University of Padua
Faculty of Engineering
Master's degree in Energy Engineering

Dynamic analysis of buildings and thermal analysis of CasaBona System

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ACCADEMIC YEAR 2012-2013

“Per l'animo avventuroso di un uomo

non esiste nulla di più devastante di un futuro certo.”

Christopher Johnson McCandless

RINGRAZIAMENTI

Ed eccoci qui, ormai giunti alla conclusione di questo lungo percorso che, a vederlo adesso, è stato più breve di quel che sembra. Tutte le cose quando finiscono sembrano più brevi di quel che sono. Tutto alla fine sembra più facile. In realtà di fatica ne è stata fatta tanta! E’ da un sacco di tempo che aspetto questo momento..e questo momento purtroppo è già arrivato.

Da ora la vita cambia!

In questa riflessione voglio dirvi che, in tutte le cose fatte, non sono mai stato solo. Ed è giusto dirlo, perché le occasioni per dire grazie, non capitano spesso. Da tutti ho imparato qualcosa, e a tutti qualcosa devo!

Ora, può sembrar banale ricordare subito i genitori, ma questa pagina è soprattutto per loro! Loro che mi hanno supportato/sopportato in tutto questo tempo, che sono sempre stati vicini nei momenti difficili, che mai mi hanno fatto mancare qualcosa..anzi.

Grazie mamma per aver portato papà in Islanda! Vi davo poche speranze per la verità, ma alla fine siete venuti e mi ha fatto un piacere immenso. Settimana indimenticabile che è trascorsa veloce come il vento. E' proprio il caso di dirlo.

Grazie papà per tutti gli insegnamenti e i preziosi consigli che sono sempre arrivati quando necessario; aspetto qualche dritta per Copenhagen prossimamente..

Grazie alla nonna, che non ha mai mancato di prepararmi un pranzo…e che comunque anche in futuro non dovrà mai mancare!

Grazie al mio fratellino, che oltre essere mastro pizzaiolo di casa (cedo ad honorem lo scettro), trova sempre il modo di far ridere con una talentuosa simpatia.

Ma un sentito grazie va anche a tutti coloro che mi sono stati vicini in questi lunghi anni, gli amici tutti Nicola, Thomas, Omar, Dario, Matteo, Alberto, Luca, Daniele e corrispondenti fidanzate, con cui ho condiviso centinaia di serate entusiasmanti e una settimana a dir poco indimenticabile. Mai avrei pensato di commuovermi nel salutarvi tutti prima di partire, ma dopo quella settimana, passata insieme in un'atmosfera unica..era inevitabile! Tanta roba ragazzi semplici!

Grazie a Marco, che sistematicamente mi aspetta ad ogni giro in bicicletta, indipendentemente dalle sue bevute del giorno prima. Grazie a Davide (detto Riz da tutti tranne me), per avermi accompagnato in 13 anni di carriera scolastica in cui ogni giorno avevo qualcosa da imparare; preziosi soprattutto i tuoi consigli pre-esame del tipo: "ah saltemo, sto chi noo domanda mia!", che riducevano discretamente il programma.

Un grande grazie va anche all'Islanda, terra sconosciuta a tanti ma che resta nel cuore ai pochi, che riescono a viverla come l'ho vissuta io. Terra che mi ha dato il tempo di riflettere sulle cose, il tempo di imparare, il tempo di pensare che fare in futuro. Qui rimarrà per sempre una parte di me, ma torno con decisamente molto di più! Ringrazio la porta aperta a Laugafell e i gran polmoni del Vitara, in una notte indimenticabile condivisa con due grandi compagni di viaggio ... Luca e Alessandro; abbiamo condiviso praticamente tutto in questi mesi. Vi ringrazio per tutti i discorsi fatti e le conclusioni non raggiunte, il supporto reciproco e le notti brave fatte nei peggiori locali di Reykjavik.. uno su tutti, l'Austur! Luca, devo darti atto che quella volta che hai detto Islanda..beh, non potevi scegliere di meglio! Un sentito grazie va anche a Dario, con cui, oltre aver condiviso la stanza giusta nel momento giusto, mi ha fatto conoscere uno stile di vita che non m'apparteneva ma che sempre terrò con me!

Grazie a tutti quelli non espressamente citati qui, che hanno in qualche modo contribuito al raggiungimento di questo obiettivo. Una persona da sola non arriva a tanto, non arriva ad essere quello che è senza l'aiuto degli altri!

Voglio finire con un ultimo grazie ad una persona che sempre più diventa speciale. Pur consapevole che sarebbero stati 5 mesi di 'Mi manchi', più di tutti mi ha appoggiato nella scelta più importante. Senza il tuo supporto non avrei fatto tutto questo, poterti riabbracciare oggi conferma che ci sei sempre stata. Grazie Chiara.

ABSTRACT

This work is the result of the MSc Thesis sustained in the Reykjavik University, where I've had the opportunity to collaborate with Prof. Guðni A. Jóhannesson, who followed my research work in the department of Mechanical Engineering.

The Thesis can be divided in 6 chapters, that will be shown as follow:

- Presentation of CasaBona system, patented by Prof. Guðni A. Jóhannesson, and active thermal heat capacity concept, that are the arguments on which the discussion is based.
- Z-profile optimization, carried out with detailed thermal analysis of the load bearing structure of the building, in order to evaluate with accuracy how effectively the thermal conductivity of the element can be reduced through the long narrow slots. Possible future developments have been then evaluated.
- CasaBona system analysis, in order to evaluate all the parameters used to characterize it: thermal conductivity of the layer, linear thermal bridge due to the steel Z-profile, linear thermal bridge due to the U profile at the bottom and the top of the element.
- Design of a real building with CasaBona System, made to show that with a prefabricated building system is possible to create buildings adapted to different needs.
- Global thermal analysis of the entire building varying the active thermal capacity and the insulation level in order to optimize the energy needs and the total cost of the building in various Italian climates.
- Energy classification of these buildings, according to Italian Technical Regulations.

In this treatment it has been described how the thermal mass is able to increase the efficiency of the building and the indoor environment comfort using both CasaBona System and traditional construction methods.

CasaBona System allows the realization of light-weight load bearing structure with an optimal degree of insulation and, at the same time, limited thickness. This

structure is characterized by lower assembly time and can be integrated with other layers, depending on the need to increase the insulation or the thermal mass.

In this discussion, various configurations of buildings in different Italian climates have been analyzed, evaluating the effects of the thermal mass changes and optimizing the best possible configuration for each different location.

To achieve the following results some simulation software have been used:

- AutoCad 2011 (for the 2D and 3D drawings);
- Comsol Multiphysics (for finite element thermal analysis);
- Consolis Energy+ (based on Microsoft Excel for the global analysis of the building).

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CHAPTER 1

INTRODUCTORY REMARKS

Nowadays the energy is playing a fundamental role in the modern world. The total dependency on energy sources makes us vulnerable to any change. Italy, most of all, has a situation of greater instability due to a strong dependence from foreign countries, regarding the energy requirement. Oil and gas are no renewable energy sources and we do not know, with accurate precision, how long these sources are available.

The main objective must be the development of technologies such as to limit as much as possible the dependence on primary energy sources; strong is the weight assumed, in this sense, from the building sector. The environmental impact produced by the current buildings, should force us to reflect on the future of the construction industry and land planning, in order to direct us toward the energy efficiency.

The energy efficiency of a building represents the capability to use the energy supplied to it, in order to meet the needs required. The lower is the energy demand, higher will be the energy efficiency.

The Energy needs in civil are usually due to an high degree of inefficiency on the houses, regarding the primary energy supply; this is principally due to the energy demand for heating and for the domestic hot water production.

Maintaining an high level of comfort, the heat energy supply can be drastically reduced. This is possible by a well insulated envelope, which prevents the heat leakage, and innovative heating system as solar thermal or heat pumps.

The current situation of the building in Italy is one of the worst in Europe, due to the way in which they have been built in the past. The average heat energy requirement of the Italian buildings is estimated in 300 kWh/m^2a, of which the most of them are lost in heat leakage of the building envelope.

In Sweden, the standard for the thermal insulation of buildings does not allow heat leakage above 60 kWh/m^{2}a while in Italy is possible to even reach peak of 500 kWh/m^{2}a. Of the total amount of the primary energy demand, just 2% is for illumination, 5% for household appliances, 15% for domestic hot water while the 78% is for heating. Furthermore, when the building has a cooling system for the summer season, it must be added 25% more energy use.

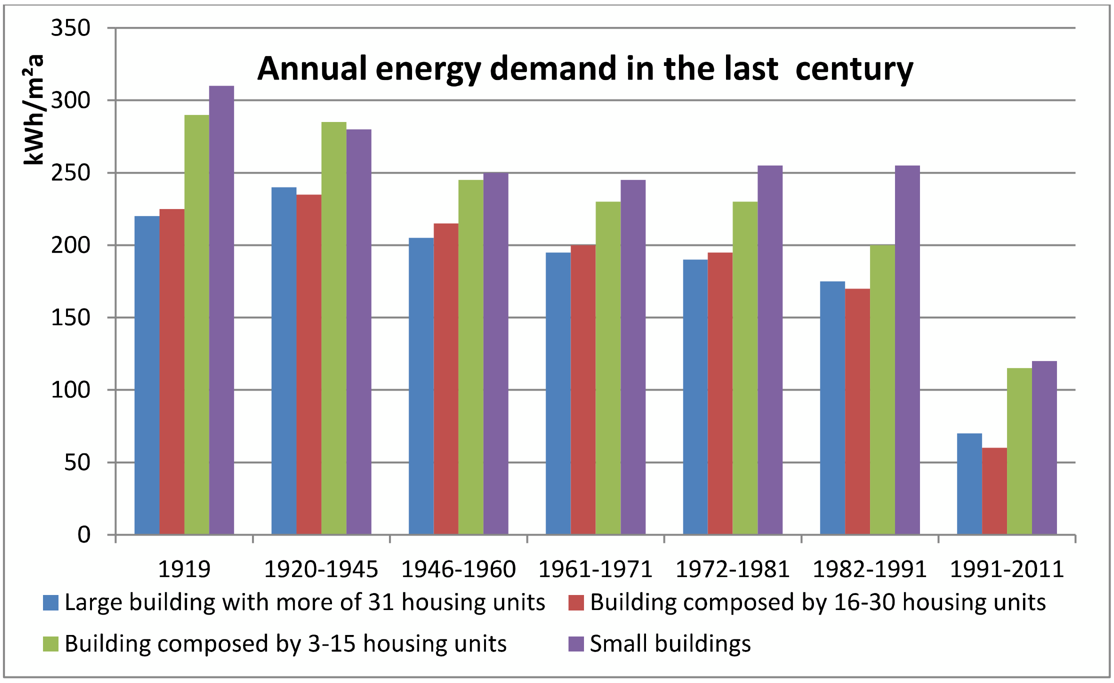


Figure 1.1. Energy demand of various sizes of building depending on th Source: sciencedirect.com

Only recently with the latest regulations, it has been started to raise public awareness on these issues, and the first high efficiency houses begin to be present.

The Italian climate is characterized of very variable condition regarding the buildings. In the Po valley, which house to about 3/5 of the Italian population, the climate is particularly cold in the winter and very hot in the summer where can be reach temperature higher than 40°C.

For these reasons, added to the high dependence on energy from foreign countries, Italy should be an ideal place to develop efficient structures, designed to effectively maintain the comfort conditions of the indoor environment, in every situation (cool in summer and warm in winter).

The traditional construction methods begin to show some gaps in terms of sustainability, understood as the environmental and economic impact, both in the construction period, during operation and in the demolition. It is therefore important to think a new building concept both in the design, construction and sustainability. Energy savings in buildings represents a great opportunity for the entire construction industry, inasmuch, offering an efficient product means to give new impulses in the housing market. Just to take an example, now, in the purchase of a new car, consumptions play a fundamental role in the consumer choice. The same is becoming, and must become, in the housing market.

Another problem of the current constructions are the special wastes generated both in the construction phase and in the demolition phase, which only after an adequate treatment they can be used as raw materials. This involves significant demolition costs which could be reduced through the use of materials that are easily separable and independent, in order to be recycled at the end of the building life.

1.1 THE CASABONA SYSTEM

An innovative building construction methods called CasaBona, able to meet all the requirements treated above, has been studied and patented by Prof. Guðni A. Jóhannesson; CasaBona System allows to realize high efficiency and low cost walls with a very fast build-up of the construction. This construction system consists of light gauge sheet metal Z-profiles integrated with precut rigid insulation block of EPS or high density mineral wool. The shape of the profile and the rigid blocks of insulate material offer a quick and easy construction assembly. The main benefits of this system are the cost efficiency, the reduced risk for moisture damages compared to wooden structures and the flexibility to adjust the performance specifications of fire, acoustics and architecture.

The Z-profile represents the nodal point of the structure. The thermal conductivity of the steel is much greater than the EPS, therefore, the web profile represents a thermal bridge for the structure. This affects the transmittance of the wall besides to be an area with high risk of surface condensation and mold growth. For this reason the central part of the Z-profile is preforated with long narrow slots in order to reduce the thermal bridge.

The particular shape of the Z-profile, together with the pre-cut EPS block allow a very fast realization of the wall (4 minutes/m^2). The components can be pre-cut in factory with high accuracy and delivered ready to built-up with the minimum waste. The materials cost, without consider any other layers, can be lower as 25 €/m^2.

The rigid blocks of EPS guarantee the insulation and support the steel Z-profile ensuring the load-bearing function up to 3 levels. A moisture proof construction is obtained though the use of water-resistant materials such as the EPS (expanded polystyrene).

COMPONENTS AND ASSEMBLY OF THE ELEMENT

The system is highly flexible and allows every configuration with other materials, in order to adapt the wall to any constructive solution. Furthermore, the polystyrene can easily be replaced with high density mineral wool to increase the fire resistance and sound insulation characteristics.

As said above the main components of this system are:

- Galvanized steel Z-profile with the perforated web to limit the thermal bridge;
- Pre-cut blocks in high density expanded polystyrene (30 kg/m^3) or other insulate materials.

The CasaBona System is usually finished at the bottom and at the top with a steel U profile to give more rigidity.

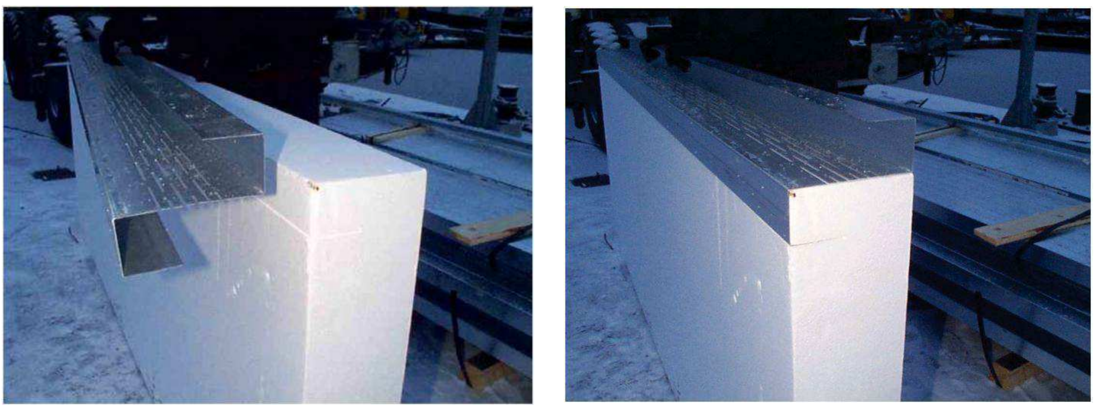


Figure 1.2. Detail of Z-profile and EPS block.

The Z-profiles is usually 35x60x200x60x35 mm with thickness 1,5 or 1,2 mm but can also be used for thinner walls with dimensions 60x60x150x60x60 mm.
The external width of the Z-profile is like the internal width of the U-Profile, in order to fit each other the components and to fasten all together by self drilling screws.
The production of the steel profile starts from a continuous steel sheet which is pre-cut and profiled, than can be either cold-rolled or bent to the final shape. The maximum sheet width is 390 mm and for this reason, the Z-profile element of 200 mm width has only 35 mm as backward flanges.
The U-profile, which completes the wall at the bottom and at the top, is also fitted with the holes in the central part, to reduce the thermal bridge. 60x200x60 mm or 60x150x60 mm, 1 mm thickness are normally used. To improve the air tightness and moisture protection, 10 mm of neoprene layer can be used on the exterior side of the U-profiles. The figure 1.3 show the U-profile detail.

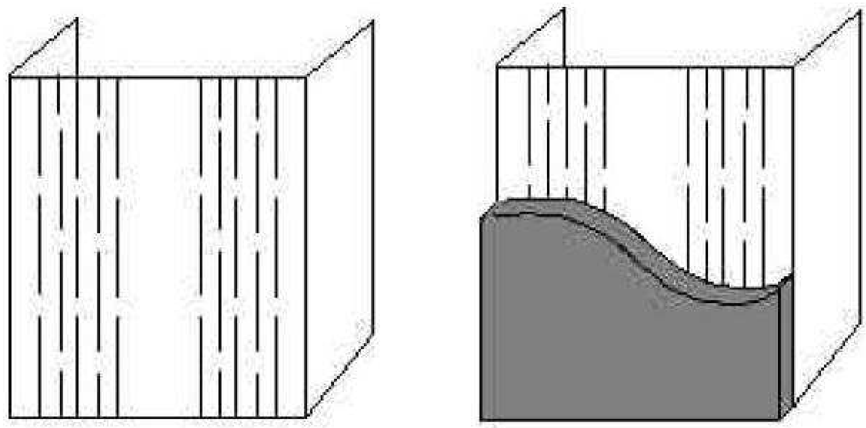


Figure 1.3. C-profiles without and with neoprene layer.

The EPS block completes the wall. This material, relatively cheaper, allows to be cut with high precision and can be delivered to building site ready for installation. High density EPS is used to increase the rigidity of the CasaBona System (30 kg/m^3).
The dimensions of an EPS block are defined by the nominal thickness of the polystyrene block. For 900 mm modules, the exactly length should be 898,5 mm with 1,5 mm of Z-profile. In this mode, a 900 mm block is realized. The EPS block can be 150 or 200 mm thick and has two deep groves (35 or 60 according to the wall thickness) in order to fasten the backward flanges. Normally these grooves are

asymmetrical with one groove for each side but could be convenient to change the orientation of the profile, for example in correspondence to the windows.

The common block has 900 mm length (including the Z-profile) but it can be realized elements with 1200 mm and 600 mm. In this way it is possible to obtain more architectonical configurations, flexibility, and to allow right space for the windows. The figure 1.4 shows the common EPS block size.

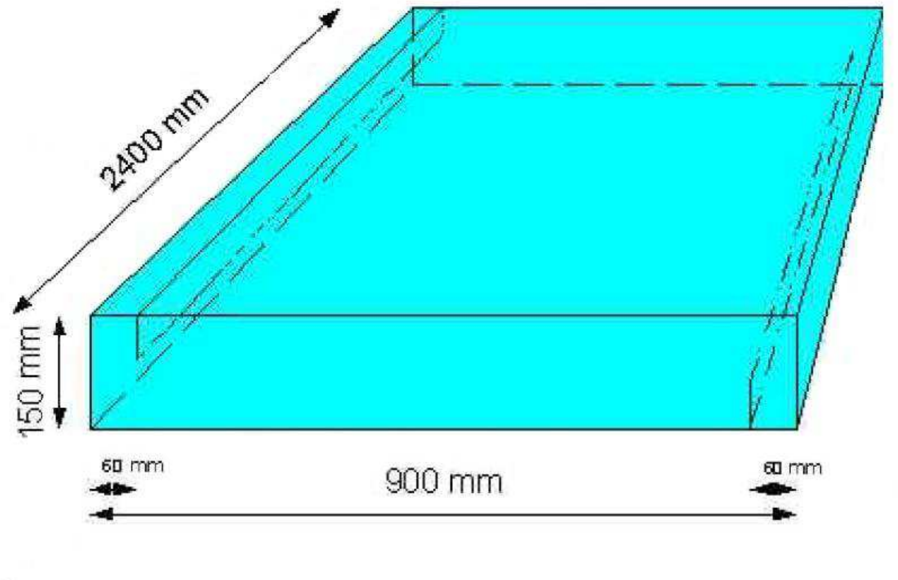


Figure 1.4. Standard dimensions EPS block

The Z-profile is attached to the EPS block simply pressing the backward flange into the corresponding groove (Figure 1.5). In this way the whole wall can be mounted very quickly.

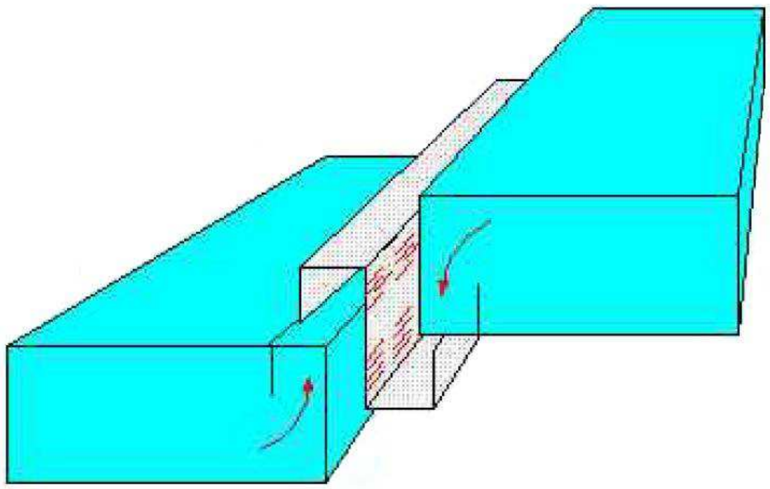


Figure 1.5. Mounting of the system.

The walls can be prefabricated or built in the building site. If they arrive prefabricated in situ, they can be mounted horizontally on a flat surface in order to cover very quickly the entire side of the building.

When the wall is realized in situ (typical realized method for houses), the blocks are usually mounted directly in the vertical position following this easy procedure:

- The U-profile is fastened in the substrate by self drilling screws;
- The EPS block, already joined with the Z-profile, is inserted into the U-profile and fastened to it;
- The next modules (EPS + Z-profile) are added from the top so that the free flange, already fastened, can enter into the groove of the new block,
- The wall is completed with the top U-profile.

It is important to bear the elements already fastened in vertically position, when the additional elements are fixed. An example of the mounting of the wall is shown in the following sequence of figures:

Figure 1.6. Installation of the U-Profile.

Figure 1.7. Fixing of the wall.

Figure 1.8. Installation of the wall.

Once made the load bearing structure of the wall (CasaBona Layer) extra layers with other materials can be added, in order to complete the wall. It is possible to add a mineral wool layer in the inner side, increasing the thermal performance, fire and sound insulation; add layers which increase the thermal mass as concrete or brick, plaster in both sides to finish etc.

DOORS AND WINDOWS

Doors and windows can be carried out both traditionally and using special windows and doors which can be fitted into the single module. The second solution may be economical for larger production volumes.

With the standard module of 900 mm it is possible to install window frames with 750 mm wide. However, other windows size can be installed, but the smallest module is 300 mm, so the nominal horizontal frame widths must be 450, 750, 1050, 1350, 1650 mm. Vertically the only limitation is that enough height should be left above the window for transferring the structural loads.

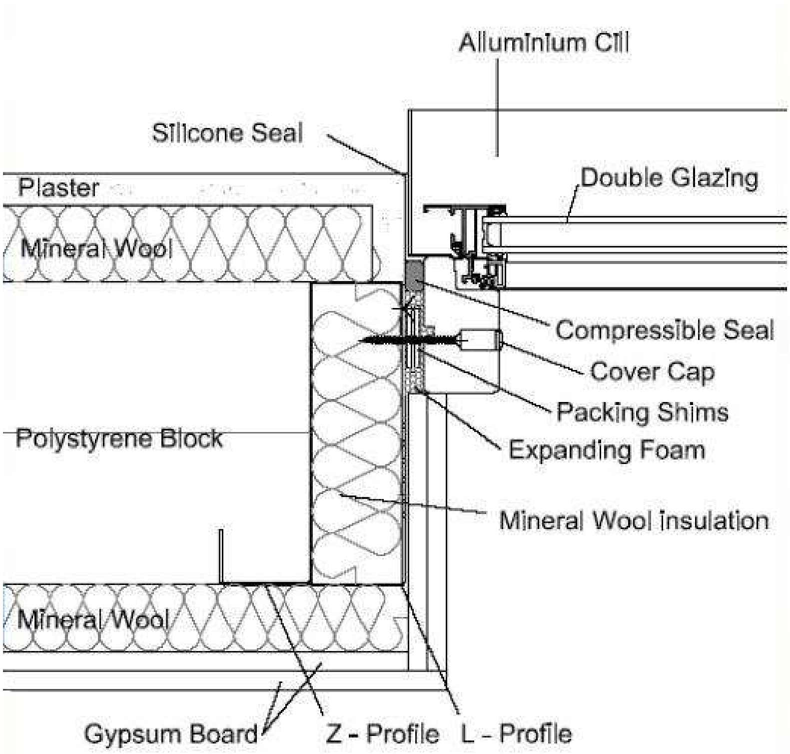


Figure 1.9. Detail of the horizontal section of the window

There is the possibility to insert a standard window of 800 mm in the module of 900 mm, which would allow to have traditional windows without an excessive cost, because the module could be delivered prefabricated. To do that the Z-profile should be realized of 40x50x200x50x40 mm; in this way in the standard module of 900 mm can house the whole window.

ROOF AND INSOLE

Horizontal elements for roofs or insoles can be built with CasaBona System in the same way as walls; this allows to have a whole building made on a light structure.
The roof can be both horizontal and sloped.
A horizontal roof and the insole as well, can be built with spans up 5 meters in the same way as walls while a primary load bearing frame can be used for larger spans.
The load bearing capacity of the structure can be adjusted choosing the Z-profile thickness and the step between two profiles. For larger spans or higher loads, another solution could be the use of the Z-profiles without the long narrow slots, an extra insulation layer can balance the growth of the thermal bridge.
The acoustical and fire characteristics can be increased by adding further layers of mineral wool to protect the steel beam. Any type of cover can then be placed over the CasaBona layer (roof tiles, tin roof, corrugated sheet metal roofs etc.) according to the local traditions.
In the case of sloping roofs can be conveniently attached to the outer wall by a wooden structure which creates the desired angle (figure 1.10). The eaves can be installed both traditionally with large overhangs and without.

