlayment, and acoustical wall coverings. These materials are made from residual cork that remains after punching cork bottle stoppers from the bark which consumes only 25%–30% of the bark. For cork flooring and these other products, the cork granules are glued together with a binder and then sliced into the finished products.

Expanded cork is one of the most environmentally friendly building materials available. Semi rigid expanded insulation cork board is produced from the natural cork granules created as the by product of the stopper industry. These cork granules are steam-heated which causes the cork to expand activating suberin, a natural binder that is in the cork. No other binders or chemicals are added. After producing these large billets of expanded cork, they are sliced into insulation boards in a wide range of thicknesses.

It is intermediate in its permeability to moisture. From a fire-resistance standpoint, it meets the European Class E designation (the standard met by other rigid insulation materials) without the need for flame retardants that are used in the most common boardstock insulation products. A 40 mm thick piece of the boardstock insulation held over a torch will resist burn-through for an 60–90 minutes, compared to less than 10 seconds for expanded or extruded polystyrene, which meets the same Class E designation.

It is mostly used for insulating internal walls and floors, as well as sedation of rattling noises at slabs. The first Passive House built in Austria (in 1995) used a 350 mm layer (nearly 14 inches) of the material. It is typically used as an exterior insulation layer.

The material is 100% natural, rapidly renewable as defined by the LEED Rating System, durable yet ultimately biodegradable, produced from sustainable forestry operations, and a by product from the cork bottle-stopper industry. Its lifetime is very high, the cork bottle stoppers give proof of that. Despite the transportation issues, it is one the greenest building materials.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m ³	W/mK	mm	mm	level
AMORIM Corktherm 040	110	0,040	1000x500	10-320	B2

Table 20 - AMORIM Corktherm 040

The main applications of expanded corkboards are: exterior walls, double walls, flat and sloping coverings, floating paving slab, partitions, door insulation, prefabricated wooden houses, thermal and acoustic wooden panels, expansion/dilatation joints, and external frontages on view.

Excelsior sheet

The production of excelsior sheets is the process of joining the wooden chips with cement based bind. This way the sheets will be rigid and flexible. Their resistance against vapour-diffusion is very low. One of their main quality lies in the sound-proofing.

They are usually used associated with other thermal insulating materials in sandwich-elements.

Quality	Density	Thermal conductivity	Format	Thickness	Flameability
Measurement	kg/m ³	W/mK	mm	mm	level
Austrotherm EPS	30-45	0,031	1000x500	60-400	B1
Neopor EPS	16	0,032	1000x600	20-400	B1
Styrofoam IB	32	0,035	1250x600	20-100	B1
Austrotherm XPS TOP 30	35	0,035	1250x600	30-200	B1
Rockwool Frontrock	135	0,039	1000x600	20-60	A1
ISOVER FDPL 5	120	0,034	1200x600	20-400	A1
AMORIM Corktherm 040	110	0,040	1000x500	10-320	B2
FOAMGLAS Wall Board	105	0,041	1200x600	40-180	A1

Table 21

The table 20 summarizes the thermal insulations used in the calculations.

Quality	Thermal conductivity	Thickness required/applied	Surface	Price/m ²	Actual price
Measurement	W/mK	cm	m ²	EUR	EUR
Austrotherm EPS	0,031	4/4	127	5,3	673,1
Styrofoam IB	0,035	4/4	127	7,04	894,1
ISOVER FDPL 5	0,034	4/5	127	4,15	527,1
Rockwool Frontrock	0,039	5/5	127	5,6	711,2
AMORIM Corktherm 040	0,040	5/5	127	19,97	2536,2
FOAMGLAS Wall Board	0,041	5/5	127	27	3429

Compliance of spanish regulations (Zone B)

Table 22

The results of the calculations of heat transfer coefficient performed on walls show the need of an average of 5 cm thermal insulation. The numbers are summarized in the *Table 21*.

Unlike in the case of floors and roofs, the prices show that silicate stringy materials are worth it more for installing them on the wall. I explained the advantages of using these kind of thermal insulations in contrast with the foam materials. Therefore I would recommend the stone wool or glass wool insulation for this prefabricated dwelling house. Using the foamglass or the expanded cork is unprofitable in this case, regarding the fact that this is system is relatively small, for that very reason the environmental advantages of using these types of thermal insulation is irrelevant, compared to their very high prices. However in the not too far future, the prices will drop due to the environmental consciousness, and the goal of reducing CO₂ use emission of the building sector. This time has to come very soon, the regulations of European Union is the first step on this road, the impact will follow soon regarding the prices of sustainable building materials.

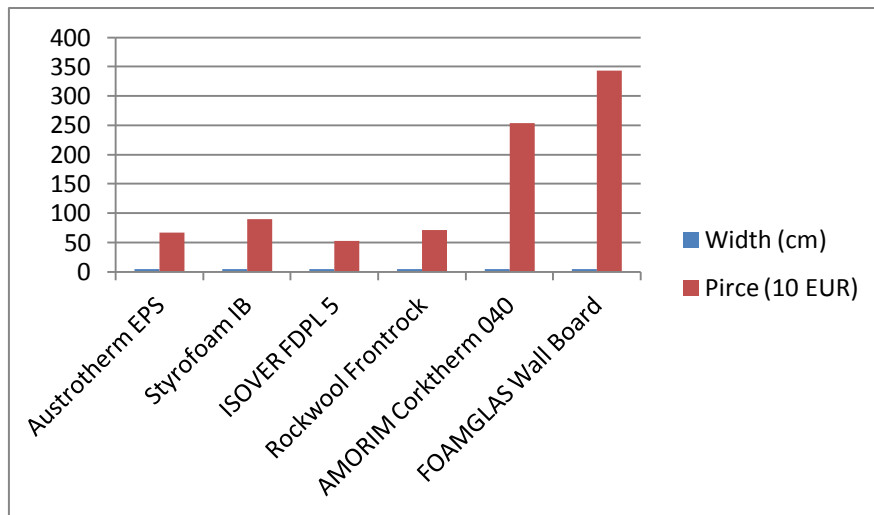


Figure 13

6. Thermal behaviour of flat roof

There are two main types of flat roofs:

- straight flat roof
- inverted roof

They can be seen on the *The figure 13*. The main difference between them is the location of the thermal insulation.

In the case of straight roof, the layers are connected to each other, there is no air movements, and the thermal insulation is always below the moisture insulation. They are also called 'warm roof'. The moisture insulation has a high vapour diffusion resistance, for that reason special arrangements are needed: installing vapour barrier and equalizer layers. The basic rule in building structures is that the vapour diffusion resistance has to be lower from the inside to the outside. In this case, the vapour needs to leave the structure another way, that what the small blow-holes are for. Examining the flat roofs, proper inclination is very important for leading away the moisture. This inclination can be provided by a light concrete below the thermal insulation, or the insulation boards can be used also, for reducing the weight of the structure. Another important factor is the fastening of the layers: all layer must be fixed against the effect of wind.

The inverted roof is the opposite of the straight roof regarding the position of thermal and moisture insulation. The thermal insulation is above, and it is under the effect of moisture. In that case the insulation can only be extruded polystyrene foam, and only in one layer. Additionally, it cannot be in water for a long time, the water needs to be leaded away effectively.