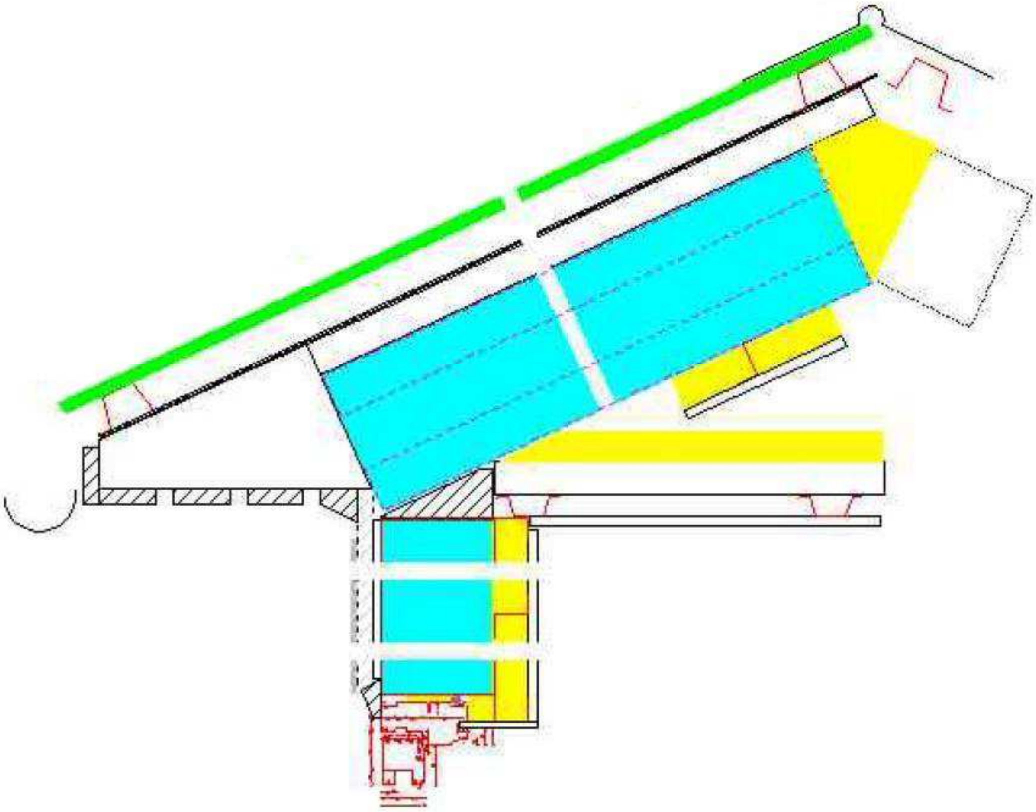


Figure 1.10. Connection details of the roof

In the integrated structure, the high performance insulation is already guaranteed by the load bearing structure for walls and roof in an economical way. In countries with warm climates where the heat energy demand is limited, as may be the southern Italy, this construction system still allows an improvement of the inner condition, and it could be further optimized simply adding thermal mass inside.
For further information regarding CasaBona System see [1].

1.2 ACTIVE HEAT CAPACITY

After these consideration, the thermal mass concept has to be added. The Italian buildings, until the postwar period, have been characterized by high thickness walls, which are built with high weight materials (concrete and rocks). This allows to reduce the influence of the hot hours of the day, maintaining stable the temperatures during the summer season. After the 60, with the advent of the housing boom, low cost dwellings have been built with high heat losses, even due to the low cost of energy. Although the technological advances, nowadays we are in front of a building stock among the worst of Europe as regards the energy requirement for heating.

The role of the thermal mass in the building is fundamental to limit the effect which the outside temperature peaks have in the indoor environment. The recent technologies are directing towards wooden prefabricated building, which can be achieved high insulation performances with lower walls thickness, but low thermal mass. These buildings allow, with a greater built-up cost than the traditional construction types, to reduce the management cost. However the lower thermal mass together with the high insulation can cause very high interior temperatures during the summer season if no cooling system are used.

The thermal mass into the building can be achieved using materials with high density and high specific heat capacity; that are materials which can absorb large amounts of heat energy when the ambient temperature increases and releasing it when the temperature goes down. Generally these materials have poor thermal insulation characteristics and to realize high efficiency buildings, they must be supplemented by a exterior insulation and finite system. The right collaboration between the thermal mass and the insulation can dampen the air temperature fluctuations which take place during the day, in this way they are transmitted to the indoor environment attenuated and delayed.

The mass placed in thermal contact with the indoor air, can have important positive effects both during the summer and winter season. Above all, in the summer, the thermal mass can limit the maximum temperature of the external wall side adsorbing the heat energy, which will be released during the night. Furthermore, using a night ventilation system it is possible to increase the benefits of the thermal mass during the summer season.

To study in detail the thermal mass behavior it is necessary to understand the response of a material subjected to a variable temperature input.

The thermal heat exchange between two surfaces of the wall is a time-depend process and governed by the differential equation:

$$\Delta\phi + \frac{\phi}{\lambda} = \frac{1}{a} * \frac{\partial\vartheta}{\partial t} \tag{1.1}$$

In which the thermal diffusivity is given by:

$$a = \frac{\lambda}{\rho c} \left[\frac{m^2}{s}\right] \tag{1.2}$$

The thermal analysis in dynamic regime is necessary to calculate the temperature and the thermal flux in the indoor side of the wall with a variable temperature and thermal flux in the outer side.

The behavior of a uniform wall with thickness l, thermal conductivity λ, specific heat capacity c and density ρ has been studied by Carslaw and Jaeger (1959) [2], from which the relationship between temperature and heat flow at the surfaces has been obtained as follow:

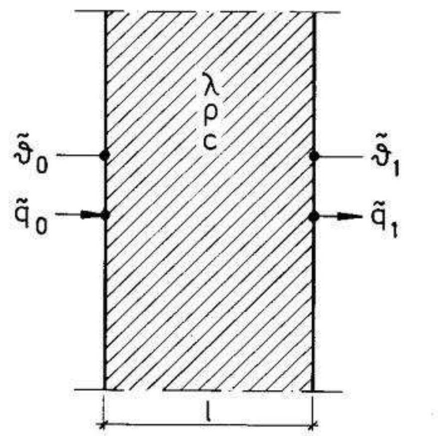


Figure 1.11. Finite layer with boundary values.

$$\begin{bmatrix} \vartheta_1 \\ q_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \vartheta_0 \\ q_0 \end{bmatrix} \tag{1.3}$$

where A, B, C, D are complex number:

$$A = \cosh\big(k \, l \, (1+i)\big) \tag{1.4}$$

$$B = -\frac{\sinh \, (k \, l(1+i))}{\lambda \, k \, (1+i)} \tag{1.5}$$

$$C = -\lambda \, k \, (1+i) \sinh\big(kl(1+i)\big) \tag{1.6}$$

$$D = \cosh\big(k \, l \, (1+i)\big) \tag{1.7}$$

with:

$$k = \sqrt{\frac{\omega}{2a}} \tag{1.8}$$

ω usually corresponds to a 24 h period and a is the thermal diffusivity, already defined above.

The equation (1.3) can be resolved for two unknown parameters; for example, knowing the evolution of the surface temperature for each side, it is possible to calculate the thermal flows at the surfaces.

For a multi-layer wall, known the characteristics for each single layer, the product of matrices must be used as follow:

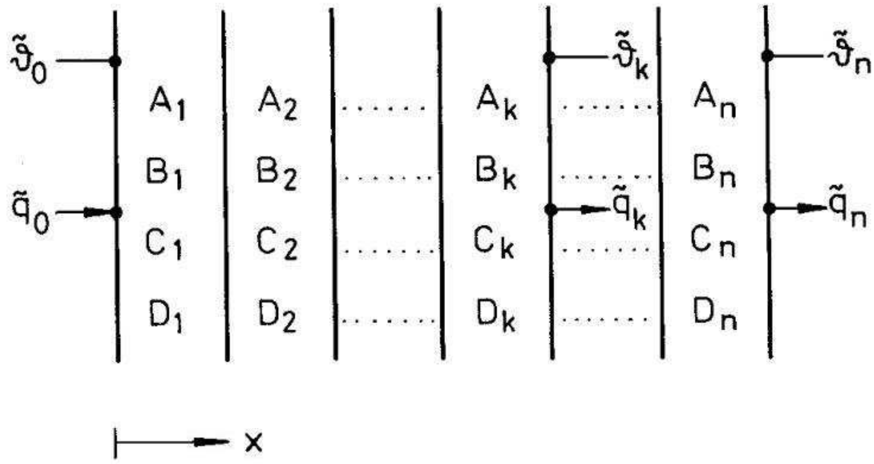


Figure 1.12. Multi-layer construction with homogeneous sublayers

$$\begin{bmatrix}\vartheta_n \\ q_n\end{bmatrix} = \begin{bmatrix}A_n & B_n \\ C_n & D_n\end{bmatrix}\begin{bmatrix}A_{n-1} & B_{n-1} \\ C_{n-1} & D_{n-1}\end{bmatrix}\cdots\begin{bmatrix}A_1 & B_1 \\ C_1 & D_1\end{bmatrix}\begin{bmatrix}\vartheta_0 \\ q_0\end{bmatrix} = \begin{bmatrix}AA & BB \\ CC & DD\end{bmatrix}\begin{bmatrix}\vartheta_0 \\ q_0\end{bmatrix} \quad (1.9)$$

As discussed by Jóhannesson (1981), to the heat capacity of the building, must be associated the active heat capacity [3].

The active heat capacity is a specific propriety of the wall surfaces which can be described as a specific heat storage concentrated at the surface; it assumes different values between the two surfaces of the same wall depending on the layers disposition.

This allows to correctly consider the effect of damping and heat storage of the various layers according as the position of the thermal mass and the insulation, which generally are different layers.

From the matrix (1.9) it is possible to define the active heat capacity C_A relative to two surfaces as follow:

$$E = \left(\frac{BB}{DD}\right) \quad ; \quad F = \left(CC + \frac{-DD\ AA}{BB}\right) \quad => \quad C_{A,inside} = \left(\frac{E+F}{\omega}\right) \quad (1.10)$$

$$G = BB \quad ; \quad H = \left(\frac{-AA}{BB}\right) \quad => \quad C_{A,outside} = \left(\frac{G+H}{\omega}\right) \quad (1.11)$$

This procedure is computable on a spreadsheet and has been implemented by Guðni A. Jóhannesson (2007) in the dynamic simulation software called Consolis Energy +, which will be used in this study.

The idea to obtain high efficiency buildings is to build well insulated wall from outside increasing the active heat capacity by the use of materials with high thermal mass from inside. This allows to reduce the annual energy requirement of the buildings, improving the winter energy cost as well as the cooling energy demand.

1.3 CONSOLIS ENERGY+

This software has been developed by Prof. Guðni A. Jóhannesson at the Royal Institute of Technology KTH of Stockholm (2007) and allows to calculate the heat energy demand for heating and cooling of the buildings.

The program is based on the European standard EN ISO 13790:2004 for the calculation of monthly energy demand, considering the ground leakages, thermal bridges and the utilization factor. The latter is updated through the time constant to consider the contribution of the solar radiation and internal loads [4]. These results are compared with the dynamic regime calculation, where some significant and reliable information on the heat energy requirement on cooling and heating are obtained from the dynamic proprieties of the building.

Various European climates are available in the software, other climates can easily added as for the Italian climates (Aosta, Milan, Padua, Rome, Palermo) has been done, in order to represent the most usual characteristics of the Italian territory.

To add a new climate are simply necessary the average monthly temperature, the number of cloudy days, partial cloudy days and sunny cloudy day for each month of the year, in addition the latitude of the place. The program calculates automatically all other necessary data.

Furthermore the software calculate the time evolution of the temperature for each month and for each type of day (cloudy, partially cloudy or sunny).

The figure 1.15 shows how the software considers the various energy flux which interact with the building.

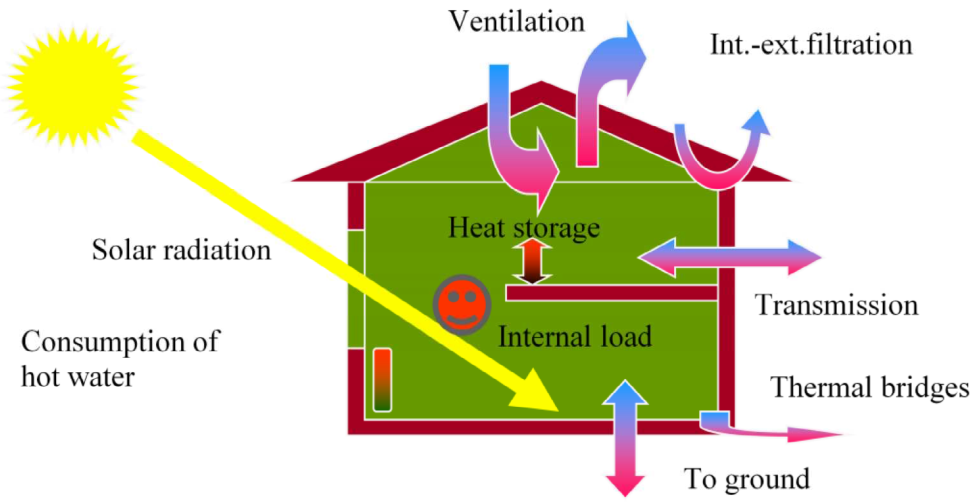


Figure 1.13. Heat Exchanges considered by Consolis Energy +.

Consolis Energy + divides the building in two zones which can exchange energy each other or can be studied as two different buildings simply eliminating any exchange of energy. So, simulations can be done both analyzing a double zone buildings, with different internal temperatures, internal loads etc. (for example the living areas and stairwell); and analyzing dwellings built with different configurations, comparing each other at the same time.

The figure below shows the representation of the two zones model in Consolis Energy + :

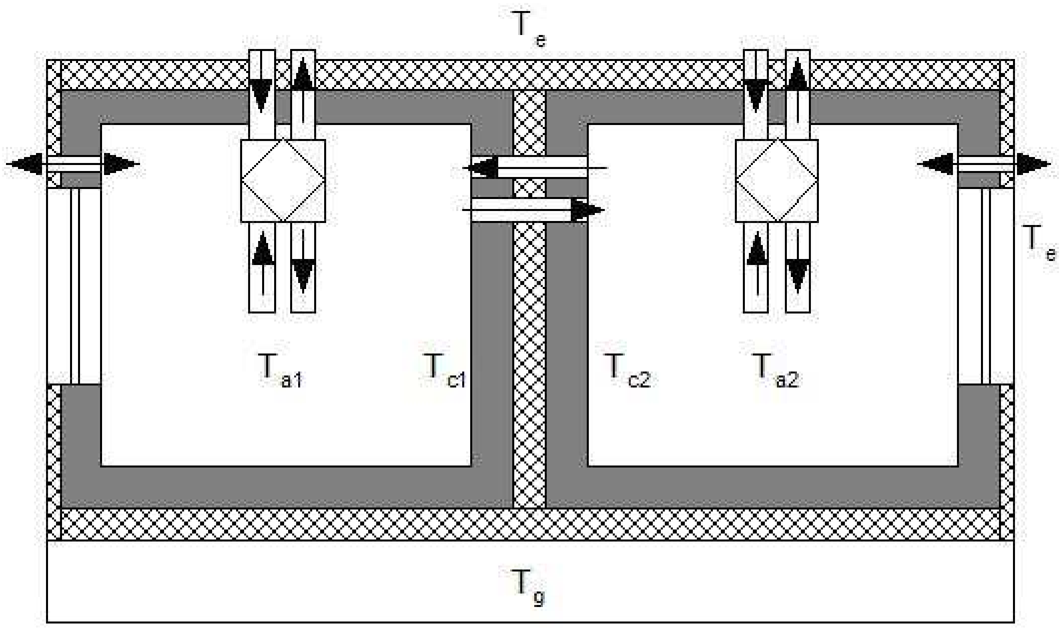


Figure 1.14. A two zones model

The necessary inputs to the program have to put in various sheets.

In the Input data sheet: minimum and maximum inside temperatures, internal loads, ventilation, air leakage at 50 Pa, heat floor surfaces, domestic hot water energy need;

The building envelope description is done in Construction data sheet: external walls, ground floors, size and orientation of the windows, roofs, internal constructions and thermal bridges;

The thermal propriety of the wall element can be calculated by Ceff sheet which give as output the U-value and the active heat capacity for both sides of the wall. There is a database with the most common materials used in building construction, with even the possibility to adding other.

For further information regarding Consolis Energy + see [4].

CHAPTER 2

Z-PROFILE OPTIMIZATION

In this chapter the Z-profile optimization of CasaBona System will be treated in order to find new solutions, with less thermal conductivity, for the web.
The main problem of this structure, highly versatile and of fast construction, is the linear thermal bridge generated by the Z-profile.
The Z-profile is suitably built with long narrow slots in the middle of the web, in order to reduce the heat flux.
After the analysis of the standard geometry, other narrow slots configuration will be verified, so as to check possible improvements to the geometry of the web profile.
The various parameters that compose the central sheet configuration will be varied in turn.

2.1 STANDARD PROFILE

The standard web profile consists of 10 rows of piecewise holes with the characteristics described in the table 2.1. As mentioned above, the target of these holes are to reduce, as much as possible, the conductivity of the steel element (which itself has a thermal conductivity λ = 36 W/mK).

Table 2.1. Standard dimensions of the web profile.

Steel thickness	Rows number	Rows distance	Hole width	Hole lenght	Holes distance
S	RD	RD	HW	HL	HD
1,5	10	7	5	80	20

The figure 2.1 shows the geometry of the web profile.

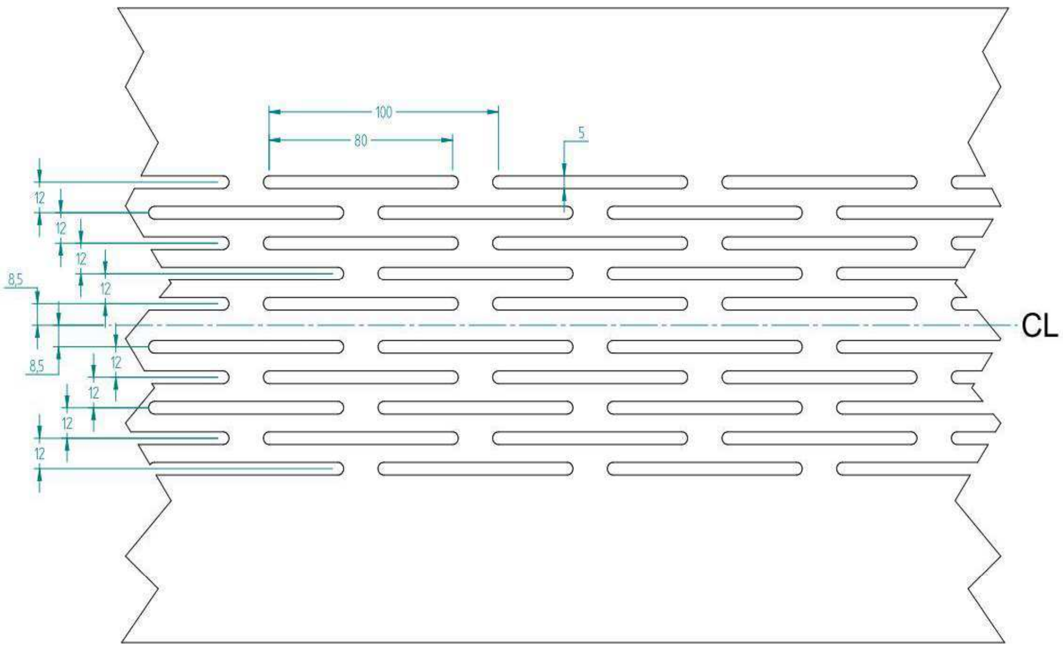


Figure 2.1. Geometry of the web profile.

Many different configurations, each with a different value of thermal conductivity, could be obtained varying these parameters. Obviously, with more holes the thermal resistance will be greater. The middle of the web profile is not subjected to particular structural load constraints, the structural task is carried out by the outer sides of the profile. Therefore it's fairly free to make these holes in the middle of the web without strict load bearing constraints.

It is reached proceed as follows: as first step the pattern of the single hole will be analyzed with a finite element simulation. As shown in the figure below, the hole is patterned as well as a rectangle, which is surrounded on two sides directly with the steel of the Z-profile, while in the other two sides it's surrounded with the insulating (EPS).

The hole contains air, and it is important to understand the thermal exchange inside it. For the solid material we already have the thermal conductivity while in the hole, in addition to the conduction, there is a radiation effect that mainly acts on the steel surfaces.

The convection is negligible because the hole has very small size.

With a double simulation with Comsol Multiphysics 3.5 it's possible to trot out the radiation effect in the air, obtaining an equivalent λ_{rad}.

In the following simulations, the radiation effect will be replaced with λ_{rad} , in addition with the thermal conductivity of the air:

$$\lambda_{hole} = \lambda_{air} + \lambda_{rad} \quad (2.1)$$

Obviously λ_{rad} is function of the emissivity of the surfaces and of the hole geometry. The figure below shows the simulation of the standard hole; other similar simulation will be done with different dimension for the follows profiles.

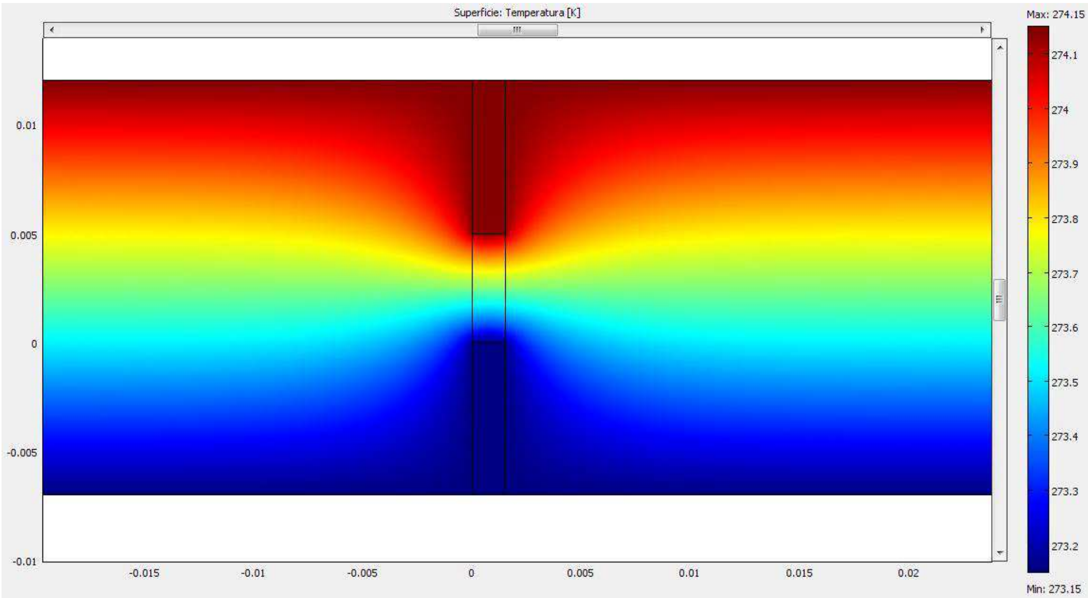


Figure 2.2. Temperature distribution in the hole.

It's easy to see as in the hole there is a concentration of flux lines, which means that here there is an intensification of the heat exchange. This can also be deduced from the steel is an excellent heat conductor compared to the EPS.

For the standard element the effect of radiation is $\lambda_{rad} = 0{,}00966\ {}^{W}\!/_{mK}$. This value will change if the hole geometry becomes different, in fact the thermal radiant exchange depends of a form factor, that is function of the distance between the surfaces according to the equation 2.2.

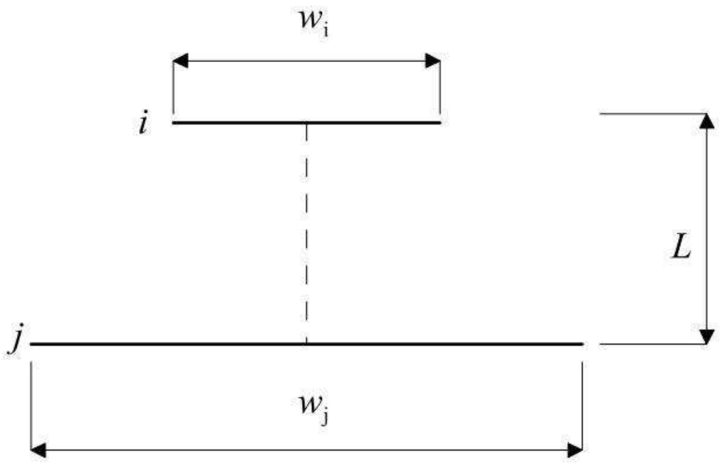


Figure 2.3. Geometry model to define the form factor.

$$F_{ij} = \frac{\left[\left(W_i + W_j\right)^2 + 4\right]^{0.5} - \left[\left(W_i - W_j\right)^2 + 4\right]^{0.5}}{2W_i} \tag{2.2}$$

Now it is possible to proceed with the simulation of the standard web profile, in order to calculate the global thermal conductivity.

So, making use of Comsol Multiphysics 3.5, a two-dimensional simulation of the standard web profile has been realized. The λ_{hole} value has been assigned as global thermal conductivity of the holes, that in this simulation are seen from the y-z plane.

With the simulation shown in Figure 2.4, the thermal conductivity of the standard web has been achieved and worth $\lambda_{web} = 2{,}50\ {}^{W}/_{mK}$.

It is possible to see that a strongly reduced of the steel thermal conductivity ($36\ {}^{W}/_{mK}$) is due to the long narrow slots.