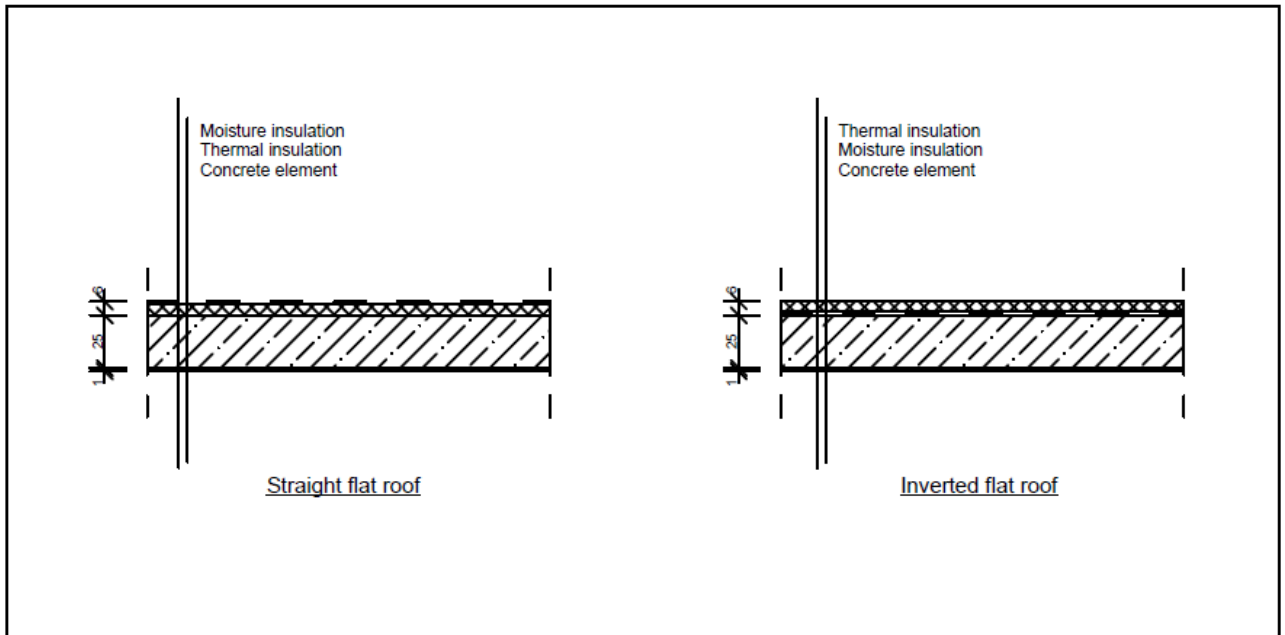


Figure 14

Quality	Thermal conductivity	Thickness required/applied	Surface	Price/m ²	Actual price
Measurement	W/mK	cm	m ²	EUR	EUR
Austrotherm EPS W20	0,031	5/5	59,5	7,89	469,5
Styrofoam XPS	0,028	4/5	59,5	8,80	523,6
ISOVER S	0,039	6/6	59,5	11,98	712,8
Rockwool Hardrock	0,039	6/6	59,5	11,57	688,4
FOAMGLAS Floor Board	0,038	6/6	59,5	18,32	1090,0
ECO Torch PIR foam	0,026	4/4	59,5	6,67	396,8

Compliance of spanish regulations (Zone B)

Table 23

The results of the heat transfer coefficient show the need of an average of 5 cm thermal insulation. The numbers are summarized in the Table 23. It is slightly wider than the insulation of external walls. The main question regarding the flat roof is to decide the way of collecting and leading away the water, and to choose between the straight and inverted type.

Regarding the prices, there is only one salient value: the FOAMGLAS foam. The main advantage of foamglass is the high compressive strength, which is only necessary on utilized or green flat roofs. Therefore I would not recommend its usage, for a prefabricated dwelling house, where the requirements of carrying capacity are not so important, especially because this is not a utilized roof.