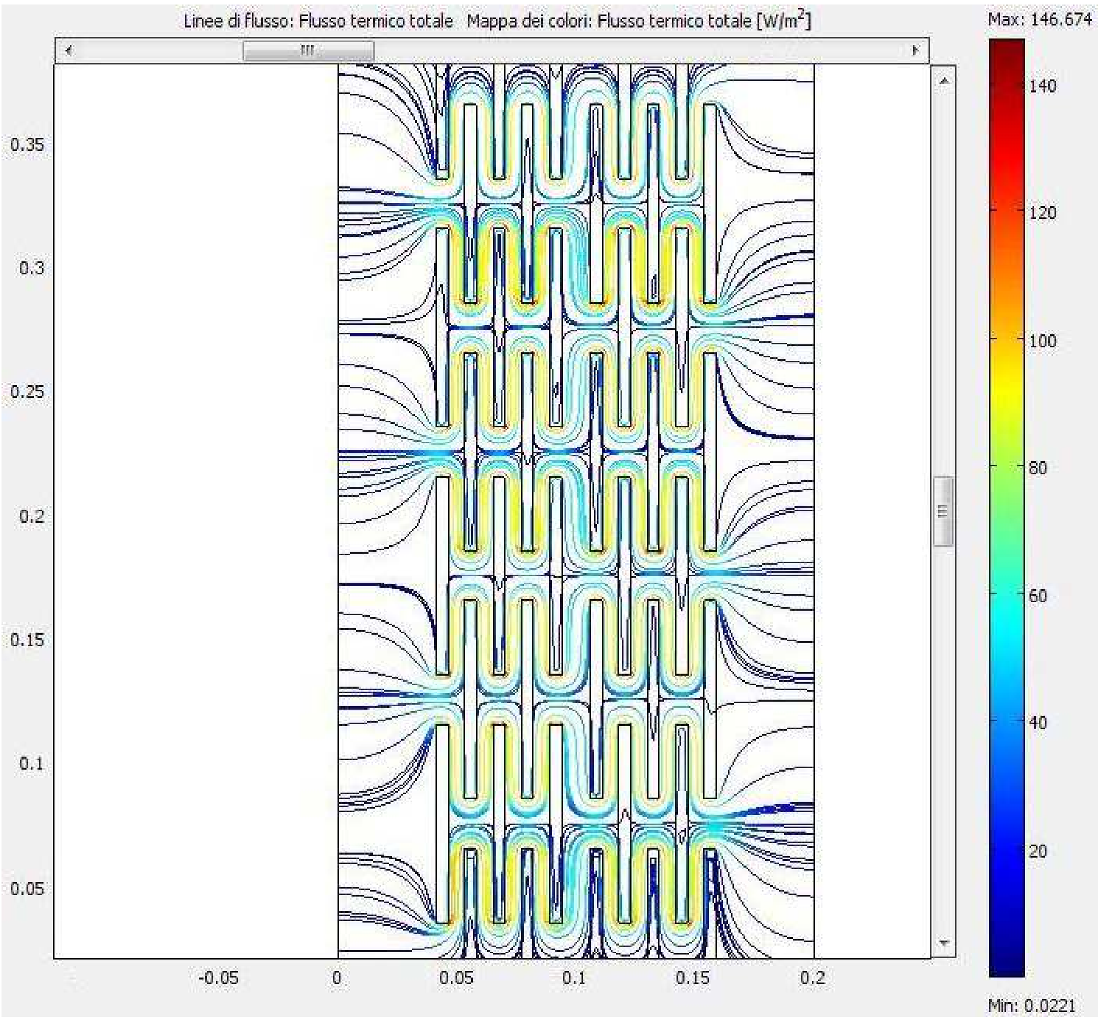


Figure 2.4. Thermal flux lines in the standard web profile.

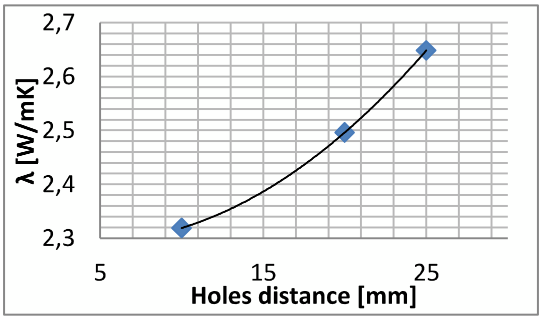
2.2 HOLES DISTANCE VARIATION

The first optimization analysis of the web profile will be done varying the holes distance while the holes and the number of the rows are kept the standard dimensions. In the standard configuration two holes of the same row are distant 20 mm each other (100 mm is the step).

The simulation with the holes distances has been repeated as shown in the Table 2.2; the graph gives the dispersion of the results and the trend line.

Table 2.2. Trend of the thermal conductivity by a holes distance variation.

Holes distance HD	λ [W/mK]
10	2,32
20	2,50
25	2,65



Obviously the global thermal conductivity will increase if the distance between the holes increase, in fact the thermal flux has to cross an easier route, and vice versa. It is important to bear in mind that the holes distances cannot be reduced beyond a minimum limit, in order to satisfy the demand for structural load.

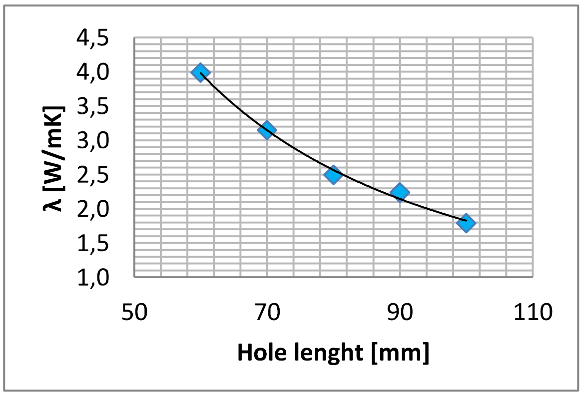
Let us look the results in percentages terms; if the holes distances are halved (from 20 to 10 mm), the thermal conductivity will improve of 8 %.

2.3 HOLES LENGTH VARIATION

Continuing with the optimization of the profile, the work has been restarted to the standard configuration and the holes length has been varied. Through numerous simulations the thermal conductivity trend has been obtained as show below:

Table 2.3. Trend of the thermal conductivity by a holes length variation.

Hole length HL	λ [W/mK]
60	3,99
70	3,15
80	2,50
90	2,24
100	1,79



It is easy shown as the increase of the holes length leads significant changes of the thermal conductivity. Let us look the results in percentages terms; increasing the length of the holes from 80 to 100 mm, an improvement of the overall conductivity of 28% it can be obtained.

2.4 HOLES WIDTH VARIATION

In the standard configuration the holes have a width of 5 mm, maximum available value with 10 rows. For more widths we should decrease the rows number, in order to don't occupy the outer sides of the profile that are the principal load bearing structure.

Analyzing the web profile with lesser width holes (1,5 mm e 3 mm), the same distance between two rows has been kept.

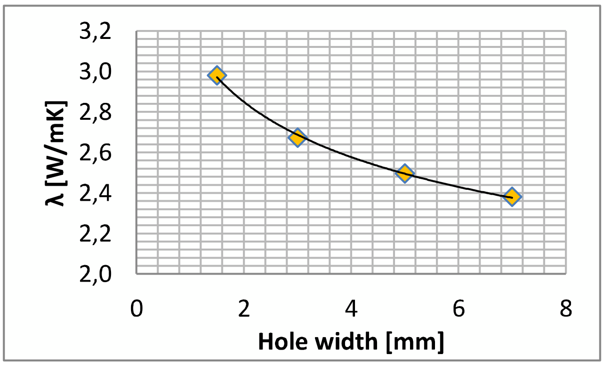
Just to give an indication, even the configuration with 7 mm width for each hole will be simulated. This solution is not available for a load bearing issue, but it's important to understand the influence of this parameter in the global transmittance of the profile. This will be necessary in the subchapter 2.8, where new configurations of the web profile will be proposed.

The radiation effect changes for each shape variation of the holes; so the detailed simulation of the hole has been repeated, with the propose to calculate the new λ_{hole} value and then the usual analysis of the web.

This is the thermal conductivity trend by a holes width variation:

Table 2.4. Trend of the thermal conductivity by a holes width variation.

Hole width HW	λ [W/mK]
1,5	2,98
3	2,67
5	2,50
7	2,38



Obviously a reduction of the holes width increases the thermal conductivity of the element. Changing from 5 mm of the standard configuration to 3 mm there is an increase of thermal conductivity of 8% while with 1,5 mm the conductivity increases to 20 %.

Finally increasing the width up to 7 mm it is possible to reduce the thermal conductivity just to 5%.

2.5 ROWS DISTANCE VARIATION

In the standard configuration, the holes have a distance of 7 mm, so adding the standard width of the holes (5 mm), the step is 12 mm. It has been decided to keep as reference variable the distance between two strips of holes instead of the step, by analogy with the previous simulations.

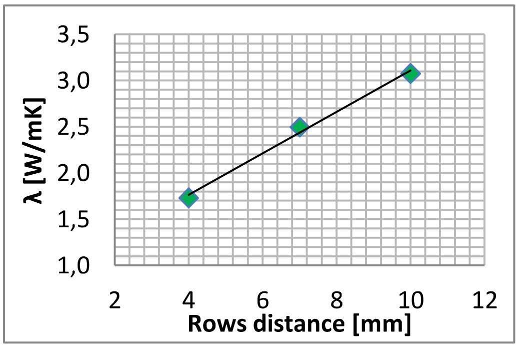
In this analysis the distance between two rows has been varied, respect the standard configuration of 7 mm. It's reached proceed repeating the simulation with 4 mm and then 10 mm as rows distance.

In the standard web profile the central part is larger respect the other spaces between the holes rows; in this simulations the central part will be left unchanged.

The following have been obtained results:

Table 2.5. Trend of the thermal conductivity by a rows distance variation.

Rows distance RD	λ [W/mK]
4	1,73
7	2,50
10	3,08



Significant improvements have been observed approaching the strips of holes; in fact passing from 7 mm (standard configuration) to 4 mm, the thermal conductivity is reduces by 30 %. It's important to bear in mind that this variations could modify the load bearing capacity.

Increasing the rows distances, there is certainly an increase of conductivity, besides an excessive use of the web space.

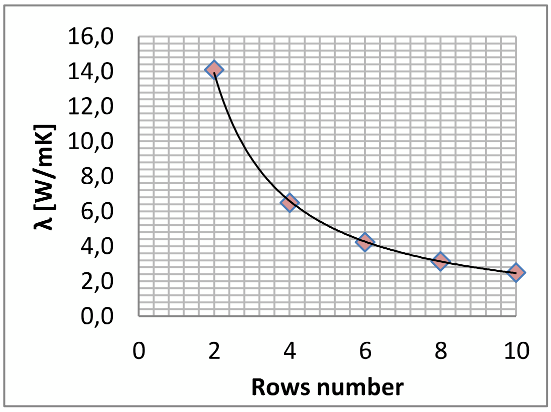
2.6 ROWS NUMBER VARIATION

In the standard configuration, the web profile already has the maximum number of rows (10) applicable for the standard width. So in these simulations only configurations with less holes strips will be analyzed.

The results are presented as usually follow:

Table 2.6. Trend of the thermal conductivity by a rows number variation.

Rows number RD	λ [W/mK]
2	14,09
4	6,48
6	4,23
8	3,14
10	2,50



We can immediately see how much the number of rows influences the overall conductivity of the web profile.

These results deserve some additional comment: it is possible to see as with just two holes strips the thermal conductivity is very high (almost 15 W/mK) while already with 4 rows significant improvements have already been obtained. Analyzing the graph in the most interesting area, it is possible to say that increasing the number of rows from 8 to 10, the thermal conductivity increases by 25%.

Seeing the trend line, a configuration with 12 holes rows could become interesting changing some other parameters.

In this mode the only central part of the web will be occupied with the hole strips, while the external parts can meet the load bearing capacity of the structure.

2.7 STEEL THICKNESS VARIATION

In the standard configuration a thickness of 1,5 mm is considered while other two configurations have been simulated with thickness respectively 1,2 and 2 mm.

The radiation effect is the only parameter that changes; this is due to the variation of the geometry of the holes. More interesting could be the analysis of the global thermal transmittance U (W/m^2K), so as to consider also the thickness of the profile. Instead in this analysis considerations have been made only on the thermal conductivity, which is influenced only from the radiation effect in the steel surfaces of the holes.

Therefore, for the two configurations mentioned above the equivalent radiation conductivity due to the change of the geometry has been recalculated, obtaining the follows λ_{rad} :

$\lambda_{rad} = 0{,}0087\ {W}/{mK}$ with thickness profile 1,2 mm;

$\lambda_{rad} = 0{,}0094\ {W}/{mK}$ with thickness profile 2 mm;

It's possible to see the variations of the radiation effect is very slight.

After that, making use of Comsol Multiphysics 3.5, standard simulation has been repeated, varying only the radiation effect in the holes surfaces.

It is easy to understand that there aren't significant variations of the global thermal conductivity of the web.

Further studies could be made analyzing the entire CasaBona element by varying the web profile thickness; moreover considering that greater thickness have greater load bearing capacity.

The right choice of the profile thickness depends on various aspects:

- the increase of the thickness generates a greater linear thermal bridge, but could allow less Z-profiles in the wall;
- the increase of the thickness increases the load bearing capacity, so as to allow a multi level realization;
- less thickness increases the number of the Z-profile in the wall, but in this way it is possible to achieve more different architectural solutions.

2.8 THE PROPOSED PROFILES

Making use of the studies mentioned above, new solutions of the web profile can be achieved, with a lower thermal conductivity than the standard web.

The aim of this propose is to reduce the thermal conductivity of the web in order to reduce the linear thermal bridge of the Z-profile.

Summing up all the previous simulations in the table below, the attention has been focused on the last column, which gives the conductivity percentage variation, due to each single change made as explained above.

Table 2.7. Summary results and percentage conductivity variation of the models compared to the standard configuration.

		Steel thichness	Rows number	Rows distance	Hole width	Hole lenght	Holes distance	λ [W/mK]	%
		S	RN	RD	HW	HL	HD		
1	Standard	1,5	10	7	5	80	20	2,50	0,00
2	HD10	1,5	10	7	5	80	10	2,32	-7,10
3	HD25	1,5	10	7	5	80	25	2,65	6,09
4	HL60	1,5	10	7	5	60	20	3,99	59,74
5	HL70	1,5	10	7	5	70	20	3,15	26,11
6	HL90	1,5	10	7	5	90	20	2,24	-10,39
7	HL100	1,5	10	7	5	100	20	1,79	-28,25
8	HW1,5	1,5	10	7	1,5	80	20	2,98	19,38
9	HW3	1,5	10	7	3	80	20	2,67	7,08
10	HW7	1,5	10	7	7	80	20	2,38	-4,63
11	RD4	1,5	10	4	5	80	20	1,73	-30,62
12	RD10	1,5	10	10	5	80	20	3,08	23,28
13	RN2	1,5	2	7	5	80	20	14,09	464,55
14	RN4	1,5	4	7	5	80	20	6,48	159,71
15	RN6	1,5	6	7	5	80	20	4,23	69,44
16	RN8	1,5	8	7	5	80	20	3,14	25,74
17	S1,2	1,2	10	7	5	80	20	2,49	-0,21
18	S2	2	10	7	5	80	20	2,49	-0,06

A negative percentage change is a reduction of the thermal conductivity, therefore an increase of the performance of the web; vice versa, a positive percentage change is an increase of the thermal conductivity, so a worsening of the web performance.

It is easy to see from the table 2.7 that the best reductions of the thermal conductivity are obtained both increasing the length of the holes (from 80 to 100 mm) and approaching the strips each other (from 7 to 4 mm).

These changes could be possible because the structural load is concentrated in the outer parts of the Z-profile; however, to confirm this, a structural analysis of the element should be made, that is beyond the content of this report.

It is possible to design a new web profile making use of the considerations above, in order to improve the efficiency of the thermal conductivity. Reducing the rows distance can also allow the addition of another pair of holes strips, so as to maximize all the precedent phenomena analyzed individually.

The first web profile is proposed as follows, the figure below shows the flux lines in the web:

Table 2.8. Dimensions of the proposed web profile, option 1.

Steel thickness	Rows number	Rows distance	Hole width	Hole lenght	Holes distance
S	RD	RD	HW	HL	HD
1,5	10	4	5	100	20

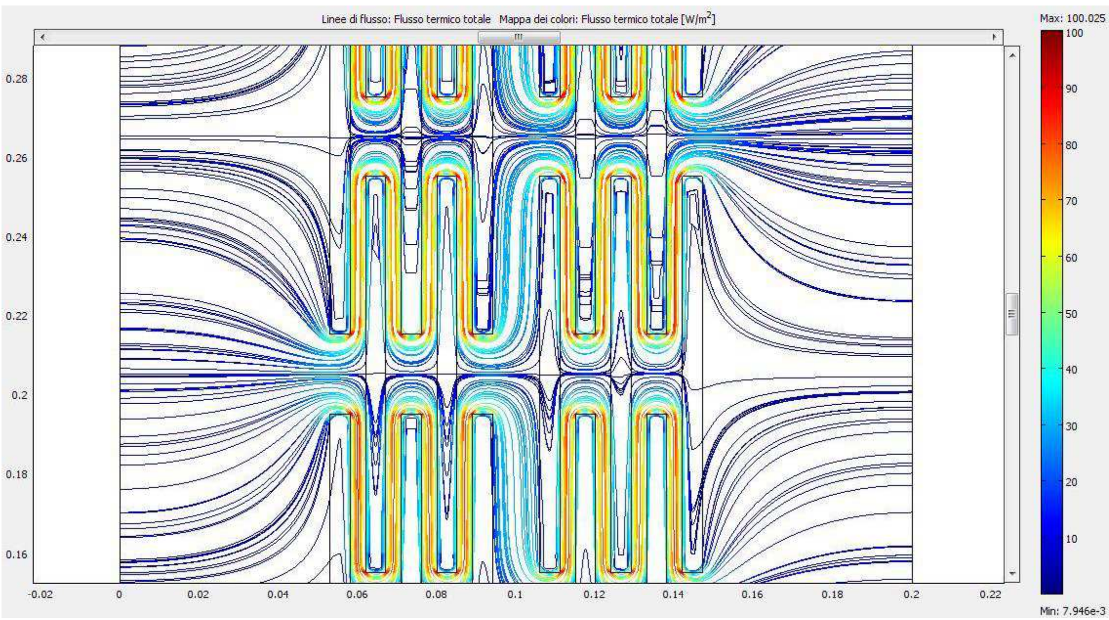


Figure 2.5. Thermal flux lines in the proposed web profile, option 1.

The new global thermal conductivity results:

$\lambda = 1.25\ {}^{W}/_{mK}$ compared to $\lambda_{steel} = 36\ {}^{W}/_{mK}$ of the steel.

Another solution could be with 12 holes rows. Just to occupy only the central part of the web, the holes width will be reduced from 5 to 3 mm. On the first hand, this penalized the thermal conductivity; on the other hand, it allows the addition of two hole strips such as to further the effectiveness of the profile.

The profile will be designed as follows:

Table 2.9. Dimensions of the proposed web profile, option 2.

Steel thickness	Rows number	Rows distance	Hole width	Hole lenght	Holes distance
S	RD	RD	HW	HL	HD
1,5	12	4	3	100	20

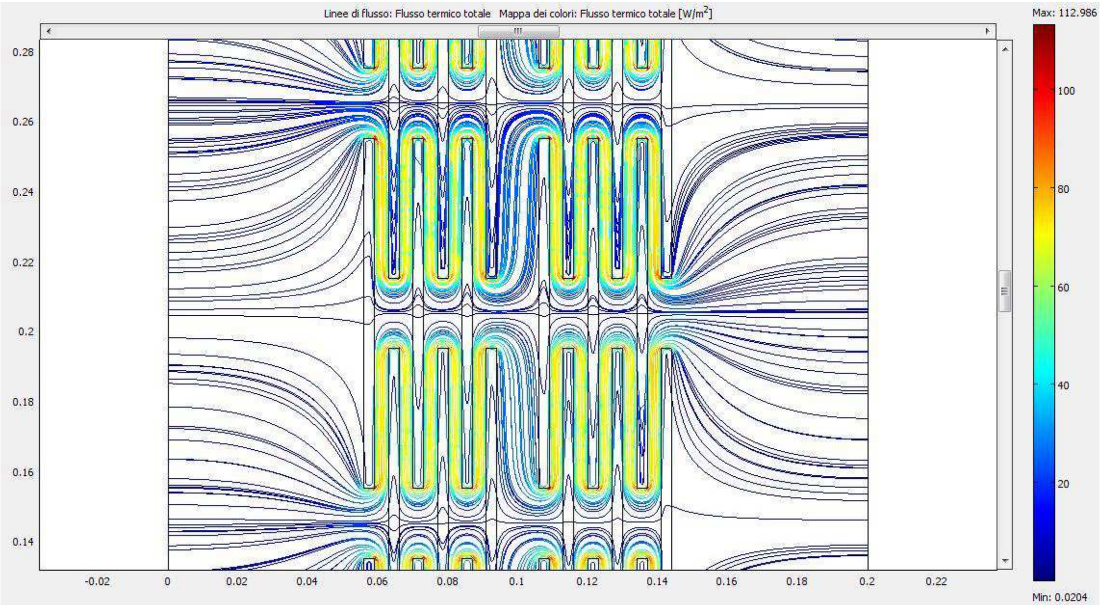


Figure 2.6. Thermal flux lines in the proposed web profile, option 2.

The new global thermal conductivity results:

$\lambda = 1.13\ {}^{W}/_{mK}$ compared to $\lambda_{steel} = 36\ {}^{W}/_{mK}$ of the steel.

The aim of this proposal has been to give an input for future development of the profile, which should be concretized with a structural analysis.

CHAPTER 3

THERMAL ANALYSIS OF CASABONA ELEMENT

The aim of this chapter is the thermal analysis of the CasaBona element in order to calculate all the parameters that characterize this structure. With a prefabricated structure, obviously, it is not possible to have a uniform surface.

As already written in the first chapter, CasaBona System is built with periodic steel Z-Profiles (every 600 or 900 mm) as load bearing structure, but they are thermal bridges regarding the thermal analysis. Furthermore there is also another discontinuity in the backing of the wall; it is realized by steel U-profiles that hold at the bottom and at the top the EPS blocks. A thin neoprene layer is put under the U-profile in order to improve the air tightness. Both the Z-profile and the U-profile are realized with long narrow slots in order to reduce the thermal bridge effect.

The aim of this chapter is to calculate the thermal bridges generated by the steel profiles and the punctual thermal bridge in their intersection, so as to define the global U-value of the wall.

Therefore a three dimensional pattern of CasaBona is studied with Comsol Multiphysics 3.5 as shown in the figure 3.1; the overall transmission coefficient of the model is defined by:

$$K_{tot} = \frac{\lambda_{EPS}}{s_{CasaBona}} * l_1 * l_2 + \Psi_{TB1} * l_1 + 2 * \Psi_{TB2} * l_2 + 2 * \chi_{IS} \qquad (3.1)$$

Where:

K_{tot} total heat transmission coefficient [W/K];

λ_{EPS} conductivity of EPS [W/mK];

$s_{CasaBona}$ thickness of the wall [m];

Ψ_{TB1} vertical linear thermal transmittance of the Z-profile [W/mK];

l_1 height of the wall [m];

Ψ_{TB2} horizontal linear thermal transmittance of the U-profile in the bottom and in the top [W/mK];

l_2 length of the wall element [m];

χ_{IS} punctual thermal transmittance of the thermal bridge [W/K].

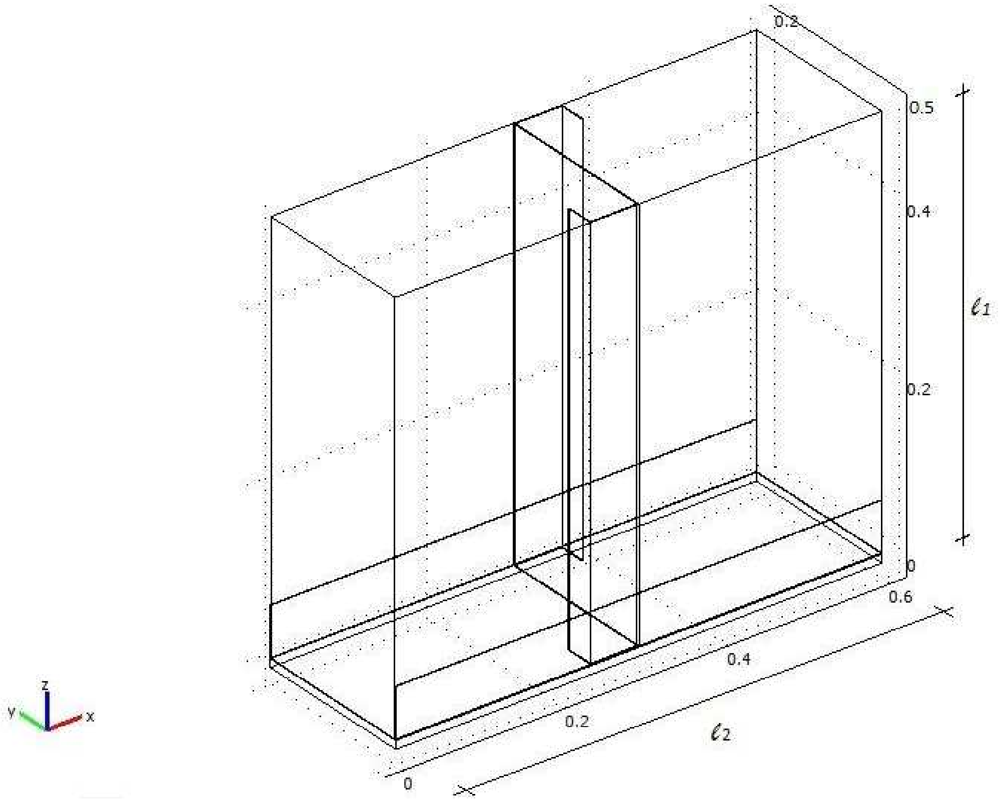


Figure 3.1. 3D-model of CasaBona System, with U-profile at the bottom and Z-profile.

3.1 OVERALL TRANSMISSION COEFFICIENT K_{tot}

It has been proceed as follows: the simulation will be done with $\Delta T = 1K$ between two external surfaces of the wall, the other surfaces are placed adiabatic.

The materials of the structure are defined according to the table (3.1.).

Table 3.1. Materials characteristics of the structure CasaBona System.