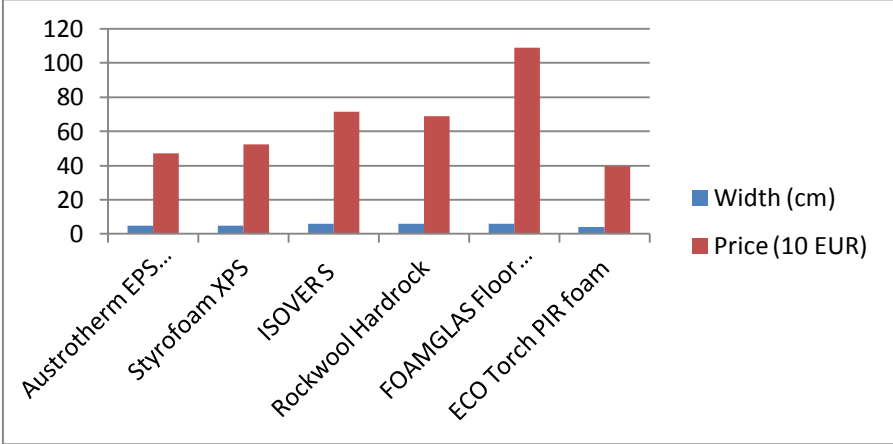


Figure 15

For this prefabricated dwelling house, I would suggest the use of straight order of layers, applied as a 'bevalved ventilated cold roof'. The orders of layers is showed on the *Figure 15*. The advantage of that structure is that it allows the vapour to exit easily, and detains the overheating of the structure in the summer. It is a very important rearding flat roofs. The insulation layer can be layed directly to the concrete element, which provides a stable underlay. Except the FOAMGLAS, the other types of insulation materials are practicable. The selection could correspond with the insulation material of the external walls. This way less waste is produced, the transportation is easer and less harmful for the environment, not to mention it is easier and more practical to use one technology for a dwelling house, due to its parameters, and the small working team.