	λ	ρ	c
	W/mK	kg/m^3	J/kgK
EPS	0,033	30	1500
Steel	36	7800	500
Web profile	2,5	7800	500
Neoprene	0,23	1400	2140

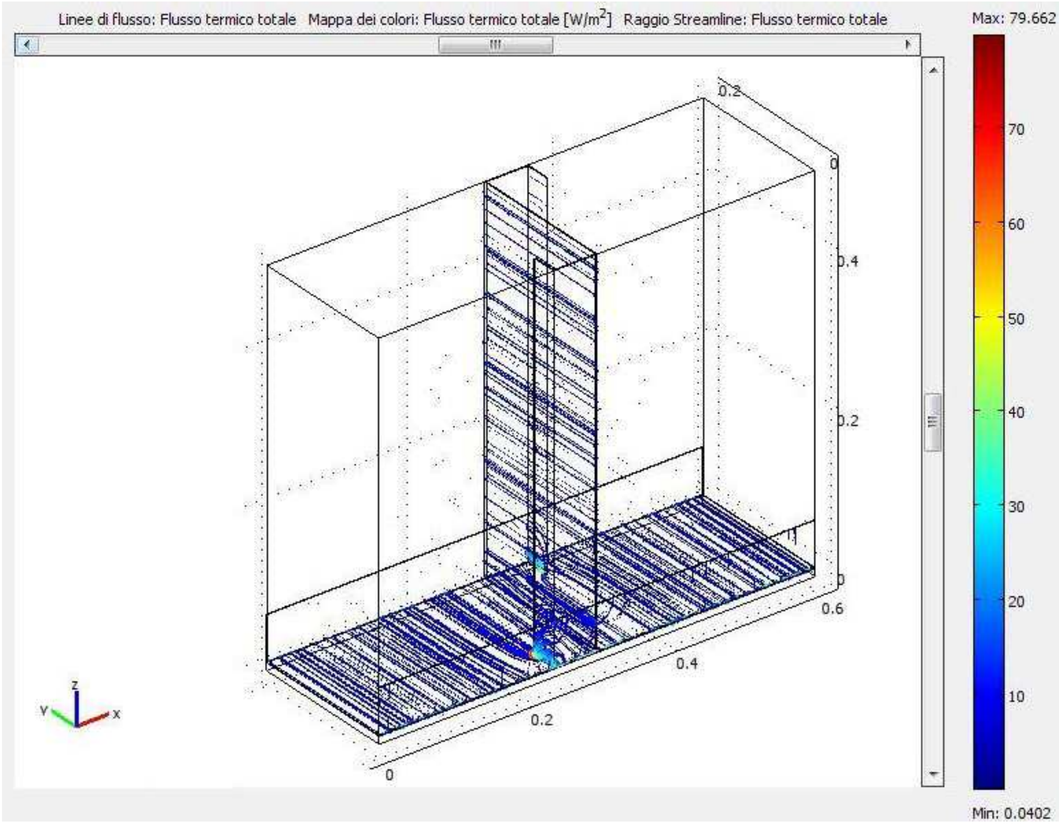


Figure 3.2. Thermal flux in the 3D-model of CasaBona System.

It's possible to see from this figure that the thermal flux is concentrated in the thermal bridges of the Z-Profile and the U-Profile. Furthermore there is an intensification of the thermal flux lines in the intersection of the two linear thermal bridges, where there is the punctual thermal bridge.

Calculating the heat flux which though the model, it is possible to extract the value K_{tot} of the equation (3.1.); it can be achieved as follow:

Integrating along the entire surface, orthogonal to the flow, the overall thermal flux has been obtained:

$$\phi_{tot} = 0.073058\ [W] \qquad (3.2)$$

from which we get:

$$K_{tot} = \frac{\phi_{tot}}{l_1 * l_2} = 0.2435\ \left[\frac{W}{m^2K}\right] \qquad (3.3)$$

3.2 LINEAR TRANSMISSION COEFFICIENT Ψ_{TB1}

It is proceed analyzing the same pattern but without the bottom, therefore without the U-Profile and the neoprene. In this way the linear thermal bridge due to the Z-Profile can be achieved, by difference with the same model realized in totally EPS.

The figures below show the heat flux concentration in correspondence of the thermal bridge; the former shows a three dimensional representation (Figure 3.3) while the latter shows the detail in two dimension (Figure 3.4).

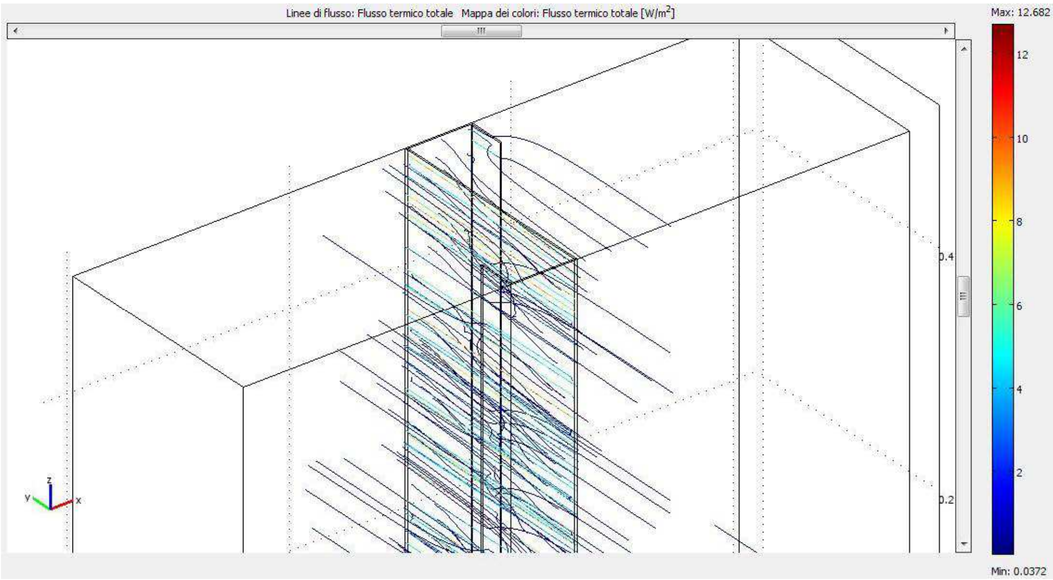


Figure 3.3. Thermal flux in the Z-profile of the 3D-model of CasaBona System.

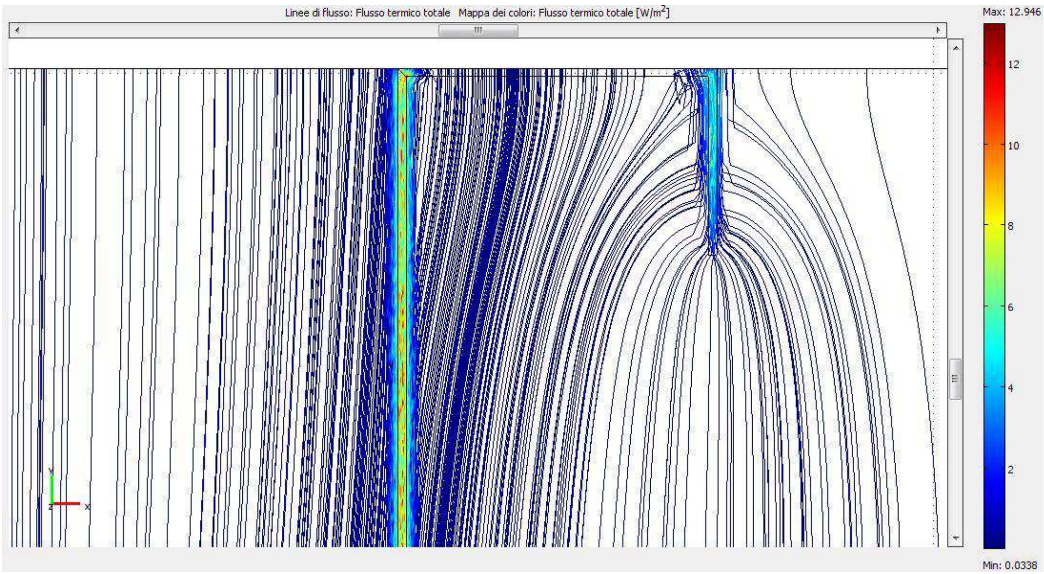


Figure 3.4. Detail of the thermal flux in the Z-profile, 2D representation.

The simulation has been repeated with the same boundary conditions of the previous pattern obtaining:

$$\phi_{wall} = 0.059236\ [W] \tag{3.3}$$

The heat flux due to the thermal bridge is obtained subtracting the heat flux due to the EPS:

$$\Delta\phi(\Psi_{TB1}) = \phi_{wall} - \frac{\lambda_{EPS}}{s_{CasaBona}} * l_1 * l_2 = 9.736 * 10^{-3}\ [W] \tag{3.4}$$

Now it's easy to calculate the linear thermal coefficient due to the Z-Profile as follow:

$$\Psi_{TB1} = \frac{\Delta\phi(\Psi_{TB1})}{l_1} = 0.0195\ \left[\frac{W}{mK}\right] \tag{3.5}$$

3.3 LINEAR THERMAL COEFFICIENT Ψ_{TB2}

It has been proceed as in the subchapter 3.2, analyzing this time only the pattern with the bottom, therefore with the U-Profile and the neoprene layer, but without the Z-Profile. In this way the value of the linear heat flux of the bottom can be reach.

The figure 3.5 shows the heat flux through the pattern; it is easy to see how the heat flux is mainly concentrated at the bottom of the model.

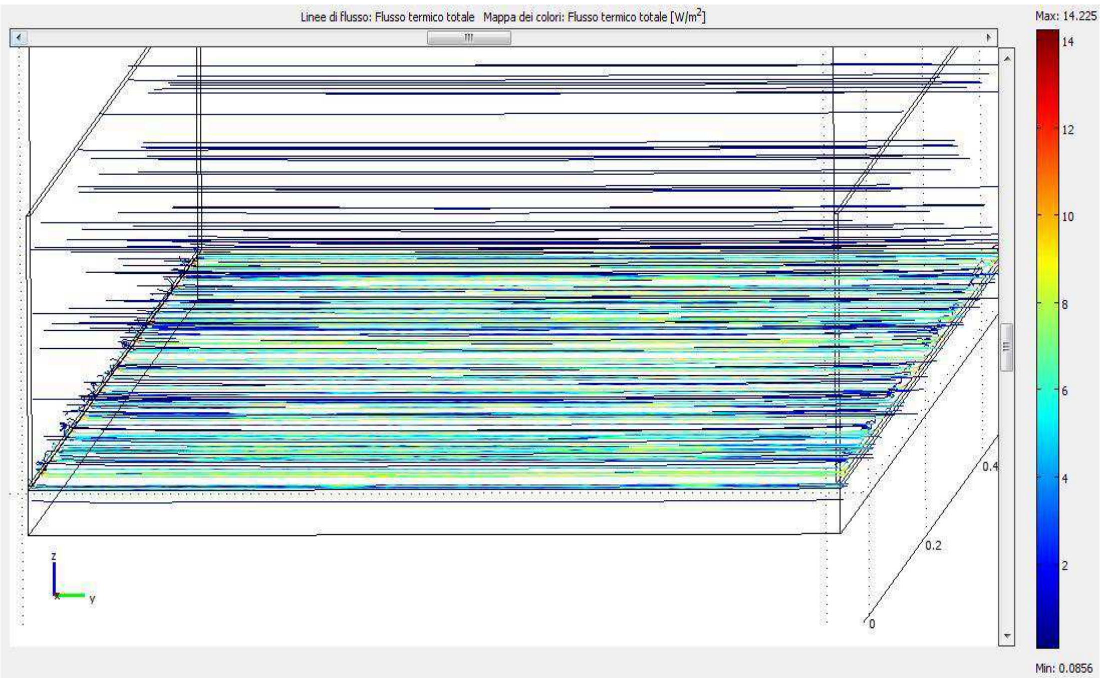


Figure 3.5. Thermal flux in the bottom of the 3D-model of CasaBona System.

Making use of Comsol Multiphysics 3.5 the heat flux has been calculated:

$$\phi_{bottom} = 0.062808\ [W] \tag{3.6}$$

whence, the heat flux due to the thermal bridge in the bottom is obtained subtracting the heat flux due to the EPS:

$$\Delta\phi(\Psi_{TB2}) = \phi_{bottom} - \frac{\lambda_{EPS}}{s_{CasaBona}} * A_{element} = \ 13.308 * 10^{-3}\ [W] \tag{3.7}$$

Now it's easy to calculate the linear thermal coefficient due to the bottom thermal bridge as follow:

$$\Psi_{TB2} = \frac{\Delta\phi(\Psi_{TB2})}{l_2} = \ 0.0222\ \left[\frac{W}{mK}\right] \tag{3.8}$$

Ψ_{TB2} is greater than Ψ_{TB1} because the former has also the neoprene layer which increases the thermal bridge.

3.4 PUNCTUAL THERMAL COEFFICIENT χ_{IS}

Let us look again the equation (3.1.); the only element not available is the value of the punctual thermal bridge χ_{IS} due to the intersection between the vertical thermal bridge Ψ_{TB1} and the horizontal thermal bridge Ψ_{TB2}.

χ_{IS} can be easily achieved by difference from the previous parameters as follows:

$$\chi_{IS} = \ K_{tot} * l_1 * l_2 - \frac{\lambda_{EPS}}{s_{CasaBona}} * A_{element} - \Psi_{TB1} * l_1 - \Psi_{TB2} * l_2 + \chi_{IS} \tag{3.9}$$

obtaining:

$$\chi_{IS} = 5.00 * 10^{-3}\ [W/m^2K] \tag{3.10}$$

These simulations allow to obtain individually the various parameters of the heat exchange, which means that it will be extremely easy to calculate the equivalent thermal coefficient for every dimension of the wall.

3.5 OVERALL THERMAL DESCRIPTION OF CASABONA LAYER

For a given wall built by CasaBona System with $l_1 * l_2$ as dimensions, it is possible to calculate the global transmittance, according to:

$$U_{tot} = \frac{\frac{\lambda_{EPS}}{s_{CasaBona}} * l_1 * l_2 + n * \Psi_{TB1} * l_1 + 2 * \Psi_{TB2} * l_2 + n * 2 * \chi_{IS}}{l_1 * l_2} \qquad (3.11)$$

Where:

U_{tot} equivalent total heat transmission coefficient [W/m^{2}K];

λ_{EPS} conductivity of EPS (0.033 [W/mK]);

Ψ_{TB1} vertical linear thermal transmittance of the Z-profile (0.0195 [W/mK]);

l_1 height of the wall [m];

Ψ_{TB2} horiz. linear thermal transmittance of the U-profile (0.0222 [W/mK]);

l_2 length of the wall [m];

χ_{IS} punctual thermal thermal bridge (0.005 [W/K]);

n number of Z-profile in the wall.

In the equation, both the punctual thermal transmittance and the horizontal thermal coefficient are multiplied by a factor 2 because there are both the bottom and at the top considering the entire wall CasaBona.

Similar considerations can be done considering the entire outer wall, so, in addition to the CasaBona layer, there will be other layers in order to give more insulation or more active heat capacity. Lastly the outer wall can be finished with a plaster layer in both sides.

3.6 THERMAL BRIDGE COMPARISON BETWEEN CASABONA SYSTEM AND WOODEN FRAME STRUCTURE

To complete the treatment about this structure, an evaluation of the thermal efficiency of the Z-profile, by a comparison with a wooden frame structure, has been done.

The CasaBona system has already been described above; this construction type is placed in the housing market as competitor of the wooden prefabricated houses.

The less cost to build up the building could be criticized for the unusual load bearing structure, and the Z profile, clearly visible as thermal bridge.

With regard the behavior as load bearing structure, studies have shown the great structural capacity while the thermal bridge of the steel Z-profile will be compared in this subchapter. It has to be considered that the steel sheet has a very low thickness and, above all, it's pre-cut with long narrow slots which reduce the thermal bridge. In a wooden structure the thermal bridge is generated by the wooden frame which fills a larger cross section than the Z-profile. In this regard a comparison between the thermal bridge of the Z-profile and the wooden frame has been carried out.

The comparison is made just considering the load bearing layer of the two structures; comparing the entire walls would not be objective due to the countless configurations achieved.

The CasaBona element is covered with two steel layer with 0.7 mm of thickness. The steel sheets have great thermal conductivity and allow a better flux uniformity.

The figure below shows the flux lines in the Z-profile; it's easy to understand that the flux is greater in the steel profile. The color of the flux lines gives an indication of the flux intensity. The blue lines are due to the lower flux in the EPS blocks while the red lines represent the higher flux intensity.

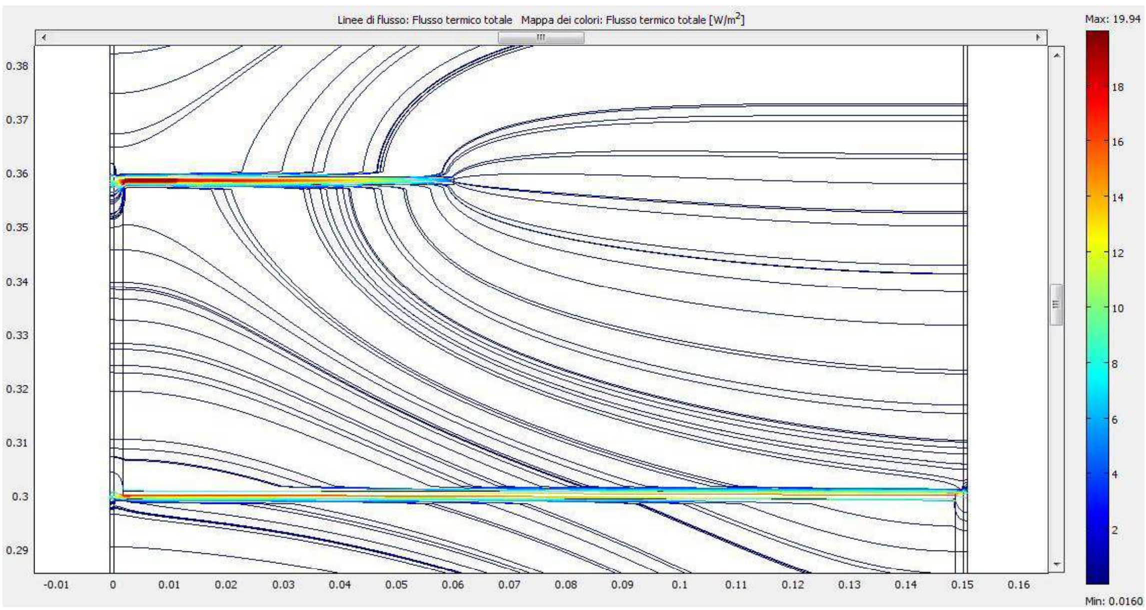


Figure 3.6. Thermal flux in the thermal bridge of the Z-profile.

Afterwards the same element without the steel element has been analyzed.

In this case the value of the thermal bridge due to the steel profile can be achieved.

The thermal flux is given by the finite element software for both cases; the linear thermal bridge is simply obtained by the difference of these two thermal flows:

$$\Psi = \Delta\phi = 0.038 \left[\frac{W}{m}\right] \tag{3.12}$$

Similarly the wooden structure in order to obtain the corresponding value of the thermal bridge is analyzed below.

The wooden structure has a frame with 45x140 mm as dimensions which is repeated every 600 mm. Mineral wool (λ= 0.038 W/mK) is put inside. With the propose of standardize this model with the former, the structure is covered by two steel sheets with thickness 0.7 mm.

Substantially CasaBona System uses the same principle, with the difference that, in the wooden structure the load bearing frame has to be necessarily thicker than the sheet steel for structural considerations. The figure below show the thermal bridge in the frame due to a more density of the flux lines.

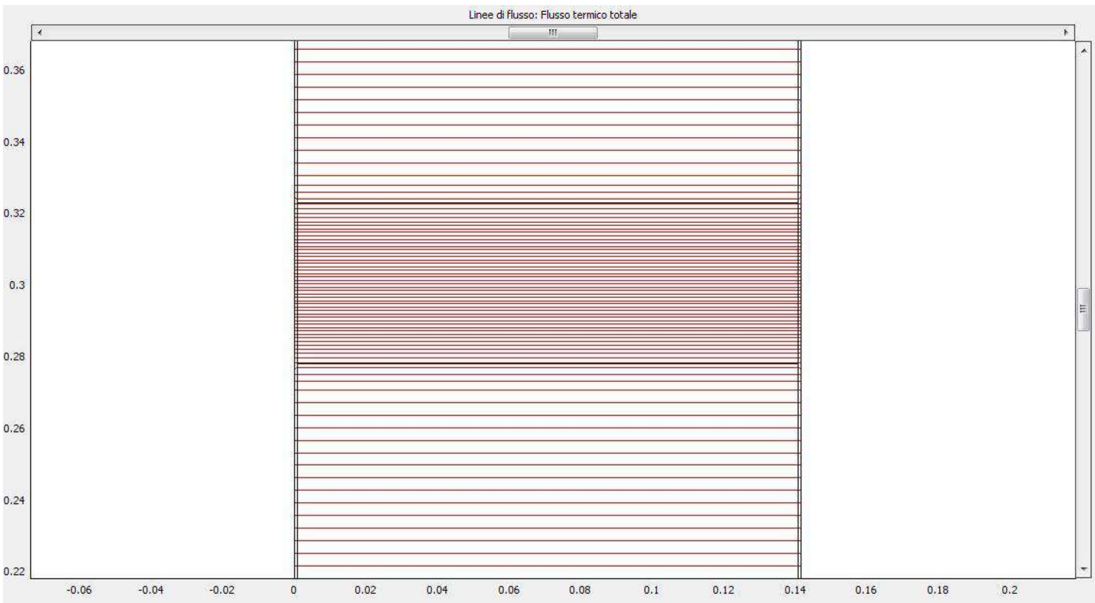


Figure 3.6. Thermal flux in the thermal bridge of the wooden frame.

Analyzing the heat flows in this model, the linear thermal bridge of the wooden frame structure has been carried out:

$$\Psi = \Delta\phi = 0.033 \left[\frac{W}{m}\right] \quad (3.13)$$

Comparing this value with the thermal bridge of the Z-profile, it is possible to see that the latter has a thermal bridge slightly higher than the former; however, it's important to bear in mind that the steel Z-profile has normally a wheelbase of 900 mm while the wooden frame is every 600 mm.

Further considerations could be done analyzing the CasaBona element with 200 mm of thickness; however, this comparison would be between two different thickness which obviously affect the thermal bridge.

CHAPTER 4

BUILDING DESIGN

The aim of this concept has been to simulate a real double-flat house with the CasaBona System. This is to show the versatility of CasaBona System, which can be adapted to any situation following the original layout of the house.

The building is composed by two identical apartments, one per floor. These flats are accessible by common stairwell, on the side.

Every flat is composed by kitchen, living room, bathroom, corridor, two bedroom and a lumber room.

The building is bordered to the east by another house, while the outer sides have several windows which illuminate the house.

The load bearing structure of the outer wall is composed by blocks of CasaBona System, with thickness 150 or 200 mm depending on the configuration of the wall. The blocks length is variable as needed (600, 900, 1200 mm) and they are placed vertically for the entire height of the building. The angular blocks have dimensions 300 x 300 mm and they are fixed in the corners.

The CasaBona layer will be covered on both sides by other layers in order to complete the wall according to the aesthetics and performance desired.

The insole and the roof are built by blocks with width 600 or 900 mm and thickness 200 mm in order to give more stiffness to the element.

All the measures of the building have been suitably studied for the sizes of the CasaBona elements, including windows and doors as shown in the drawings in the Appendix B.

The load bearing structure is composed by these outer walls plus the internal walls, in order to reduce the spans of the insole and roof; wooden beams and steel profiles complete the support structure. In this way the outer walls are continuous, limiting the air infiltration and the thermal bridge in the insole.

The stairs are supported by a wooden frame structure.

The foundation is simply realized by a concrete layer over an EPS layer, directly in contact with the ground.

The thickness of the concrete and the EPS affect the heat thermal capacity and the insulation level of the basement. These thickness will have different value depending on the various configurations analyzed.

In correspondence with the load-bearing walls, the foundation has reinforced concrete with thickness of 300 mm, in order to carry the whole building load.

The whole concrete casting of the foundation, is separated by an insulating layer, these structure is completed by a vapor barrier and draining pipes in all its length to protect the house from the moisture.

All the drawings of the building are reported in Appendix B.

For the dynamic analysis of the building with Consolis Energy +, the parameters characterizing the building have been calculated as follows:

Table 4.1. Main dimensions of the dwelling.

Heated floor area		185	m^2
Ground area (Footprint)		105	m^2
Perimeter against the free		35	m^2
Window	S	12,6	m^2
	W	13,9	m^2
	N	14,7	m^2
External walls		260	m^2
Roof		120	m^2
Intermediate constructions	Insole	95	m^2
	Internal wall	180	m^2
Linear thermal bridges	Balcony	11,5	m

To make a fair comparison between the various configurations which will be proposed in the next chapter, these parameters will be the same for each simulation.

With the propose of do not introduce too many complex parameters, only the linear thermal bridge of the balconies have been considered, as the most significant. The other thermal bridges have been considered by an over sizing of the outer walls.

CHAPTER 5

DYNAMIC OPTIMIZATION OF THE BUILDING

The importance of the dynamic analysis of the buildings is becoming increasingly important. The increase of the insulation level, the electric internal loads and the use of big windows areas on south facades, can cause very high internal temperatures during the cooling season.

To keep excellent indoor environmental quality, the rule of air conditioning of the building increases in importance if the insulation level increases, to the point that it becomes the main energy demand of the building. Furthermore, the effect of thermal mass can affect the energy consumption of the building; above all it allows considerable energy savings where there are great temperature fluctuations.

This chapter treats the analysis of different building configurations obtained changing the thermal insulation level and the thermal mass.

The analysis will be treated below with different building configurations regarding the insulation level and the active heat capacity. It will be treated with the following structures:

- Lw-Wi Light weight - Well insulation;
- Lw-Mi Light weight - Medium insulation;
- Lw-Li Light weight - Low insulation;
- Mw-Wi Medium weight - Well insulation;
- Mw-Mi Medium weight - Medium insulation;
- Hw-Wi High weight - Well insulation;
- Hw-Mi High weight - Medium insulation;
- Hw-Li High weight - Low insulation;

These solutions will be compared in five Italian cities (Aosta, Milan, Padua, Rome, Palermo), in order to give an overall view of the building behavior in the Italian climates.

The configuration Medium weight - Low insulation has not been analyzed because it would be almost the same as Hight weight - Low insulation.

In the dynamic simulation carried out by Consolis Energy+ , the follow significant parameters for each wall are necessary:

- Global thermal coefficient U [W/m²K];
- Internal active heat capacity [J/m²K];

For the internal walls the active heat capacity for both sides of the wall are necessary if the layers configuration is asymmetrical.

These parameters are calculated by an appropriate spreadsheet in Consolis Energy+, where it's possible to create walls with any layers composition from a database of construction materials; it's also possible to add new materials.

5.1 INPUTS

For each configuration the layers of the various structures have been chosen, respecting the insulation value and the active heat capacity, as already said above. The follow tables describe the eight building types.

It is important to bear in mind that not all the constructive solutions of the housing market can be represented; the configurations shown below are such as to pick out the effects of the transmittance variation and active heat capacity variation in the buildings and to show the various applications which CasaBona system can have.

However, similar transmittance values and similar active heat capacity values can be obtained by other layers solutions, without significantly changing the final results.