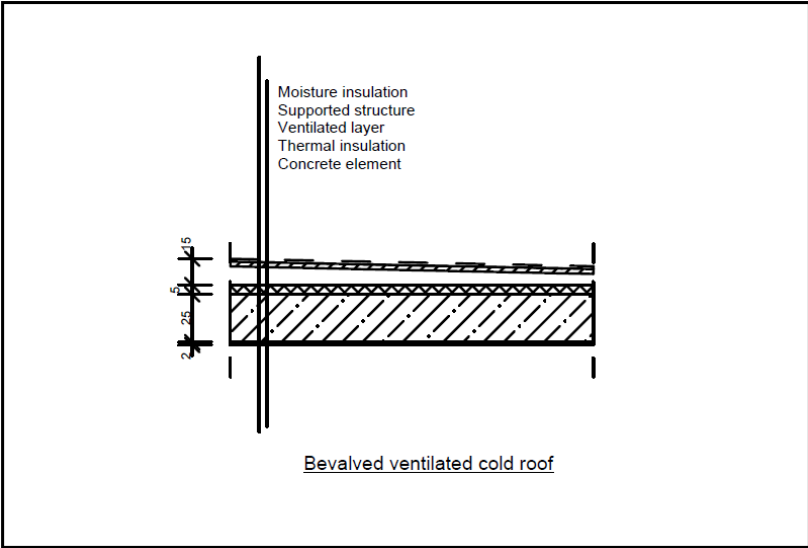


Figure 16

IV. CONCLUSIONS

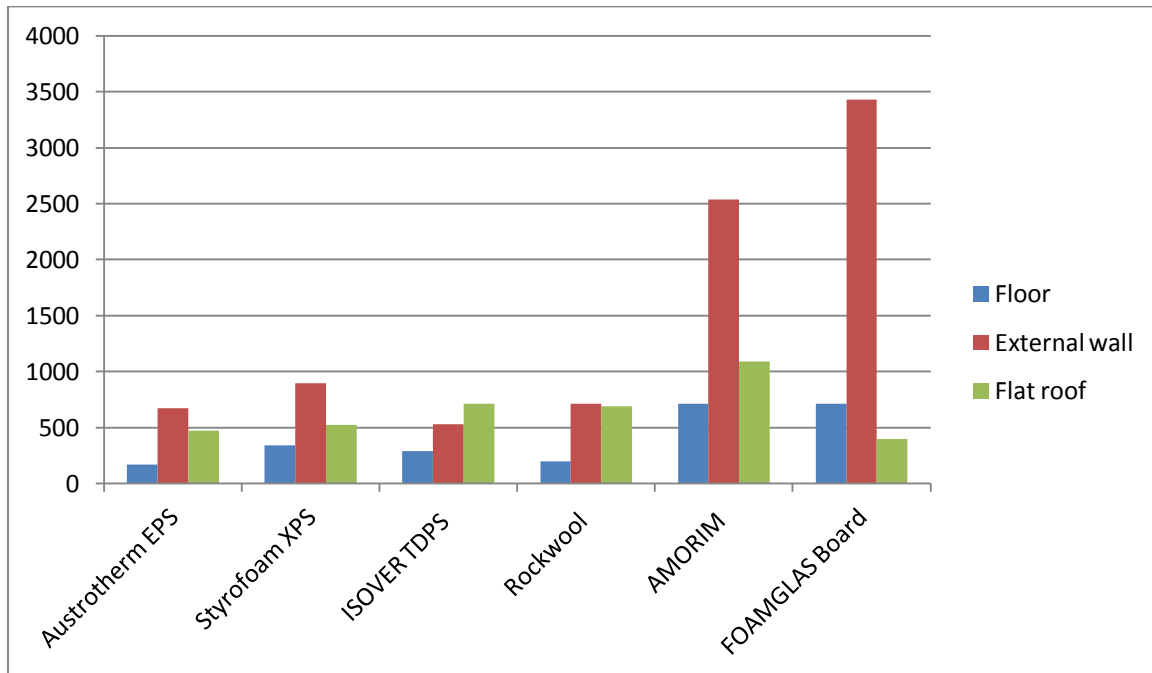


Figure 17

Figure 17 shows a comparison in prices of the thermal insulations for building envelope elements offered by different manufacturers. First the red columns show high contrast. Generally, we can find the biggest difference in the area of wall thermal insulations. The expanded cork and foamglass insulations are not affordable for using on walls due to their very high prices, despite their low environmental impact. The figure also let us see that in price the silicate stringy materials are worth to use over against foam thermal insulations. Regarding their other advantages, I am on the side of using silicate stringy materials for this prefabricated system.

Analysing the blue columns led us to the conclusion of using expanded cork or foamglass as thermal insulation and noise protection worth consideration, the difference in price is not as high as it is seen in the wall application, but still almost double. On the other hand, the advantages of expanded cork and foamglas are the most valuable using them in the floor system. As expanded cork is easily available in this region, I would suggest the use of the material as insulation, it is the most sustainable solution considering the very low impact to the environment.

Regarding the flat roof, the foam insulations seem the best solution. The expanded cork I would not recommend, the foamglass is practicable for utilized flat roofs. In the bevalved ventilated cold roof, both silicate and foam thermal insulations can be used. The choise can be made knowing the insulation type of the wall, applying the same kind could ease the transportaion and the construction.