The tables below shows the detailed characteristic for every single layer, and the overall result for the entire walls as obtained in the Ceff spreadsheet.

It has been chosen to define the various building types by abbreviations in order to make easier the next identifications.

Table 5.1. Detailed description of the construction types.

Lw-Wi	1) LIGHT-WEIGHT WELL INSULATION							
	material description	D mm	λ W/mK	ρ kg/m^3	c J/kgK	U W/m^2K	Ceff in J/m^2K	Ceff out J/m^2K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,152	26976	38851
	CasaBona layer	200	0,043	30	1500			
	Mineral wool	60	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
ROOF	Terracotta tiled roof					0,153	26940	5391
	Ventilation space	50						
	CasaBona layer	200	0,043	30	1500			
	Mineral wool	60	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	200	0,036	25	1000	0,174	14413	2462
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,158	27636	16254
	Mineral wool	50	0,038	30	1000			
	CasaBona layer	200	0,043	30	1030			
	Gypsum plasterboard	26	0,250	900	1000			
INT. WALL	Gypsum plasterboard	26	0,250	900	1000	0,455	12746	12746
	Mineral wool	70	0,038	30	1000			
	Gypsum plasterboard	26	0,250	900	1000			

Lw-Mi	2) LIGHT-WEIGHT MEDIUM INSULATION							
	material description	D mm	λ W/mK	ρ kg/m^3	c J/kgK	U W/m^2K	Ceff in J/m^2K	Ceff out J/m^2K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,262	26242	37550
	CasaBona layer	150	0,043	30	1500			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
ROOF	Terracotta tiled roof					0,265	26138	3736
	Ventilation space	50						
	CasaBona layer	150	0,043	30	1500			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	100	0,036	25	1000	0,338	13230	1266
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,158	27636	16254
	Mineral wool	50	0,038	30	1000			
	CasaBona layer	200	0,043	30	1030			
	Gypsum plasterboard	26	0,250	900	1000			
INT. WALL	Gypsum plasterboard	26	0,250	900	1000	0,455	12746	12746
	Mineral wool	70	0,038	30	1000			
	Gypsum plasterboard	26	0,250	900	1000			

Lw-Bi	3) LIGHT-WEIGHT BAD INSULATION							
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,602	23846	46642
	Gypsum plasterboard	13	0,250	900	1000			
	Mineral wool	50	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
ROOF	Terracotta tiled roof					637	23183	1658
	Mineral wool	50	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	50	0,036	25	1000	639	12593	657
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,158	27636	16254
	Mineral wool	50	0,038	30	1000			
	CasaBona layer	200	0,043	30	1030			
	Gypsum plasterboard	26	0,250	900	1000			
INT. WALL	Gypsum plasterboard	26	0,250	900	1000	0,455	12746	12746
	Mineral wool	70	0,038	30	1000			
	Gypsum plasterboard	26	0,250	900	1000			

Mw-Wi	4) MEDIUM-WEIGHT WELL INSULATION							
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,152	26976	38851
	CasaBona layer	200	0,043	30	1500			
	Mineral wool	60	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
ROOF	Terracotta tiled roof					0,153	26940	5391
	Ventilation space	50						
	CasaBona layer	200	0,043	30	1500			
	Mineral wool	60	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	200	0,036	25	1000	0,173	218571	3599
	Concrete	100	1,700	2300	1000			
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,324	76698	166845
	Concrete	70	1,700	2300	1000			
	Mineral wool	80	0,038	30	1000			
	Concrete lightened	40	0,450	1100	1000			
	Bricks and block interp.	280	0,480	700	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
INT. WALL	Plaster gypsum/sand	10	0,700	1600	1000	1,946	64997	64997
	Bricks almost full	80	0,340	1500	840			
	Plaster gypsum/sand	10	0,700	1600	1000			

	5) MEDIUM-WEIGHT MEDIUM INSULATION							
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,244	81532	38888
	CasaBona layer	150	0,043	30	1500			
	Moisture barrier							
	Bricks 8x19x50 cm	80	0,223	1050	840			
	Plaster gypsum/sand	10	0,700	1600	1000			
ROOF	Terracotta tiled roof					0,265	26138	3736
	Ventilation space	50						
	CasaBona layer	150	0,043	30	1500			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	100	0,036	25	1000	0,332	216978	3795
	Concrete	100	1,700	2300	1000			
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,324	76698	166845
	Concrete	70	1,700	2300	1000			
	Mineral wool	80	0,038	30	1000			
	Concrete lightened	40	0,450	1100	1000			
	Bricks and block interp.	280	0,480	700	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
INT. WALL	Plaster gypsum/sand	10	0,700	1600	1000	1,946	64997	64997
	Bricks almost full	80	0,340	1500	840			
	Plaster gypsum/sand	10	0,700	1600	1000			

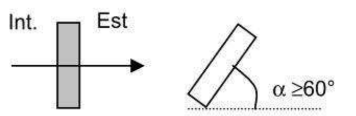
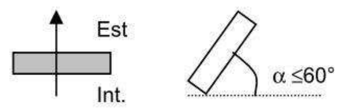
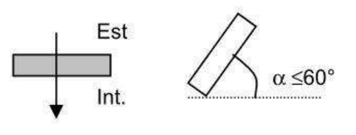
	6) HIGH-WEIGHT WELL INSULATION							
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster gypsum/sand	15	0,700	1600	1000	0,152	221997	29234
	Mineral wool	60	0,038	30	1000			
	CasaBona layer	200	0,043	30	1500			
	Moisture barrier							
	Concrete	150	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
ROOF	Terracotta tiled roof					0,153	26940	5391
	Ventilation space	50						
	CasaBona layer	200	0,043	30	1500			
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	200	0,036	25	1000	0,171	247043	4041
	Concrete	200	1,700	2300	1000			
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,325	227545	217814
	Concrete	100	1,700	2300	1000			
	Mineral wool	100	0,038	30	1000			
	Concrete	200	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
INT. WALL	Plaster gypsum/sand	10	0,700	1600	1000	3,071	106738	106738
	Concrete	100	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			

7) HIGH-WEIGHT MEDIUM INSULATION									
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	0,253	226912	37796
	Mineral wool	140	0,038	30	1000			
	Moisture barrier							
	Concrete	120	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
ROOF	Terracotta tiled roof					0,265	26138	3736
	Ventilation space	50						
	CasaBona layer	150	0,043	30	1500			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	EPS	100	0,036	25	1000	0,326	247316	5824
	Concrete	200	1,700	2300	1000			
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,325	227545	217814
	Concrete	100	1,700	2300	1000			
	Mineral wool	100	0,038	30	1000			
	Concrete	200	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
INT. WALL	Plaster gypsum/sand	10	0,700	1600	1000	3,071	106738	106738
	Concrete	100	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			

8) HIGH-WEIGHT LOW INSULATION								
	material description	D mm	λ W/mK	ρ kg/m³	c J/kgK	U W/m²K	Ceff in J/m²K	Ceff out J/m²K
OUTER WALL	Plaster cement/sand	20	1,000	1700	1000	1,286	210277	84988
	Brick	0,12	0,250	1100	840			
	Concrete	120	1,700	2300	1000			
	Plaster gypsum/sand	20	0,700	1600	1000			
ROOF	Terracotta tiled roof					0,637	23183	1658
	Mineral wool	50	0,038	30	1000			
	Moisture barrier							
	Gypsum plasterboard	26	0,250	900	1000			
GROUND FLOOR	Concrete	200	1,700	2300	1000	3,398	210324	222878
	Floor tiles	6	0,900	2000	1000			
INT. FLOOR	Floor tiles	6	0,900	2000	1000	0,325	227545	217814
	Concrete	100	1,700	2300	1000			
	Mineral wool	100	0,038	30	1000			
	Concrete	200	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			
INT. WALL	Plaster gypsum/sand	10	0,700	1600	1000	3,071	106738	106738
	Concrete	100	1,700	2300	1000			
	Plaster gypsum/sand	10	0,700	1600	1000			

To calculate correctly the global transmittance coefficient U (W/ m^2K), the surface heat transfer coefficients between the air and the surface must also be considered. For a vertical wall these values are: 23 W/m^2K for the external side and 8 W/m^2K for the internal side. For other types of wall the values are according to Italian normative UNI 7357/76 and are shown in the follow table:

Table 5.2. Surface heat transfer coefficients which incorporate the radiation and convection effects according to Italian normative UNI 7357/76.

Type of wall		Surface to the outside	Surface to the inside
Vertical wall		αi = 8 W/m^2K αe = 23 W/m^2K	αi = 8 W/m^2K αe = 8 W/m^2K
Horizontal wall upward flow		αi = 9,3 W/m^2K αe = 23 W/m^2K	αi = 9,3 W/m^2K αe = 9,3 W/m^2K
Horizontal wall downflow		αi = 5,8 W/m^2K αe = 16 W/m^2K	αi = 5,8 W/m^2K αe = 5,8 W/m^2K

The U-values of windows and doors have been defined according to the insulation level of the construction types. Therefore there are three kind of doors and windows with the follow characteristics:

Table 5.3. Windows description.

Type of construction	U W/m^2K	g-value	Frame factor
Well insulation	1,2	0,5	0,8
Medium insulation	3	0,6	0,8
Low insulation	6	0,7	0,8

The ventilation has been considered differently according to the insulation degree of the construction types. For the well insulated constructions, mechanical ventilation flow of 0,5 Vol/h and heat recovery from the exhaust air have been considered. The latter has 85% as efficiency. The average insulated buildings have still a mechanical ventilation flow of 0,5 Vol/h but the heat recovery from the

exhaust air has only 50% as efficiency. The badly insulated buildings represent old construction methods, without heat recovery and with 0,3 Vol/h due to air leakage.
The simulation software needs the 'Air leakage at 50 Pa q50' parameter, which consists in the outgoing air flux of the building if it is subjected at 50 Pa as pressure.
This parameter allows to define the air infiltration into the building envelope. The air infiltration have a greater effect in the heating energy than in the cooling energy; this is due to the temperature difference between the air inside and outside. During the winter season this difference is greater than the summer season and as consequence of this, the winter infiltrations produce a greater energy requirements.
For well insulated building envelopes 1 Vol/h at 50 Pa has been considered as air tightness, for average insulation buildings 2 Vol/h, while for the badly insulated envelopes 3 Vol/h.
Thermal bridges are also considered in the calculation, but to simplify the problem, only the balconies are inserted as the greater thermal bridges. Three different values have been assumed according to the insulation levels previously defined:

Table 5.4. Thermal bridge values for each category of insulation.

Type of construction	Ψ-value W/mK
Well insulation	0.3
Medium insulation	0.45
Low insulation	0.8

With these parameters the software for dynamic simulation has been compiled.

5.2 GENERAL INFORMATION ON CALCULATION

The aim of this treatment is to evaluate the thermal mass effect (exactly spoken the effect of thermal heat capacity) in the heating and cooling energy of the building. For this reason the internal walls have been considered in the simulations. They have not much influence in the energy losses, as they usually separate warm rooms at the same temperature. However the internal constructions have an important function regarding the thermal inertia of the building.

If the sunlight hits the internal walls, they will store up a certain amount of heat, depending on the heat capacity; this heat will be given back to the air when it begins to cool.

The heat flux is composed by two main components: a low-radiative wavelength flux due to the sunlight through the windows surfaces and an high-radiative wavelength due to the mutual radiation between the walls.

For this reason the internal walls have great importance both as thermal storage and to evaluate the internal temperature.

It has been chosen to consider the building as a single heated zone, in order to simplify the calculation and which therefore it's possible to obtain unit parameters giving a directly efficiency perception of the building.

The climate of the various locations is described by simple meteorological parameters:

- Average monthly temperatures;
- Average clear days for each month;
- Average cloudy days for each month.

The half cloudy days are obviously obtained as difference.

Some Italian locations have been added in order to describe the main geographic areas of the Italian territory. Aosta represents the alpine climate; Milan and Padua are two locations situated in the Po valley; Rome represents the centre Italian climate while Palermo describes the south of Italy.

Table 5.5. Climate data for 5 Italian locations: Aosta, Milan, Padua, Rome, Palermo.

Aosta	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ext.temp	-0,3	2,6	6,7	11	14,7	18,7	20,5	19,4	15,9	10,3	4,8	0,8
Clear days	11,9	8,9	12,2	8,2	6,3	6,4	9,3	8,5	9,3	8,7	12,6	13
Cloudy days	7,7	8,9	9,3	9,4	8,1	7,6	5,9	6,9	7,5	10,4	8,1	5,8

Milano	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ext.temp	1,7	4,2	9,2	14	17,9	22,5	25,1	24,1	20,4	14	7,9	3,1
Clear days	5,0	6,2	10,1	9,3	8,7	9,1	13,0	10,4	11,7	7,6	5,2	4,0
Cloudy days	17,5	14,1	11,8	8,1	5,3	4,4	1,6	4,6	4,6	11,6	16,7	16,3

Padova	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ext.temp	1,9	4	8,4	13	17,1	21,3	23,6	23,1	19,7	13,8	8,2	3,6
Clear days	6,1	7,1	10,1	6,7	7,3	7,3	10,0	10,4	11,7	9,9	7,8	8,6
Cloudy days	16,2	12,3	11,8	11,2	7,0	6,5	5,0	4,6	4,6	9,0	13,7	10,9

Roma	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ext.temp	7,6	8,7	11,4	14,7	18,5	22,9	25,7	25,3	22,4	17,4	12,6	8,9
Clear days	11,6	8,9	13,3	11,9	15,5	15,7	20,9	19,4	17,4	14,4	12,3	15,6
Cloudy days	9,8	9,0	8,0	5,2	2,4	2,1	1,0	1,2	2,1	3,6	8,4	14,8

Palermo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ext.temp	11,1	11,6	13,1	15,5	18,8	22,7	25,5	25,4	23,6	19,8	16	12,6
Clear days	10,6	10,0	15,2	13,7	18,5	20,5	22,9	22,2	20,9	14,6	14,7	16,9
Cloudy days	7,3	6,8	5,8	3,1	2,0	1,0	1,0	0,3	1,7	3,5	5,6	13,3

The temperatures have been found by Italian normative UNI 10349. The monthly clear and cloudy days have been carried out by the 'solver' function of Microsoft Excel in Consolis Energy +, repeating the monthly horizontal radiation for each month and for each location from the monthly horizontal radiation data, available in the Italian normative UNI 10349.

Furthermore, to calculate all the necessary parameters, the software needs the geographic coordinates of each location.

5.3 GENERAL RESULTS

The program gives as results the heating and cooling energy according to EN ISO 13790 and according to the dynamic simulation. Furthermore it shows the annual and monthly trend of the internal temperature, the heat gains, utilization factor and other important parameters to evaluate the buildings as the time constant and Ceff of the building.

For the eight configurations proposed above, simulated in the precedents 5 Italian climates, the heating and cooling energy have been calculated considering to keep the internal temperature between 20 and 26 °C.

Table 5.6. Heating and cooling energy for each type of building, for each location. The values are expressed in kWh/m^2a

kWh/m^2a	Aosta		Milano		Padova		Roma		Palermo	
	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING
Lw-Wi	16,4	32,2	13,1	52,7	12	46,1	1,9	71,6	0	85,5
Lw-Mi	63,2	25,6	49,1	51,3	48,2	42,5	18,4	69,6	5,6	82,1
Lw-Bi	173,9	20,5	135,9	52,5	136,2	40,9	72,7	73,4	40,8	85,4
Mw-Wi	14,7	28,6	12,2	50,2	10,8	43,5	1,7	67,8	0	81,6
Mw-Mi	55,8	18,4	44,9	45,3	43,3	36,4	13,4	61,5	3	71,3
Hw-Wi	14,4	27,9	12,0	49,8	10,6	43,0	1,6	67,2	0	81,0
Hw-Mi	59,6	17,0	47,9	43,9	46,3	34,8	14,7	59,7	3,4	69,1
Hw-Bi	226,5	4,3	177	34,2	178,8	22	91,6	50,9	43,8	56,1

The annual heat energy demand is highly conditioned to the insulation level of the building; in fact, for the same location the heating energy can vary from 17 kWh/m^2a to more than 200 kWh/m^2a. In the south of Italy the building can even have zero energy demand for heating.

The thermal mass improves slightly the heating and cooling energy demand for the buildings at the same insulation level; especially the thermal mass (active heat capacity) can dampen the external temperature variations reducing the energy requirements. The major fluctuations in temperature are during the cooling season and therefore, an increases of the thermal mass can reduce above all cooling energy while lower is the effect during the heating season.

The graph below shows an overview of the global result, obtained adding the energy demands of heating and cooling:

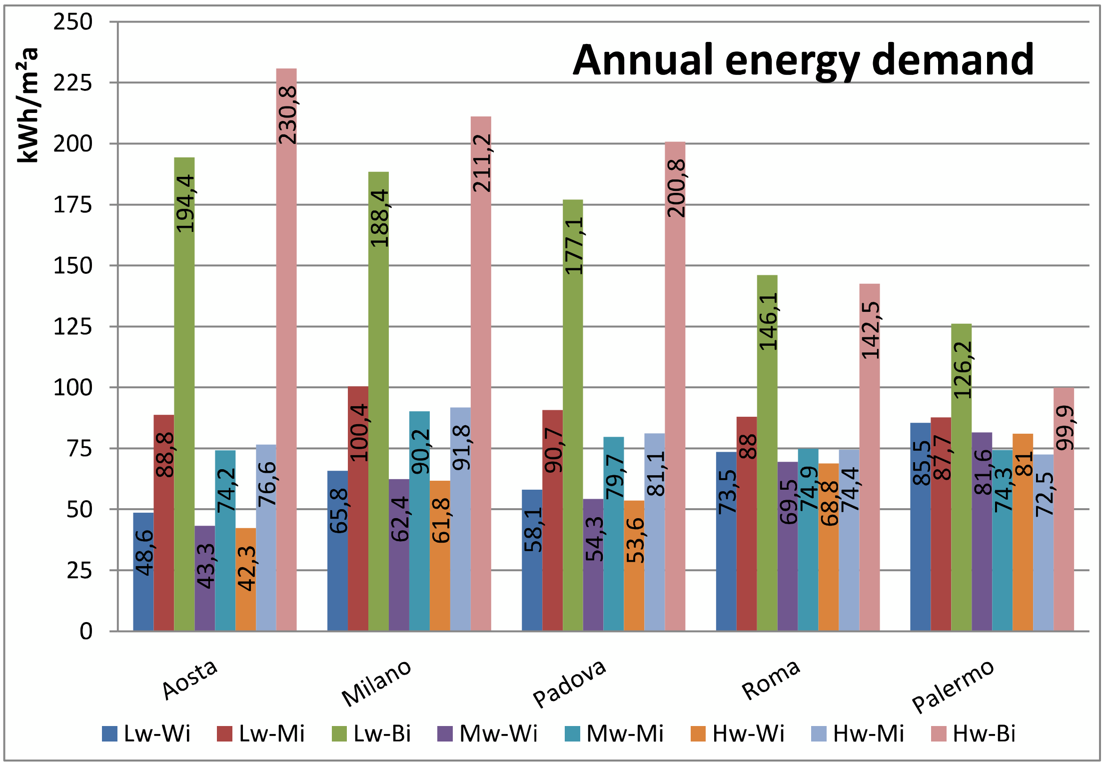


Figure 5.1. Annual total energy demand for each type of building for each city.

The badly insulated buildings generate the highest energy cost in every climate, independently from the thermal mass level. Generally it is possible to halve the energy cost making use of the solution Hw-Mi, which can be considered as a typical Italian house with the outer coat. This solution gives improvements especially in the towns of north Italy where the energy demand of the bad insulated buildings is very high due to the cold winters.

It is possible to see as Aosta, Milan and Padua give similar results. These climates are characterized of cold winters and rather hot summers (particularly Milan and Padua). In these climates, the insulation level takes fundamental importance such as to allow a considerable reduction of the energy cost.

The thermal mass basically reduces the energy demand for heating and cooling with different percentage variations respect the light weight structure depending on the climates. Dwellings with inside high thermal mass, get slightly better characteristics than the medium thermal mass constructions.

In Rome and Palermo, where the temperature are much milder, the energy demand is due almost exclusively to the cooling energy, to the point that the heating demand is almost zero in the more efficient solution. In these warm climates the active thermal mass takes further importance than the insulation, allowing sensible energy saving.

5.4 CLIMATE RESULTS

The results of the various configurations for each climate are shown below. The heating and cooling energy will be treated distinctly in order to compare the different behaviors of the buildings each other.

Aosta is the capital of the homonym Val d'Aosta region; it is situated at 600 m s.l. and represents the colder weather of this treatment which means that there is a prevalence of the winter conditions during the year. For this reason the heating energy results show an obvious dependence of the insulation level.

Increasing the thermal mass can be achieved an energy demand reduction of about 5 kWh/m²a for well insulated building envelopes and 14 kWh/m²a for average insulated building envelope. Furthermore, there is not considerable variation between the high weight constructions and medium weight constructions regarding the active heat capacity.

Milan and Padua are placed in the Po valley. The climate is characterized by cold winters and hot summers with fairly good temperature fluctuations. The results are similar than Aosta, but the cooling energy is higher. The thermal mass effect allows a reduction of the energy cost of about 3-4 kWh/m²a for well insulated building envelopes and 10-11 kWh/m²a for average and insulated building envelope.

The badly insulated buildings have almost the double energy cost respect the others mainly due to heating energy demand, which means that even a simple coat in old buildings can greatly improve their energy cost.

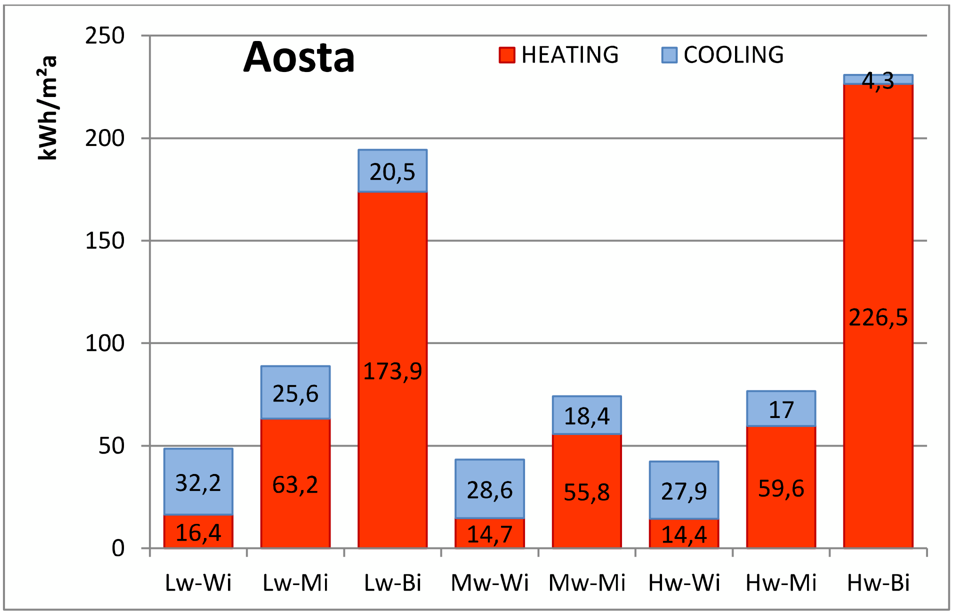


Figure 5.2. Annual heating and cooling energy required for the building situated in Aosta. Effect of the thermal mass and of the insulation level in the annual heating and cooling energy for the building situated in Aosta.

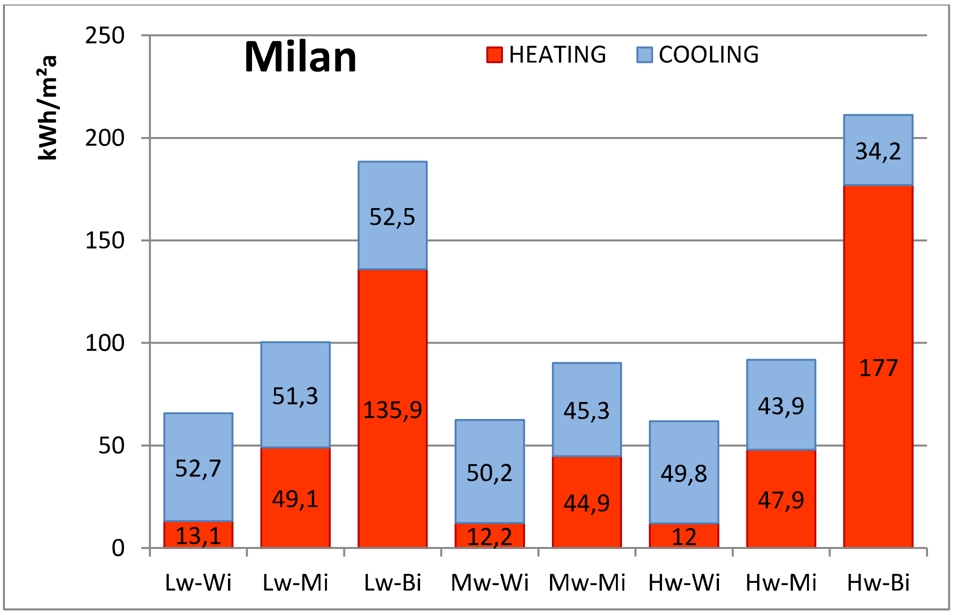


Figure 5.3. Annual heating and cooling energy required for the building situated in Milano. Effect of the thermal mass and of the insulation level in the annual heating and cooling energy for the building situated in Milano.

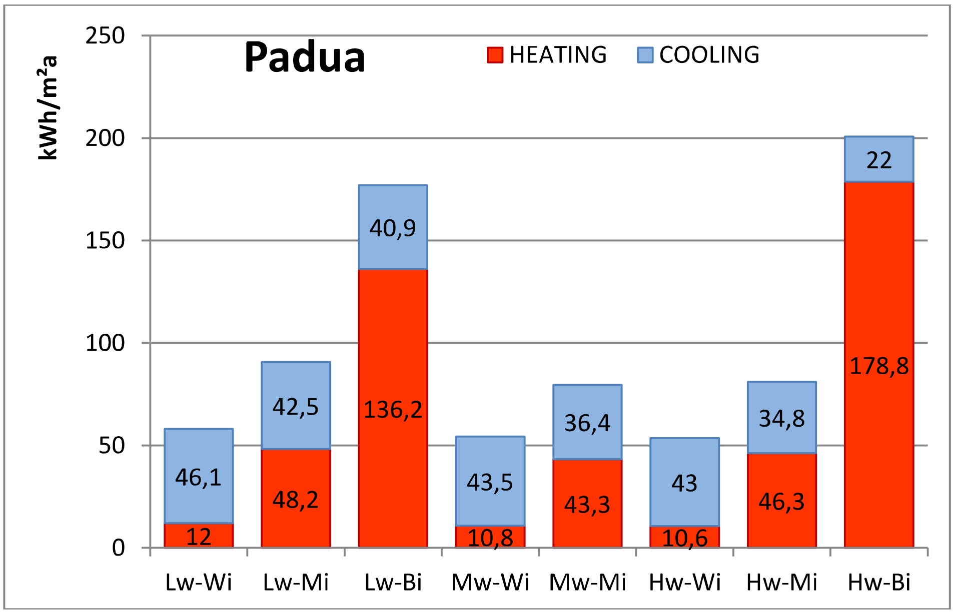


Figure 5.4. Annual heating and cooling energy required for the building situated in Padova. Effect of the thermal mass and of the insulation level in the annual heating and cooling energy for the building situated in Padova.

Rome and Palermo represent the climates of the center and southern Italy, characterized by moderate winters and hotter summers. The energy demand is above all due to the cooling season and the thermal mass assumes more importance because it allows a reduction of the temperatures fluctuations.

The best buildings for Rome in fact seem to be Well insulated - High weight and Well insulated – Medium weight constructions which need almost the same energy values. For Palermo a hyper-insulation does not significantly improve the behavior of the building. Actually the better solutions seem to be the Medium insulated - High weight construction even if the Medium insulated - Medium weight construction gives results only slightly higher.

It is possible to see as in these climates, the insulation level of the building envelope has less relevance than the north of Italy while has more importance the thermal mass (active heat capacity).

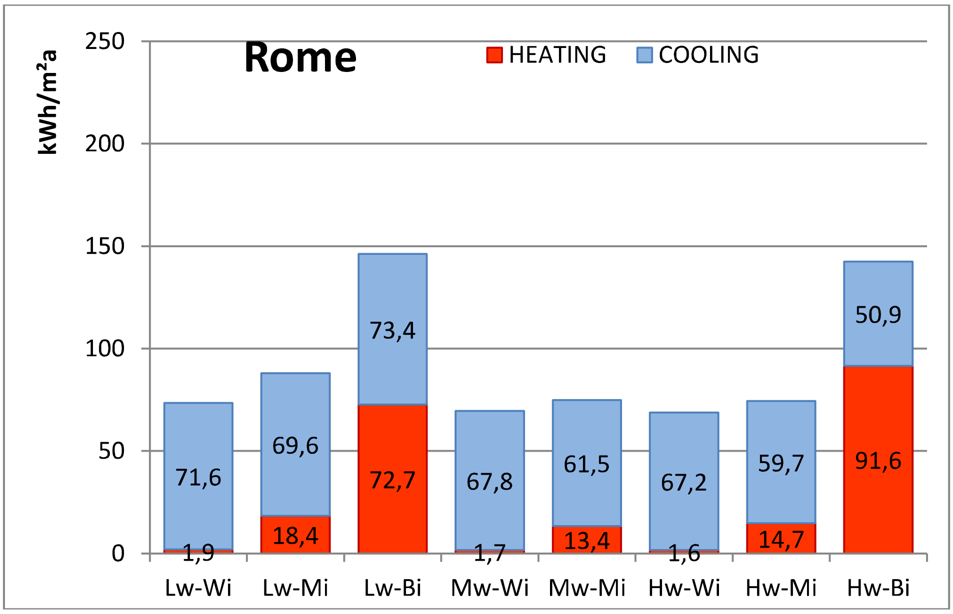


Figure 5.5. Annual heating and cooling energy required for the building situated in Roma. Effect of the thermal mass and of the insulation level in the annual heating and cooling energy for the building situated in Roma.

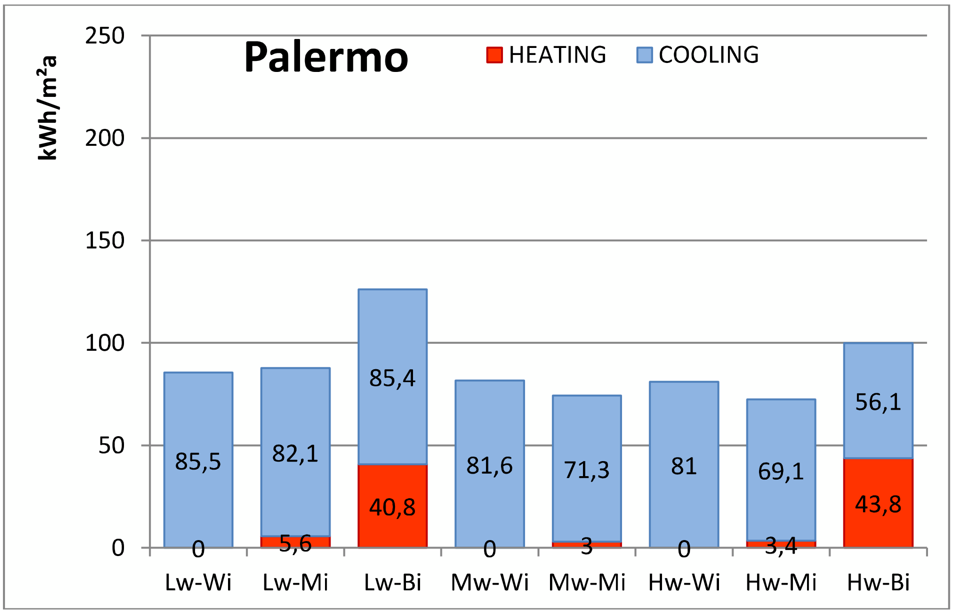


Figure 5.6. Annual heating and cooling energy required for the building situated in Palermo. Effect of the thermal mass and of the insulation level in the annual heating and cooling energy for the building situated in Palermo.

The table below summarizes the comparisons between the energy demands of the buildings at the same insulation level, showing the heating and cooling energy variations compared to the relative values for the light weight construction. For each insulation level has been taken as reference the light weight building and the table 5.7 shows how lower are the heating and cooling energy demand of the medium and high massive construction types, compared with the light weight construction.

Table 5.7. Heating and cooling energy variations between buildings at the same insulation level. For each insulation level has been taken as reference the light weight building and the table shows the improvement given by the thermal mass increment.
The values are expressed in kWh/ m^2a

kWh/m²a	Aosta		Milano		Padova		Roma		Palermo	
	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING	HEATING	COOLING
Lw-Wi	0	0	0	0	0	0	0	0	0	0
Mw-Wi	-1,7	-3,6	-0,9	-2,5	-1,2	-2,6	-0,2	-3,8	0	-3,9
Hw-Wi	-2,0	-4,3	-1,1	-2,9	-1,4	-3,1	-0,3	-4,4	0	-4,5
Lw-Mi	0	0	0	0	0	0	0	0	0	0
Mw-Mi	-7,4	-7,2	-4,2	-6,0	-4,9	-6,1	-5,0	-8,1	-2,6	-10,8
Hw-Mi	-3,6	-8,6	-1,2	-7,4	-1,9	-7,7	-3,7	-9,9	-2,2	-13,0
Lw-Bi	0	0	0	0	0	0	0	0	0	0
Hw-Bi	52,6	-16,2	41,1	-18,3	42,6	-18,9	18,9	-22,5	3,0	-29,3

Comparing the buildings each other, it is possible to say that the thermal mass reduces differently the energy use of the buildings, depending on the climate conditions. Above all the thermal mass assumes fundamental importance as to reduce the high external temperature fluctuation, which are greater in the summer season. Institute of Energy and process engineering (2006) has demonstrated which there is only a small change in the heating and cooling energy, if the time constant is between 70-210 h (high time constant is equal to high thermal mass) [5]. Let us look the table above, these claims can be confirmed in the north Italy climates while regarding to the south Italy climates (Roma and above all Palermo), higher time constants can achieve greater results.

For a correct building design should consider not only the insulation level, but also the thermal mass inside, depending on the type of climate. This paper shows that, in the north Italy climates, already an active thermal mass of $8x10^7$ J/K contributes enough to the energy cost reduction.

Different considerations must be done for the south Italy regions, where the warm climate reduces the importance of the thermal insulation but increases the importance of the thermal mass; therefore, an high weight building can further improve the energy demand. Furthermore, for Palermo the best results have been obtained with the medium insulation level of the building.

5.5 COMPARISON BETWEEN WELL INSULATED BUILDING VARYING THE EFFECTIVE THERMAL MASS

It is proceed analyzing the three types of well insulated constructions in order to understand how the thermal mass can change the energy behavior of the building. During the heating season the software gives for each month the energy contributions entering in the building which are composed by the net heating energy and the total heat sources. The total heat sources consist from the internal heat sources, such as lighting and heat from appliances and persons, and from the solar heat sources, which mainly consists from the solar radiation transmitted through windows. The total heat sources must be reduced using the monthly gain utilization factor for heating which is calculated by the software.

All these values are shown as follow for each type of well insulated configuration. In order to simplify the analysis, the simulations have been made only for Padua.

The three type of buildings in substance defer only for the different values of the heat capacity. Light weight building is characterized by an active heat capacity of Ceff=2.1x10^7 J/K and the time constant is almost of 30 h. The medium weight building is characterized by an active heat capacity of Ceff=8x10^7 J/K and a time constant of about 120 h while the high weight building has the greatest heat capacity (Ceff=1.7x10^8 J/K) and time constant that exceed 240 h.

This means that the total heat sources are used differently by the three building configurations due to a variation of the utilization factor. The light weight building uses almost 8500 kWh/y as free gain, the medium weight building uses almost 9700 kWh/y and the high weight building uses 9900 kWh/y. It is possible to say that, at the same insulation level, if the active heat capacity increases, the monthly utilization factors increase as well, reducing the heat energy demand.

The follow pages show the results of the three types of well insulated buildings, obtained by Consolis Energy + ; These constructions have almost the same insulation characteristics but different thermal masses inside.

LIGHT WEIGHT - WELL INSULATED:

Table 5.8. Light weight - Well insulated results according to EN 13790 and the dynamic method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	The year	
Temperature	1,9	4	8,4	13	17,1	21,3	23,6	23,1	19,7	13,8	8,2	3,6		
Sun in	665,0	886,6	1303,5	1347,6	1557,5	1644,3	1801,9	1663,0	1483,5	1151,6	823,8	743,9	15072	kWh
Internal heat load	688,2	621,6	688,2	666,0	688,2	666,0	688,2	688,2	666,0	688,2	666,0	688,2	8103	kWh
Total heat gain	1353,2	1508,2	1991,7	2013,6	2245,7	2310,3	2490,1	2351,2	2149,5	1839,8	1489,8	1432,1	23175	kWh
Utilization factor	0,90	0,83	0,70	0,53	0,31	0,07	0,00	0,00	0,01	0,33	0,67	0,84		
Ut. Factor Dyn calc	0,95	0,91	0,79	0,58	0,31	0,07	0,00	0,00	0,01	0,33	0,74	0,92		
Used free heat	1212,0	1253,9	1385,6	1071,3	686,0	159,6	0,0	0,0	26,0	598,8	997,7	1203,8	8595	kWh
Heat energy EN13790*	**969,6**	**647,4**	**339,2**	**109,4**	**14,2**	**0,0**	**0,0**	**0,0**	**0,0**	**14,8**	**213,4**	**657,7**	**2966**	**kWh**
Do dynamic method	**893,0**	**529,5**	**142,0**	**15,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**101,9**	**540,9**	**2223**	**kWh**
Cool energy ut f 1	**0,0**	**0,0**	**0,0**	**25,9**	**711,6**	**1343,6**	**1828,1**	**1756,8**	**1316,4**	**392,3**	**0,0**	**0,0**	**7375**	**kWh**
Do dynamic method	**0,0**	**6,9**	**243,4**	**430,8**	**854,2**	**1378,7**	**1836,7**	**1764,7**	**1350,8**	**572,9**	**96,0**	**0,0**	**8535**	**kWh**
El property household	549,9	496,7	549,9	532,2	549,9	532,2	549,9	549,9	532,2	549,9	532,2	549,9	6475	kWh
Hot water consumption	439,9	397,4	439,9	425,8	439,9	425,8	439,9	439,9	425,8	439,9	425,8	439,9	5180	kWh

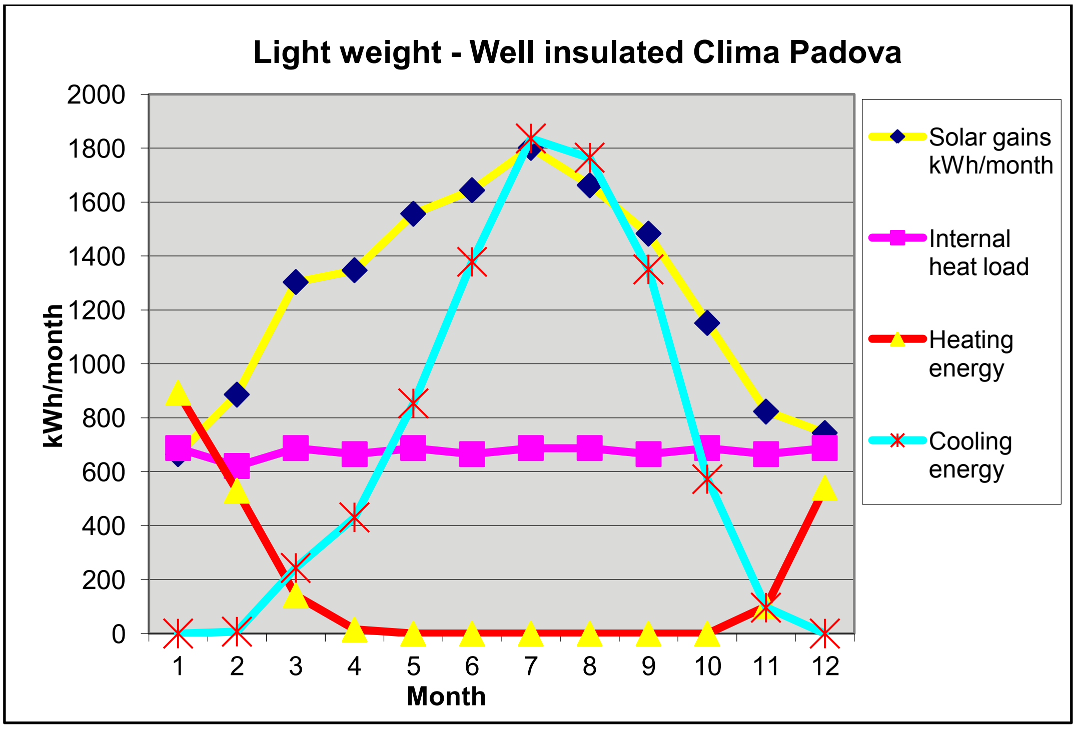


Figure 5.7. Trend of the energy contributions entering in the Light weight - Well insulated building

MEDIUM WEIGHT - WELL INSULATED:

Table 5.9. Medium weight - Well insulated results according to EN 13790 and the dynamic method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	The year	
Temperature	1,9	4	8,4	13	17,1	21,3	23,6	23,1	19,7	13,8	8,2	3,6		
Sun in	665,0	886,6	1303,5	1347,6	1557,5	1644,3	1801,9	1663,0	1483,5	1151,6	823,8	743,9	15072	kWh
Internal heat load	688,2	621,6	688,2	666,0	688,2	666,0	688,2	688,2	666,0	688,2	666,0	688,2	8103	kWh
Total heat gain	1353,2	1508,2	1991,7	2013,6	2245,7	2310,3	2490,1	2351,2	2149,5	1839,8	1489,8	1432,1	23175	kWh
Utilization factor	0,99	0,97	0,82	0,58	0,31	0,07	0,00	0,00	0,01	0,33	0,79	0,98		
Ut. Factor Dyn calc	0,99	0,94	0,80	0,59	0,31	0,07	0,00	0,00	0,01	0,33	0,75	0,98		
Used free heat	1345,8	1464,2	1640,5	1176,7	700,3	159,8	0,0	0,0	26,0	613,6	1170,0	1397,6	9695	kWh
Heat energy EN13790*	**836,0**	**437,4**	**84,7**	**4,2**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**41,2**	**464,1**	**1868**	**kWh**
Do dynamic method	**844,7**	**478,2**	**129,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**86,5**	**464,0**	**2002**	**kWh**
Cool energy ut f 1	**0,0**	**0,0**	**0,0**	**25,5**	**711,3**	**1343,3**	**1827,8**	**1756,7**	**1316,3**	**392,1**	**0,0**	**0,0**	**7373**	**kWh**
Do dynamic method	**0,0**	**0,0**	**165,4**	**334,3**	**777,2**	**1338,0**	**1815,6**	**1744,8**	**1312,0**	**503,7**	**51,8**	**0,0**	**8043**	**kWh**
El property household	549,9	496,7	549,9	532,2	549,9	532,2	549,9	549,9	532,2	549,9	532,2	549,9	6475	kWh
Hot water consumption	439,9	397,4	439,9	425,8	439,9	425,8	439,9	439,9	425,8	439,9	425,8	439,9	5180	kWh

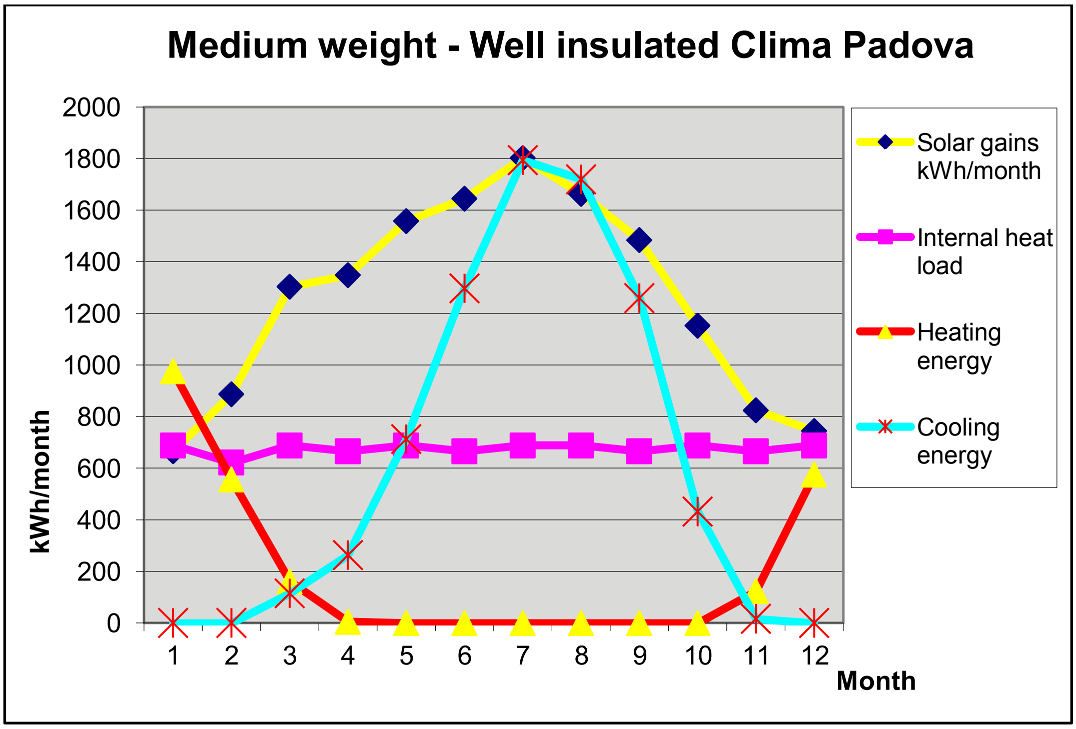


Figure 5.8. Trend of the energy contributions entering in the Medium weight - Well insulated building

HIGH WEIGHT - WELL INSULATED:

Table 5.10. High weight - Well insulated results according to EN 13790 and the dynamic method.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	The year	
Temperature	1,9	4	8,4	13	17,1	21,3	23,6	23,1	19,7	13,8	8,2	3,6		
Sun in	665,0	886,6	1303,5	1347,6	1557,5	1644,3	1801,9	1663,0	1483,5	1151,6	823,8	743,9	15072	kWh
Internal heat load	688,2	621,6	688,2	666,0	688,2	666,0	688,2	688,2	666,0	688,2	666,0	688,2	8103	kWh
Total heat gain	1353,2	1508,2	1991,7	2013,6	2245,7	2310,3	2490,1	2351,2	2149,5	1839,8	1489,8	1432,1	23175	kWh
Utilization factor	1,00	1,00	0,85	0,58	0,31	0,07	0,00	0,00	0,02	0,34	0,81	1,00		kWh
Ut. Factor Dyn calc	0,99	0,95	0,80	0,58	0,31	0,07	0,00	0,00	0,02	0,34	0,76	0,99		
Used free heat	1353,0	1502,6	1697,6	1173,7	696,6	160,0	0,0	0,0	34,9	622,4	1210,4	1428,9	9880	
Heat energy EN13790*	**824,9**	**391,9**	**18,4**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**6,5**	**433,6**	**1675**	**kWh**
Do dynamic method	**832,4**	**467,6**	**125,4**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**86,2**	**451,8**	**1963**	**kWh**
Cool energy ut f 1	**0,0**	**0,0**	**0,0**	**32,4**	**714,7**	**1342,9**	**1823,9**	**1749,2**	**1307,1**	**383,1**	**0,0**	**0,0**	**7353**	**kWh**
Do dynamic method	**0,0**	**0,0**	**156,4**	**322,6**	**767,7**	**1332,8**	**1810,2**	**1735,9**	**1297,9**	**486,7**	**43,5**	**0,0**	**7954**	**kWh**
El property household	549,9	496,7	549,9	532,2	549,9	532,2	549,9	549,9	532,2	549,9	532,2	549,9	6475	kWh
Hot water consumption	439,9	397,4	439,9	425,8	439,9	425,8	439,9	439,9	425,8	439,9	425,8	439,9	5180	kWh

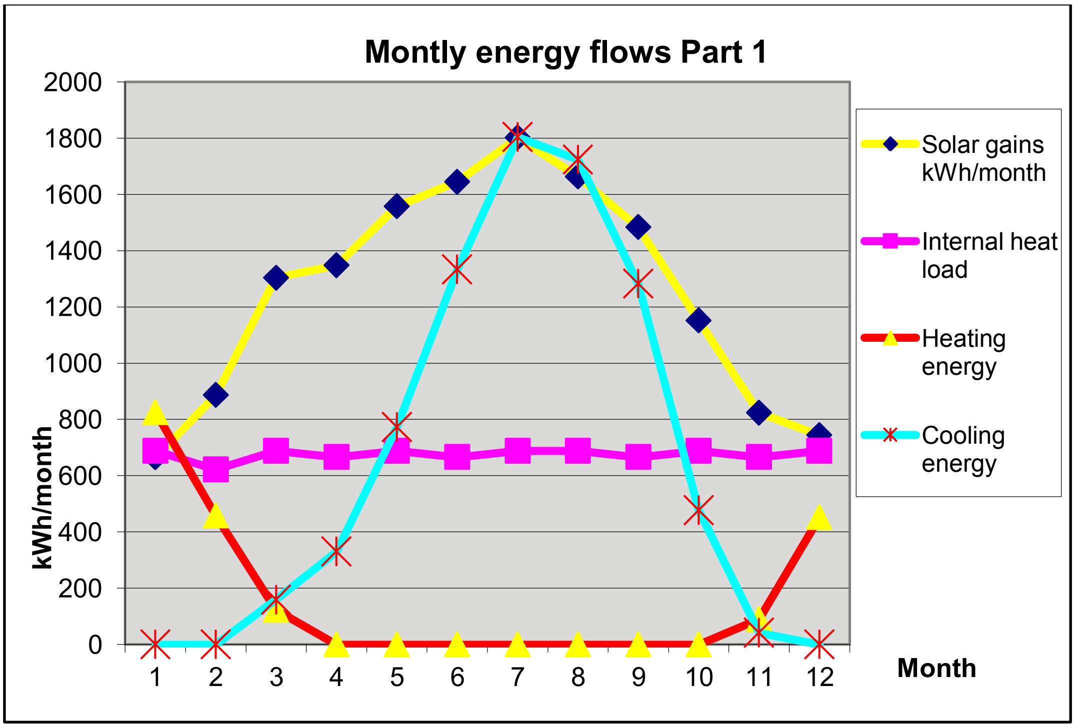


Figure 5.9. Trend of the energy contributions entering in the High weight - Well insulated building

These consideration demonstrate the many positive effects of the thermal mass. Maintaining the same insulation level, the thermal mass can be regarded as a thermal storage of energy. It decreases the cooling and heating energy, especially in the climates where there are great temperature fluctuations. Analyzing the results above, it is possible to say the medium weight building reduces the heating energy of 10% and cooling energy of 5,8%; the high weight building instead, reduces the heating energy demand of 13% and cooling energy demand of 7,3%. So, the thermal mass in the building is not negligible in a correct design building approach. For a correct building design, according to a energy efficient solution, the thermal mass should be a design parameter in national building regulations.

5.6 COOLING ENERGY REDUCTION BY A SOLAR FACTOR REDUCTION

During the cooling season the main issue of the buildings is the sun energy which enters through the window and remains inside.

However, during the normal use of the building, this energy is limited by adequate shadows.

It is possible to distinguish three type of shadows:

- Shadow due to the projection of some dwelling elements in other portions of the building envelope;
- Shadow due to nearby obstacles such as fixed screens (horizontal or vertical projections) or mobile (blinds, curtains etc.);
- Shadow due to obstructions surrounding the building, which can be other buildings, tall vegetation or orographic reliefs.

In principle, the dwellings should be designed in order to control the incident solar radiation, allowing to directly hit the building envelope in the heating season and to block it in the cooling season. This is partially possible in the Italian latitudes, where the solar height is high during the summer, and quite low during the winter. Where this is impossible to realize, the incident solar radiation should be reduced by external mobile screens during the summer season.

These precautions allow to reduce the solar heat sources during the cooling season.

For quantify the advantage due to the correct use of the shadows during the summer, it is proceed as follow.

Let us suppose to be able to properly shade the window surfaces, making a value 0.2 to the solar gain factor.

The figures below compare the cooling energy obtained previously, with the cooling energy demand, at the same condition but with 0.2 as solar gain factor.

In this way it is possible to understand the benefits of a smart use of the shadows during the summer season.