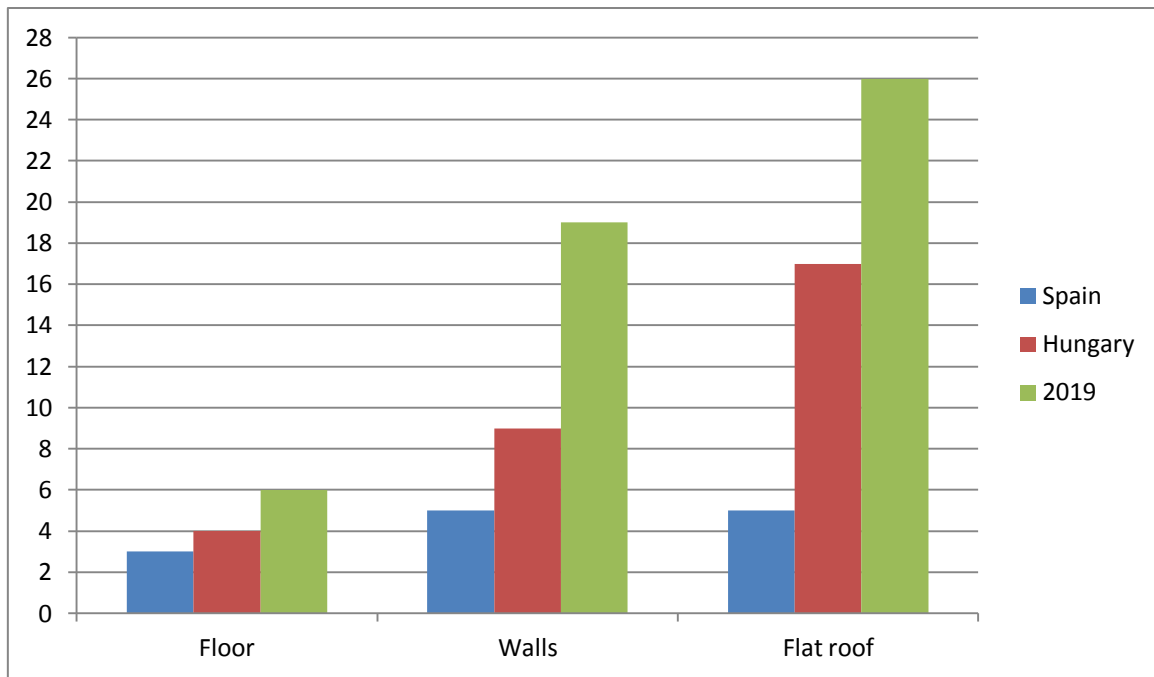


Figure 18

Figure 18 shows the comparison of width of insulation applied on the elements of building envelope following the current regulations of Hungary and Spain, and looking forward the suggested value to 2019.

The blue columns shows the compliance of regulations in Spain. The differences are not major, all thermal insulation is below 6 cm. In the future these numbers will increase, but presumably not as dramatically, as the hungarian widths.

The comparison between the current and predicted values in hungary show a dramatic increase in the width of thermal insulations. The 18 cm for walls and 26 cm for flat roofs are startling, applying these numbers mean that the 'wrap', the thermal insulation of building is almost as wide as the load-bearing structure. This fact should set us thinking about finding other solutions to fulfil the stricter requirements of building envelope, and find other solutions instead of wrapping buildings with more and more insulation. Using that much thermal insulation is only good for manufactorors, but not useful for residents, the users of the building, not mention the design issues. The dramatic increase of the width of thermal insulation eventuate in structural problems, our view of order of layers and connection of elements is changing and causing more problems to solve. Prefabrication could provide a good answer to that issue, due to its flexibility in design and the production process.

The environmental effect of using more and more thermal insulation is without a question, because the production of commonly used, cheaper materials conduct more CO₂ emission, and this is the very thing the new regulations tries to find against. For this reason, new sustainable solutions has to be introduced for the goal of improving the energy efficiency of buildings.

Possible sustainable methodologies for improving the energy efficiency of buildings:

- transparent thermal insulation
- propitious building siting
- optimal design of building envelope elements
- design in zones
- good thermal insulation, sufficient heat holding
- efficient passive solar systems

V. REFERENCES

- European Performance of Building Directive (EPBD): EC 2009/28 Directive
EC 2010/31 Directive
- Hungarian regulations: 7/2006 regulation (V.24) calculation and requirements
176/2008 : Energy Performance Certificate
264/2008: supervision of boilers and ventilation systems
- Drawings of concrete element Marco 3000x2500 Gadea Hermanos
- Catalog of thermal insulation manufacturers:
 - Austrotherm
 - Neopor
 - Styrofoam
 - Amorim
 - Rockwool
 - Isover
 - Foamglas
 - Ecotherm