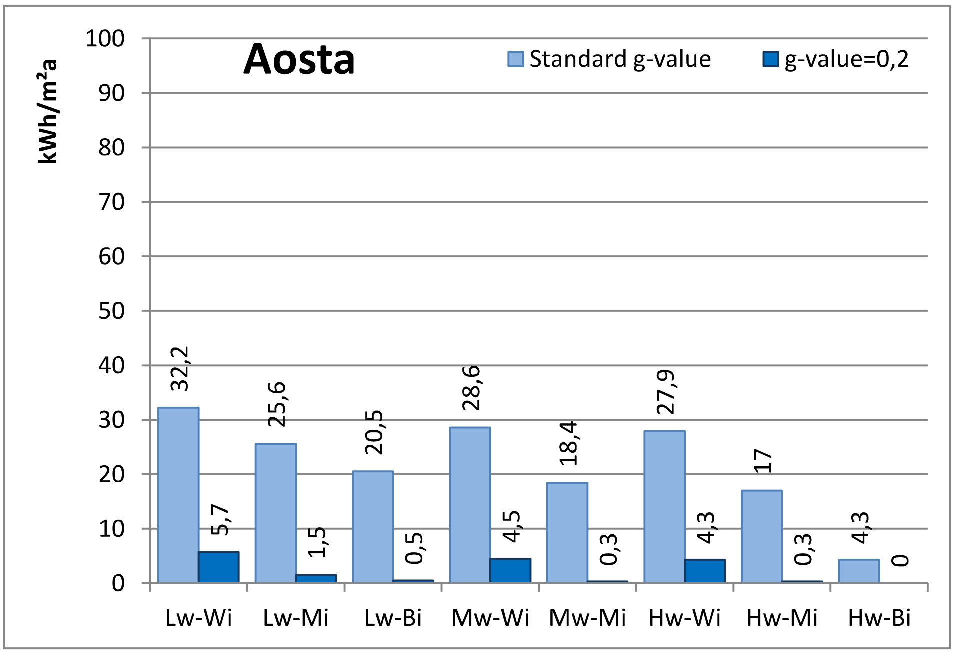


Figure 5.10. Comparison in the Aosta climate between the cooling energy demand with the standard g-value and the cooling energy demand with 0.2 as g-value.

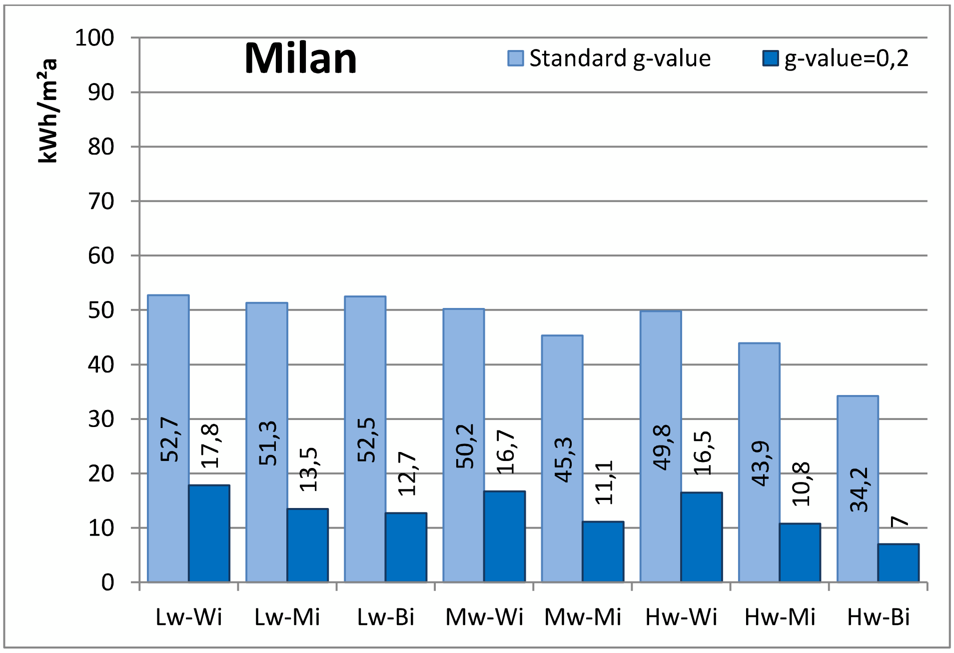


Figure 5.11. Comparison in the Milan climate between the cooling energy demand with the standard g-value and the cooling energy demand with 0.2 as g-value.

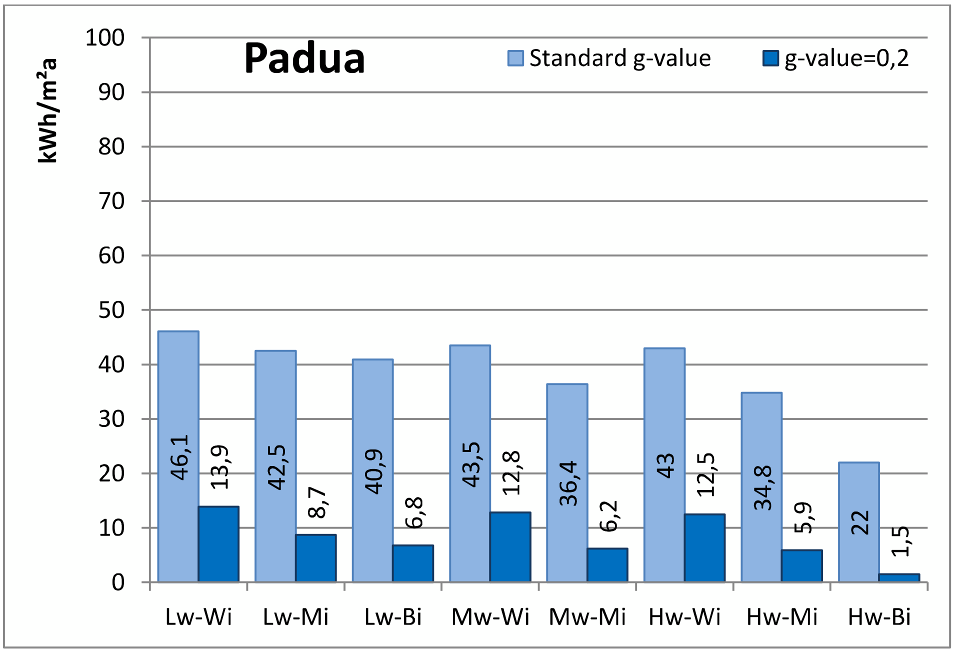


Figure 5.12. Comparison in the Padua climate between the cooling energy demand with the standard g-value and the cooling energy demand with 0.2 as g-value.

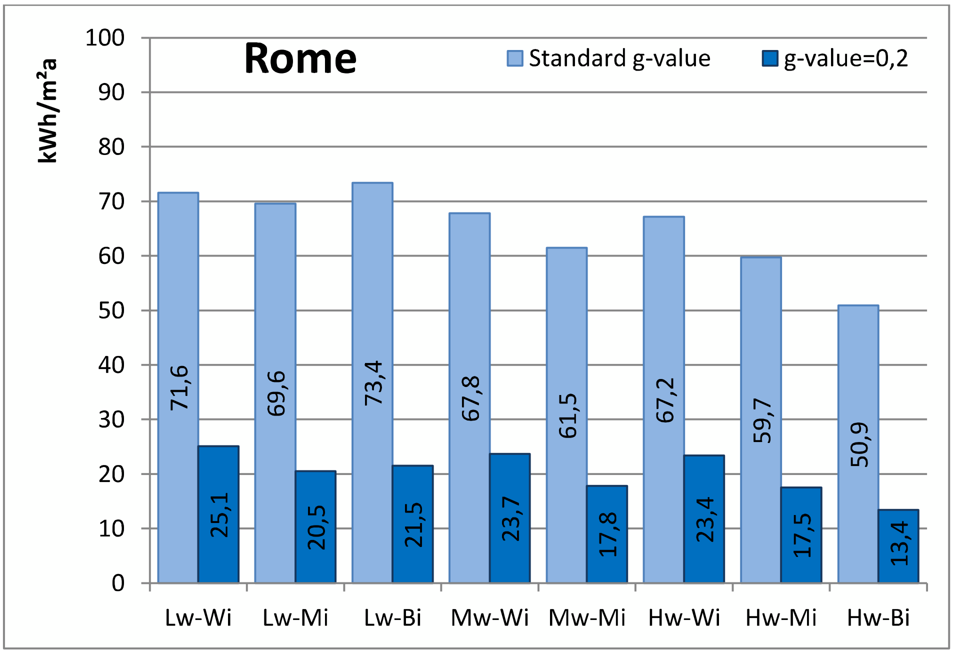


Figure 5.13. Comparison in the Rome climate between the cooling energy demand with the standard g-value and the cooling energy demand with 0.2 as g-value.

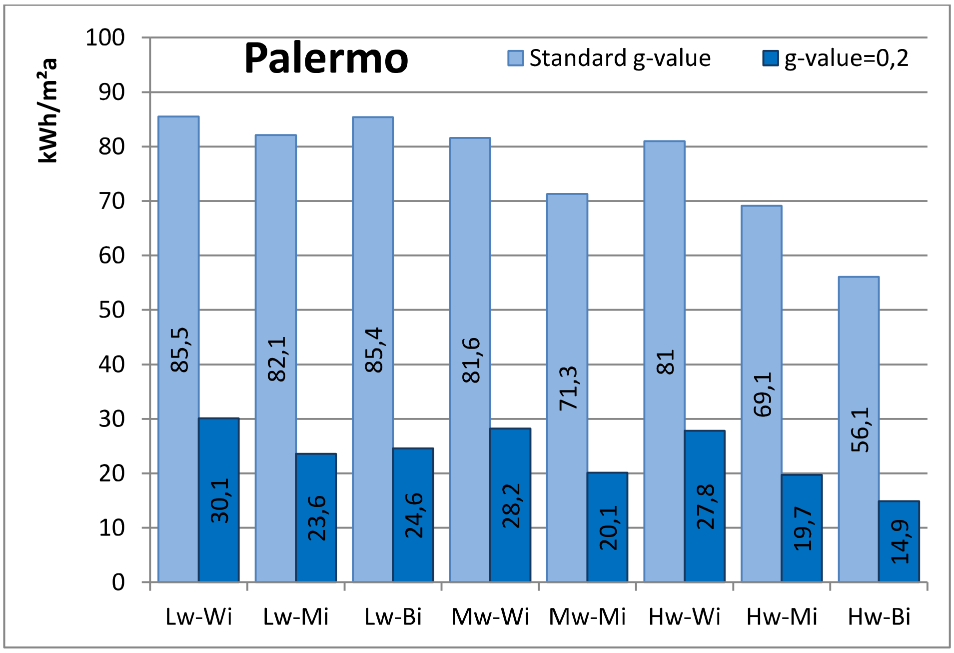


Figure 5.14. Comparison in the Palermo climate between the cooling energy demand with the standard g-value and the cooling energy demand with 0.2 as g-value.

It is possible to see as the solar gain factor affects the internal temperature of the building. A correct use of the shadows during the summer season can give important reductions in the cooling energy demand (over 50%), maintaining nevertheless the pre-set comfort levels.

Furthermore, with the lifestyle of recent years, the buildings are usually un-used during the central hours of the day. In this conditions, screen the windows completely in the warmer hours of the day during the summer period, helps the reduction of the energy cost.

Obviously this could be possible, thinking with a correct dwelling management according to the comfort of the final users.

From the results that have been obtained, the reduction of cooling energy has to be of course considered, while the heating energy has not been taken account of in these conditions. In fact the sun energy gives an important contribution to the winter heating of the building and it would not make sense not exploit it; especially in the well insulated buildings.

By way of example the improvement of the heating energy demand due to a reduction of the solar factor has been proposed below. The well insulated buildings increase their consumes of 8,5 - 9,5 kWh/m²a while the medium insulated buildings increase their consumes of 22 - 24 kWh/m²a.

The results are shown just for Padua Climate.

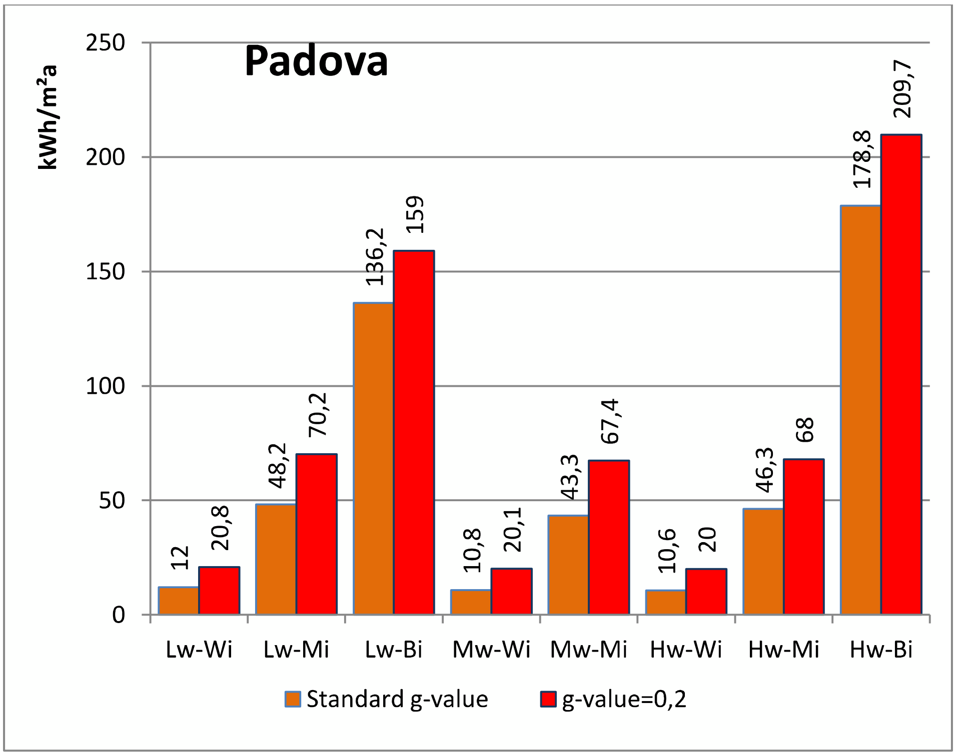


Figure 5.15. Comparison in the Padua climate between the heating energy demand with the standard g-value and the heating energy demand with 0.2 as g-value.

CHAPTER 6

ENERGY CLASSIFICATION OF THE BUILDINGS ACCORDING TO ITALIAN TECHNICAL REGULATIONS

The last topic of this thesis is the energy classification of the various types of buildings analyzed in the Chapter 5, according to the legislation currently in force in Italy. In particular, the national guidelines for energy certification (Annex A of D.M. 26 June 2009) will be followed for this analysis.

6.1 PRELIMINARY CONSIDERATIONS

The determination of the energy performance of buildings requires calculation methods as follow:

- energy requirements for heating and cooling;
- energy requirements for domestic hot water;
- efficiency and primary energy requirements for the heating season;
- efficiency and primary energy requirements for the cooling season;
- efficiency and primary energy requirement for domestic hot water;
- primary energy savings for heating and domestic hot water which can be obtained using renewable Energy and other generation methods.

These calculation methods are illustrated in the technical specifications UNI/TS 11300 – (1,2,3,4) , according with the European directive 2002/91/EC on the energy performances of buildings and European standard UNI EN ISO 13790:2008 regarding the calculation of thermal energy for heating and cooling.

The energy certification allows to give a quality evaluation of the energy demand of the buildings, in order to alert the user to the responsible use of energy, and the choice of efficient construction methods.

The energy performance certificate for buildings, with the attribution of specific performance classes, is an instrument of housing market orientation heading toward efficient dwellings. It allows an easier evaluation of the building compared with the best performances technically achievable, according to cost / benefit balance.

The global energy performance of the building is described by the rate of overall energy performance EP_{gl}:

$$EP_{gl} = EP_i + EP_{acs} + EP_e + EP_{ill} \tag{6.1}$$

Where:

EP_i : rate of energy performance for the winter climate control;

EP_{acs} : rate of energy performance for the domestic hot water;

EP_e : rate of energy performance for the summer climate control;

EP_{ill} : rate of Energy performance for the artificial lighting.

In the case of residential buildings, all the rates are expressed in kWh/m^2a , while in the case of other building types (commercial & Industrial), the rates are expressed in kWh/m^3a.

Therefore, the rate of overall energy performance EP_{gl} takes into account:

- primary energy demand for heating and cooling, for domestic hot water and for the artificial lighting;
- energy output and the auxiliary plant systems, including systems for energy self from renewable source;

However, in this start up phase still in force, for the energy certification of buildings, only the rate of energy performance for the winter climate control and the rate of energy performance for the domestic hot water have to be considered.

Different calculation methods can be used to calculate the energy performance of the buildings:

- Design calculation method, which considers the evaluation of the energy performance starting from the input data of the energy design at the moment of the realization of the building;
- Post analysis methods, which considers the evaluation of the energy performance starting from the input data analyzing directly the existing building.

These two methods are different for use and complexity; for further information refer to the D.M. 26 June 2009.

6.2 GENERAL CONSIDERATIONS ON CALCULATION

In this analysis, specific information are not available about the domestic hot water of the building, just the evaluation of the energy performance rate will be made (EP_i), following the simplified procedure available in the Annex 2 of the D.M. 26 June 2009.

EP_i can be carried out according to:

$$EP_i = \frac{(Q_h/A_{floor})}{\eta_g} \quad [kWh/m^2K] \tag{6.2}$$

Where:

Q_h: heat Energy demand of the building, expressed in kWh;

A_{floor}: heated floor area, expressed in m^2;

η_g : global average season efficiency.

In the table 5.6 the energy demands of the buildings during the winter season are already available, according to the considerations of chapter 5.

The global average season efficiency evaluates the characteristics of the heating plant as follows:

$$\eta_g = \eta_e * \eta_{rg} * \eta_d * \eta_{gn} \tag{6.3}$$

Where:

η_e: emission efficiency, values from the table 17 of UNI/TS 11300-2;

η_{rg} : regulation efficiency, values from the table 20 of UNI/TS 11300-2;

η_d: distribution efficiency, values from the table 21 of UNI/TS 11300-2;

η_{gn} : generation efficiency, values from the table 23 of UNI/TS 11300-2;

It is proceed defining the characteristics of the heat plants for the various building types. The dwellings are divided in three categories according to the insulation level.

As regarding the definition of the emission efficiency η_e, air systems are chosen for each building type. Different efficiencies are obtained according to the average annual heat load of the building (W/m^3) as specified in the UNI 11300 – 2.

The regulations efficiencies are defined according to the insulation level as well:

- Well insulated buildings: environment climate control with more control PI or PID Type, with 0,995 as efficiency;
- Average insulate buildings: zone climate control with proportional band regulator of 1°C, with 0,98 as efficiency;
- Low insulated buildings: location control with proportional band regulator of 2°C, with 0,95 as efficiency.

The distribution efficiencies are defined according to the table 21 of UNI 11300 –2; 0,99 is taken for the well insulated and medium insulated buildings, while 0,98 is taken for the low insulated buildings.

The generations efficiencies are classified as follow:

- Well insulated buildings: condensing boiler with efficiency 1,04;
- Medium insulated buildings: sealed chamber boiler type C for autonomous classified systems, with efficiency 0,93;
- Low insulated buildings: atmospheric boiler type B, with efficiency 0,9.

With these considerations it is possible to carry out, for each building, the primary energy demand for heating according to the equation (6.2).

6.3 ENERGY CLASSIFICATION OF THE BUILDINGS

The energy classification divides the buildings performances in eight energy classes; belonging to each class is described in the Table 6.1 which shows the limits of each class. The figure 6.1 show how the energy classes are shared.

Table 6.1. Limits for each class. They depend on the EP_i (limit 2010) which is available in the table 6.2.

	CLASSE A_i +	< 0,25 EPi(limite 2010)
0,25 EPi(limite 2010) ≤	CLASSE A_i	< 0,50 EPi(limite 2010)
0,50 EPi(limite 2010) ≤	CLASSE B_i	< 0,75 EPi(limite 2010)
0,75 EPi(limite 2010) ≤	CLASSE C_i	< 1,00 EPi(limite 2010)
1,00 EPi(limite 2010) ≤	CLASSE D_i	< 1,25 EPi(limite 2010)
1,25 EPi(limite 2010) ≤	CLASSE E_i	< 1,75 EPi(limite 2010)
1,75 EPi(limite 2010) ≤	CLASSE F_i	< 2,50 EPi(limite 2010)
	CLASSE G_i	≥ 2,50 EPi(limite 2010)

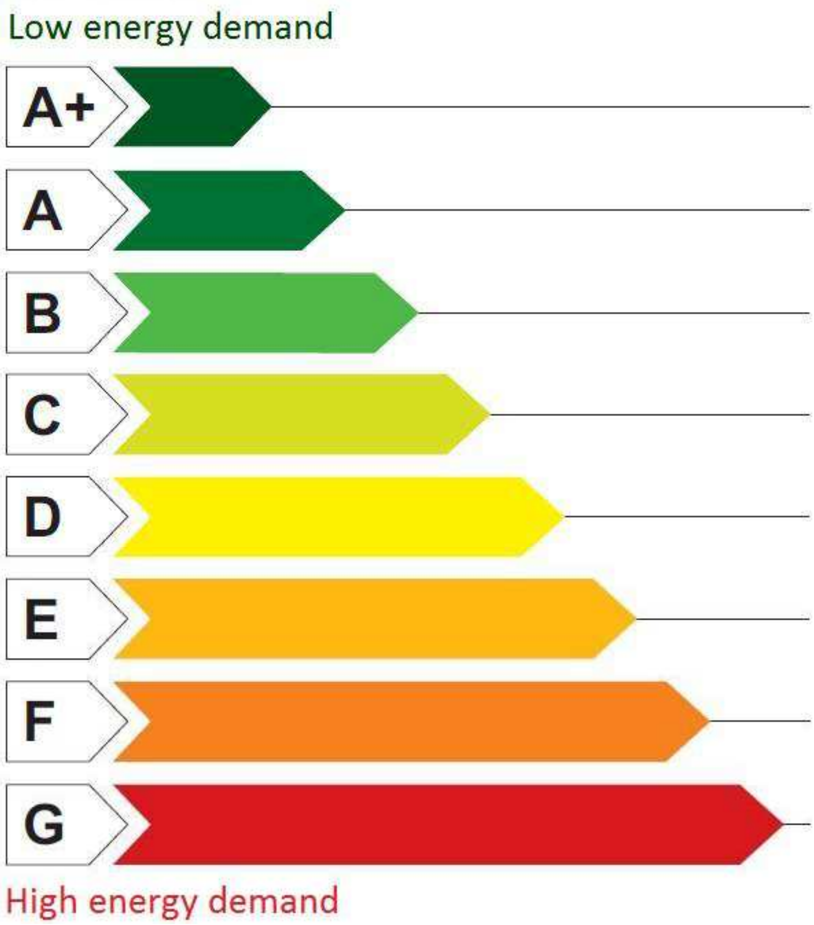


Figure 6.1. Energy classes according to Italian technical regulation.

The EP_i (limit 2010) values of the table 6.1 depend on the climatic area of the various locations (with the degree day parameter), and on the floor/volume ratio. The EP_i (limit 2010) value represents the maximum energy demand of the building in order to belong on C class.

The limit energy demands for each class are shown in the table 6.2 as follow:

Table 6.2. The EP_i (limit 2010) which is function of the degree day parameter and the floor/volume ratio.

	EP_i limite dal 1 gennaio 2010 (valori in **kWh/m² anno**)									
S/V	**Zona climatica**									
	A	B		C		D		E		F
	<600 GG	601 GG	900 GG	901 GG	1400 GG	1401 GG	2100 GG	2101 GG	3000 GG	>3000 GG
≤0.2	**8.5**	**8.5**	**12.8**	**12.8**	**21.3**	**21.3**	**34**	**34**	**46.8**	**46.8**
≥0.9	**36**	**36**	**48**	**48**	**68**	**68**	**88**	**88**	**116**	**116**

The EP_i (limit 2010) is weighted according to the floor surface/volume ratio of the building and the table gives the extreme values, respectively for the ratios S/V=0,2 and S/V=0,9. The analyzed building has been considered with ratio S/V=0,37. The EP_i (limit 2010) for each location has been carried out, weighted with the degree day.

AOSTA:

Degree day (GG) 2850 therefore Aosta is in climate zone E;

The EP_i (limit 2010) value achieved is 60,9 kWh/m^{2}a.

MILAN:

Degree day (GG) 2404 therefore Milan is in climate zone E;

The EP_i (limit 2010) value achieved is 52,7 kWh/m^{2}a.

PADUA:

Degree day (GG) 2850 therefore Padua is in climate zone E;

The EP_i (limit 2010) value achieved is 52,3 kWh/m^{2}a.

ROME:

Degree day (GG) 1415 therefore Rome is in climate zone D;

The EP_i (limit 2010) value achieved is 33,0 kWh/m^{2}a.

PALERMO:

Degree day (GG) 751 therefore Palermo is in climate zone B;

The EP_i (limit 2010) value achieved is 18,3 kWh/m^{2}a.

The table (6.3) shows the primary energy demand for heating, calculated as said above, for all types of building, for each location.

Alongside of the primary energy demand for heating, the energy classes of each building have been reported, according to the national guidelines for energy certification available in the Annex A of the D.M. 26 June 2009.

Table 6.3. Primary energy demand for heating and energy classes, for each type of building and for each location. The results are calculated according the national guidelines in the D.M. 26 June 2009.

kWh/m²a	Aosta		Milano		Padova		Roma		Palermo	
	PRIMARY ENERGY	BUILDING CLASS	PRIMAR ENERGY	BUILDING CLASS	PRIMARY ENERGY	BUILDING CLASS	PRIMARY ENERGY	BUILDING CLASS	PRIMARY ENERGY	BUILDING CLASS
Lw-Wi	17,0	A	13,6	A	12,5	A+	2,0	A+	0,0	A+
Lw-Mi	76,1	E	59,1	D	58,1	D	21,7	B	6,6	A
Lw-Bi	230,6	G	180,2	G	180,6	G	96,4	G	54,1	G
Mw-Wi	15,3	A	12,7	A+	11,2	A+	1,8	A+	0,0	A+
Mw-Mi	67,2	D	54,1	D	52,2	C	15,8	A	3,5	A+
Hw-Wi	15,0	A+	12,5	A+	11,0	A+	1,7	A+	0,0	A+
Hw-Mi	71,8	D	57,7	D	55,8	D	17,3	B	4,0	A+
Hw-Bi	300,4	G	234,7	G	237,1	G	121,5	G	58,1	G

It can be seen that there are fewer restrictions in the warm climates of southern Italy, where the primary energy demand for heating reaches very low values.

For this regions, the energy classification of the cooling energy demand would be very important. The technical specifications UNI 11300 – 3 considers this, but it has not entered into force yet.

This study has compared directly different types of buildings in the same climates, evaluating the different energy demands. The aim of these results is to encourage the construction of high efficiency houses by raising awareness among actors in the housing market on the aspects of energy saving, reducing the energy demand and the air pollution.

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APPENDIXES

A. SYMBOL FOR CALCULATION CASES

The following specifications are used for identification the calculation cases.

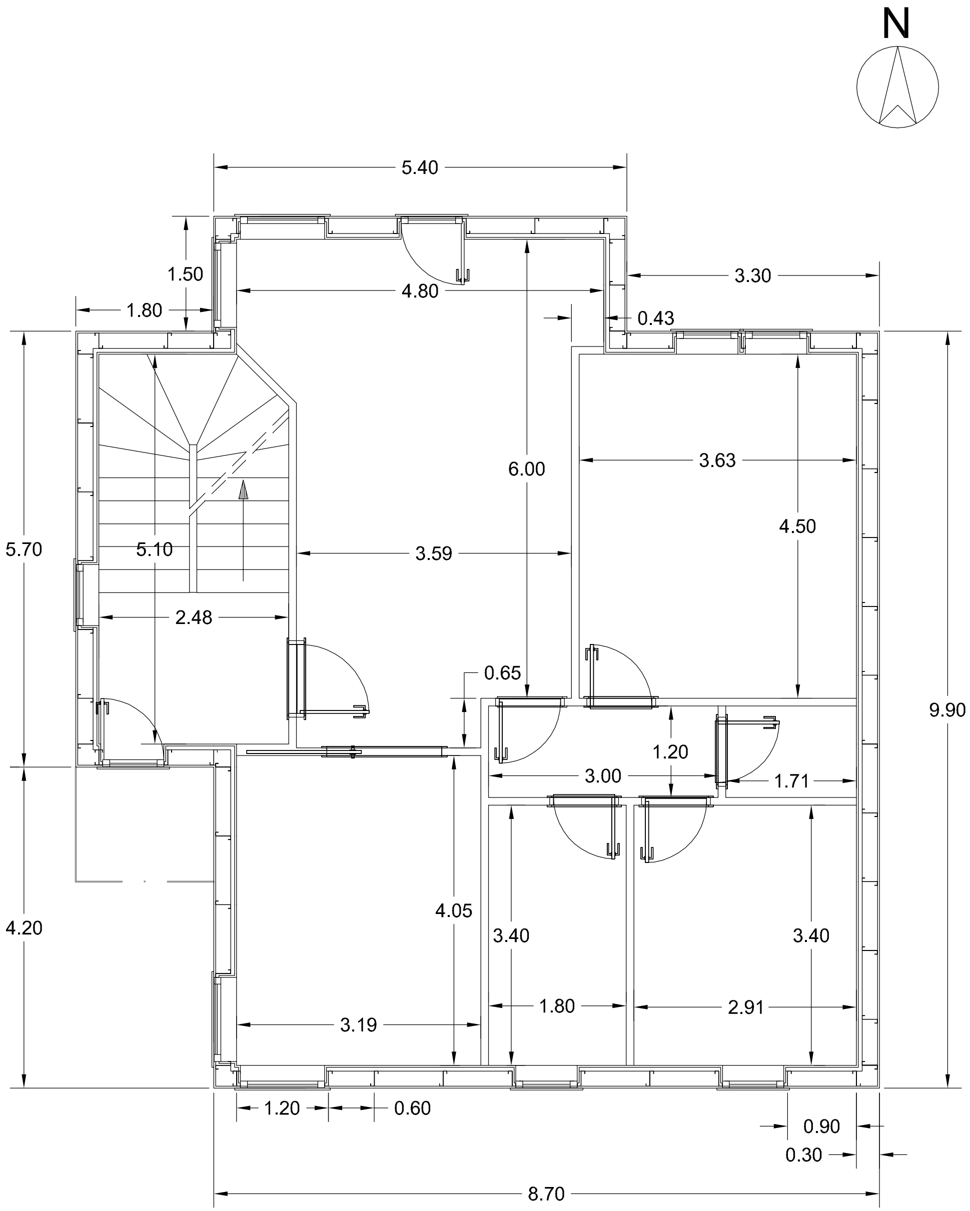
1. Construction type:

Lw-Wi	Light weight - Well insulation;
Lw-Mi	Light weight - Medium insulation;
Lw-Li	Light weight - Low insulation;
Mw-Wi	Medium weight - Well insulation;
Mw-Mi	Medium weight - Medium insulation;
Hw-Wi	High weight - Well insulation;
Hw-Mi	High weight - Medium insulation;
Hw-Li	High weight - Low insulation;

B. BUILDINGS DRAFT

The follow pages show the drafts of the building.
They are composed by 10 sheets:

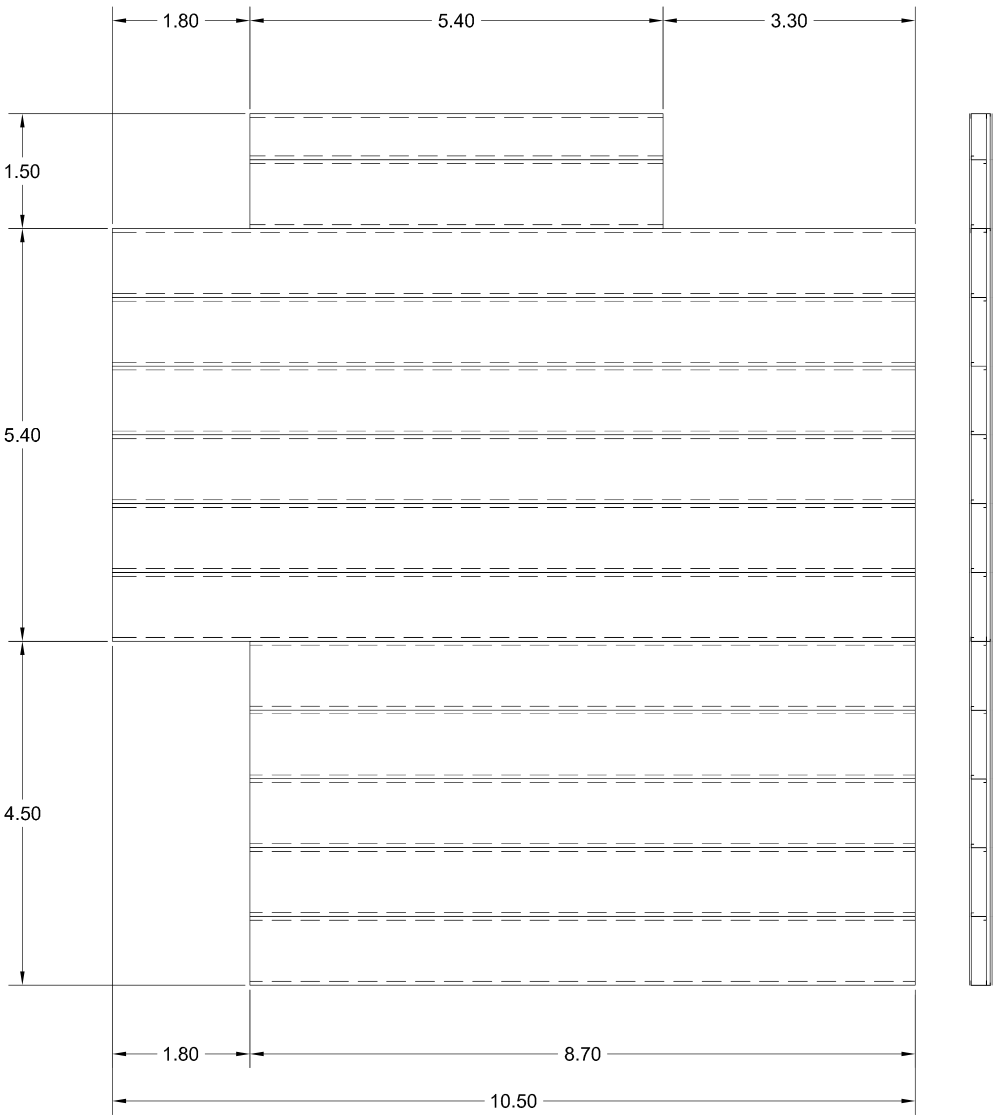
- Down floor;
- Insole;
- First floor;
- Roof;
- Foundation;
- Sections;
- West façade;
- South façade;
- North façade;
- East façade.



	n° 10 CORNER 30x30 cm
	n° 0 ELEMENT 120x30 cm
	n° 26 ELEMENTS 90x30 cm
	n° 10 ELEMENTS 60x30 cm
	n° 5 WINDOWS 80 cm (ELEMENT 90x30)
	n° 4 WINDOWS 110 cm (ELEMENT 120x30)
	n° 2 OUTER DOOR 80 cm (ELEMENT 90x30)

Down floor

DESCRIPTION	DATE	SCALE
DOWN FLOOR	October 2012	1:100
	STUDENT	
	DAL CASON ALBERTO	



n° 5 ELEMENTS 90x870 cm

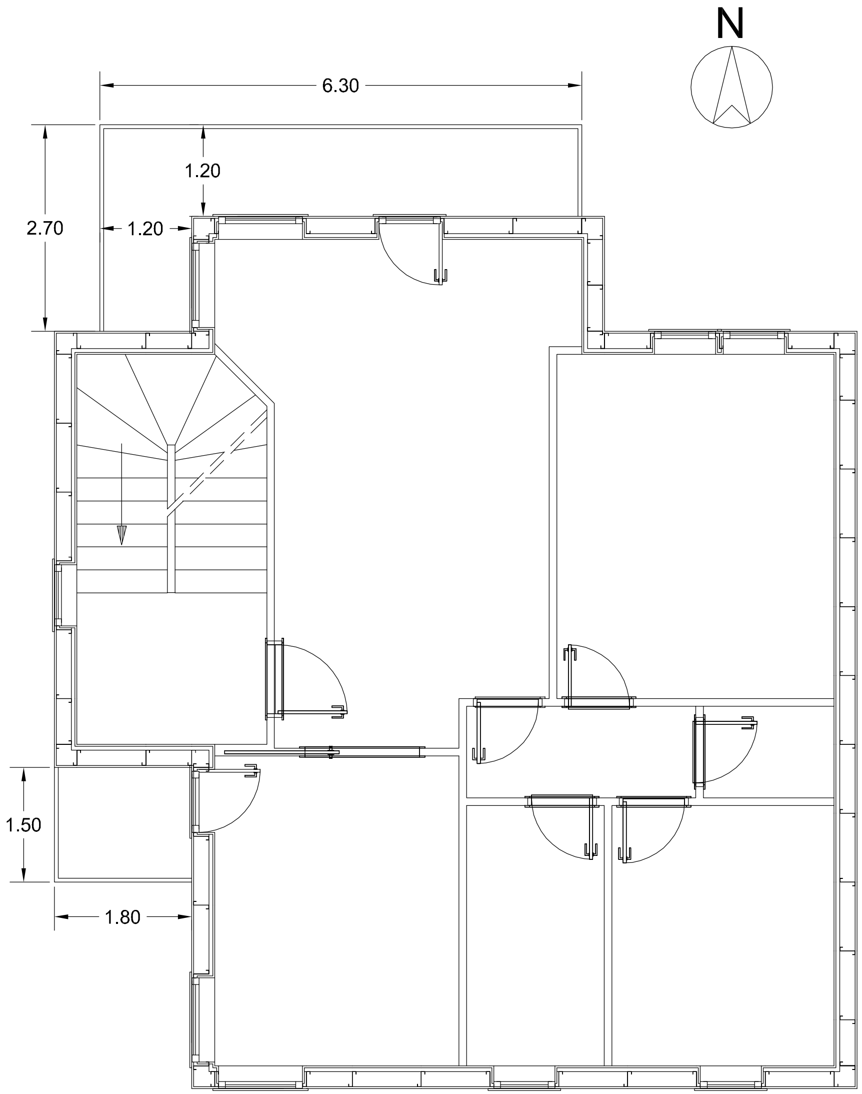
n° 6 ELEMENTS 90x1050 cm

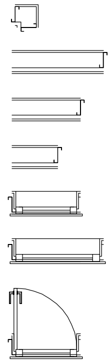
n° 1 ELEMENTS 60x540 cm

n° 1 ELEMENTS 90x540 cm

Insole

DESCRIPTION	DATE	SCALE
INTERNAL STRUCTURE (CEILING/FLOOR)	October 2012	1:100
	STUDENT: DAL CASON ALBERTO	





n° 10 CORNER 30x30 cm

n° 0 ELEMENT 120x30 cm

n° 26 ELEMENTS 90x30 cm

n° 10 ELEMENTS 60x30 cm

n° 5 WINDOWS 80 cm (ELEMENT 90x30)

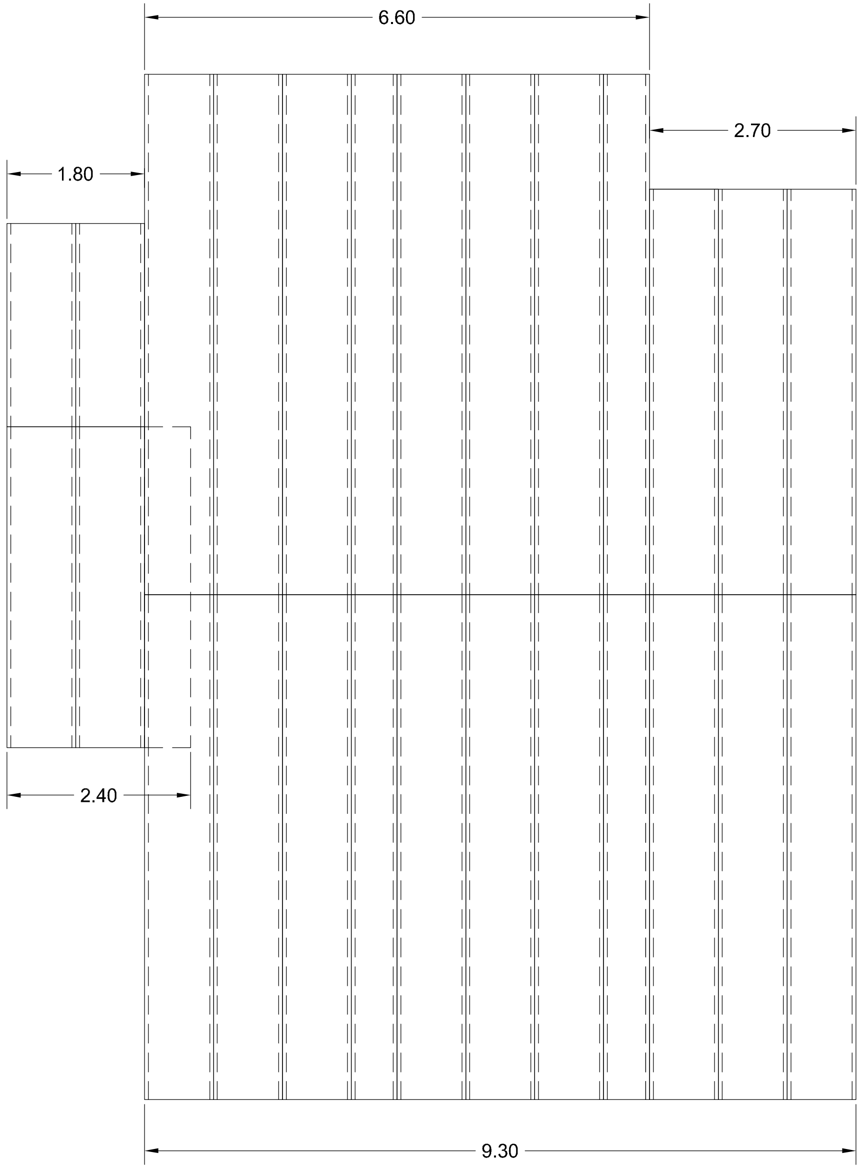
n° 4 WINDOWS 110 cm (ELEMENT 120x30)

n° 2 OUTER DOOR 80 cm (ELEMENT 90x30)

First floor

DESCRIPTION	DATE	SCALE
FIRST FLOOR	October 2012	1:100
	STUDENT	
	DAL CASON ALBERTO	

A4



n° 3 ELEMENTS 90x530 cm

n° 6 ELEMENTS 90x680 cm

n° 2 ELEMENTS 60x680 cm

n° 9 ELEMENTS 90x660 cm

n° 2 ELEMENTS 60x660 cm

n° 2 ELEMENTS 90x419 cm

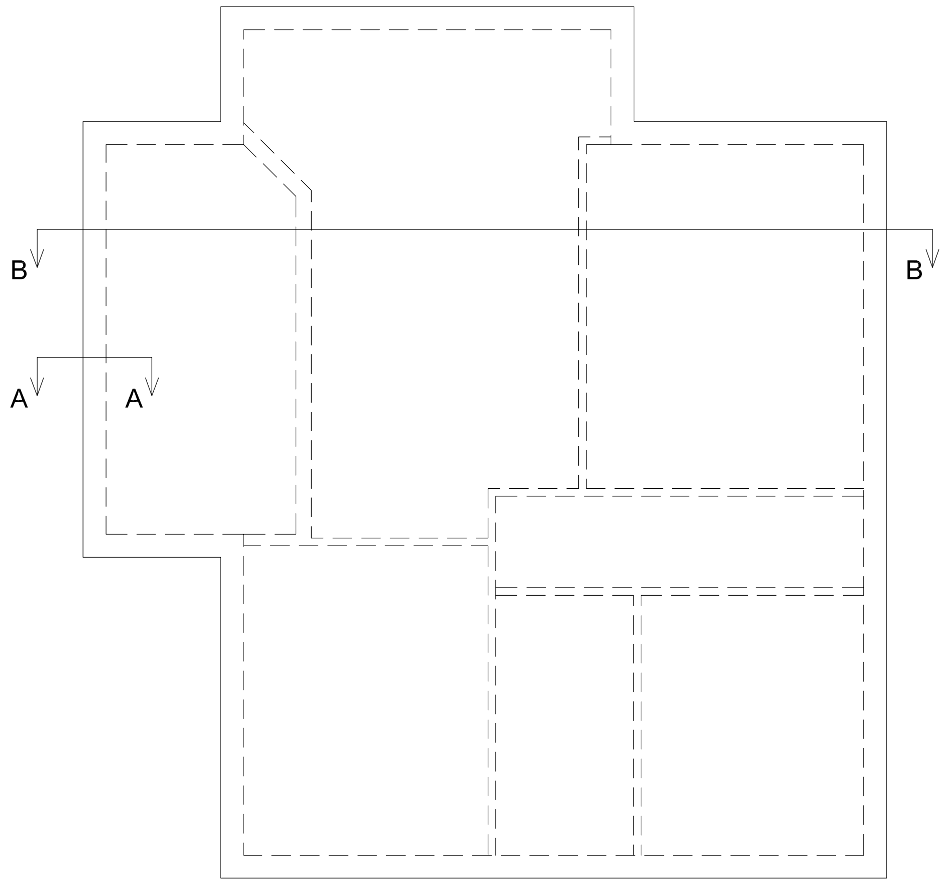
n° 2 ELEMENTS 90x266 cm

n° 1 ELEMENTS 60x419 cm

n° 1 ELEMENTS 60x266 cm

Roof

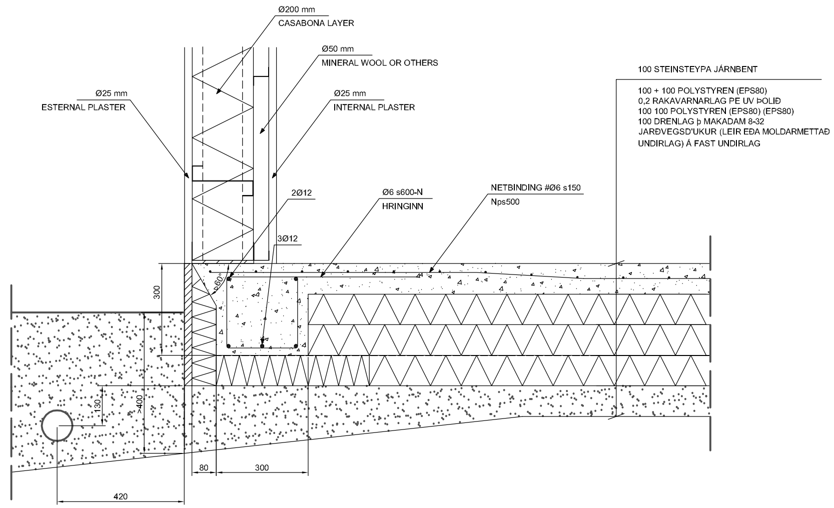
DESCRIPTION	DATE	SCALE
ROOF	October 2012	1:100
	STUDENT DAL CASON ALBERTO	



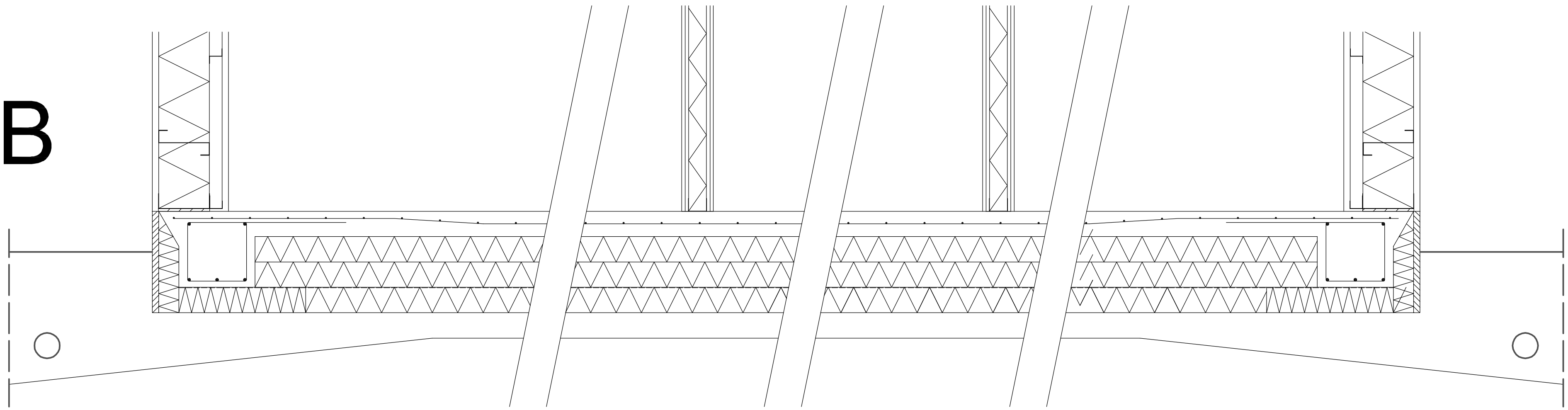
Foundation

DESCRIPTION	DATE	SCALE
FOUNDATIONS	October 2012	1:100
	STUDENT DAL CASON ALBERTO	

A

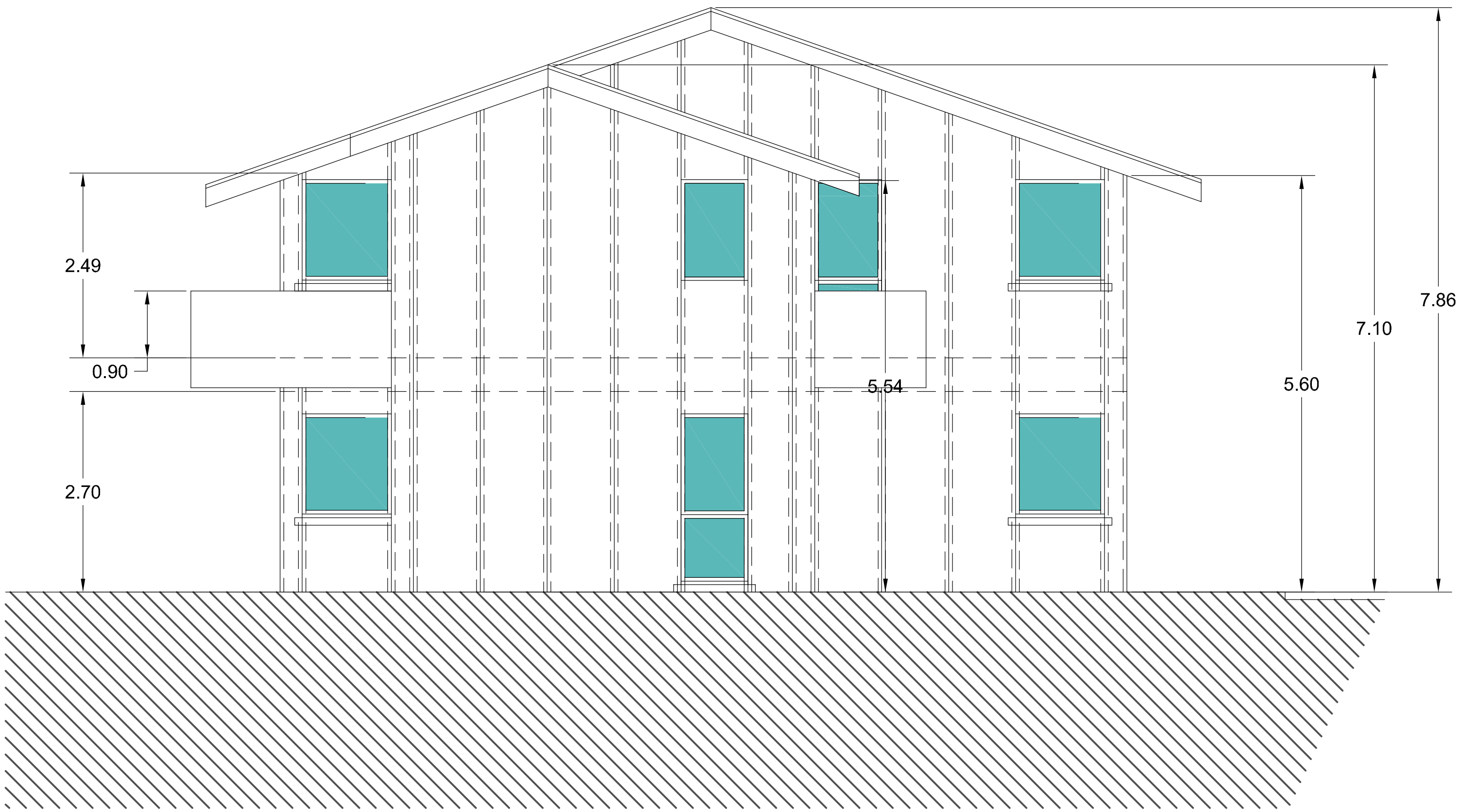


B



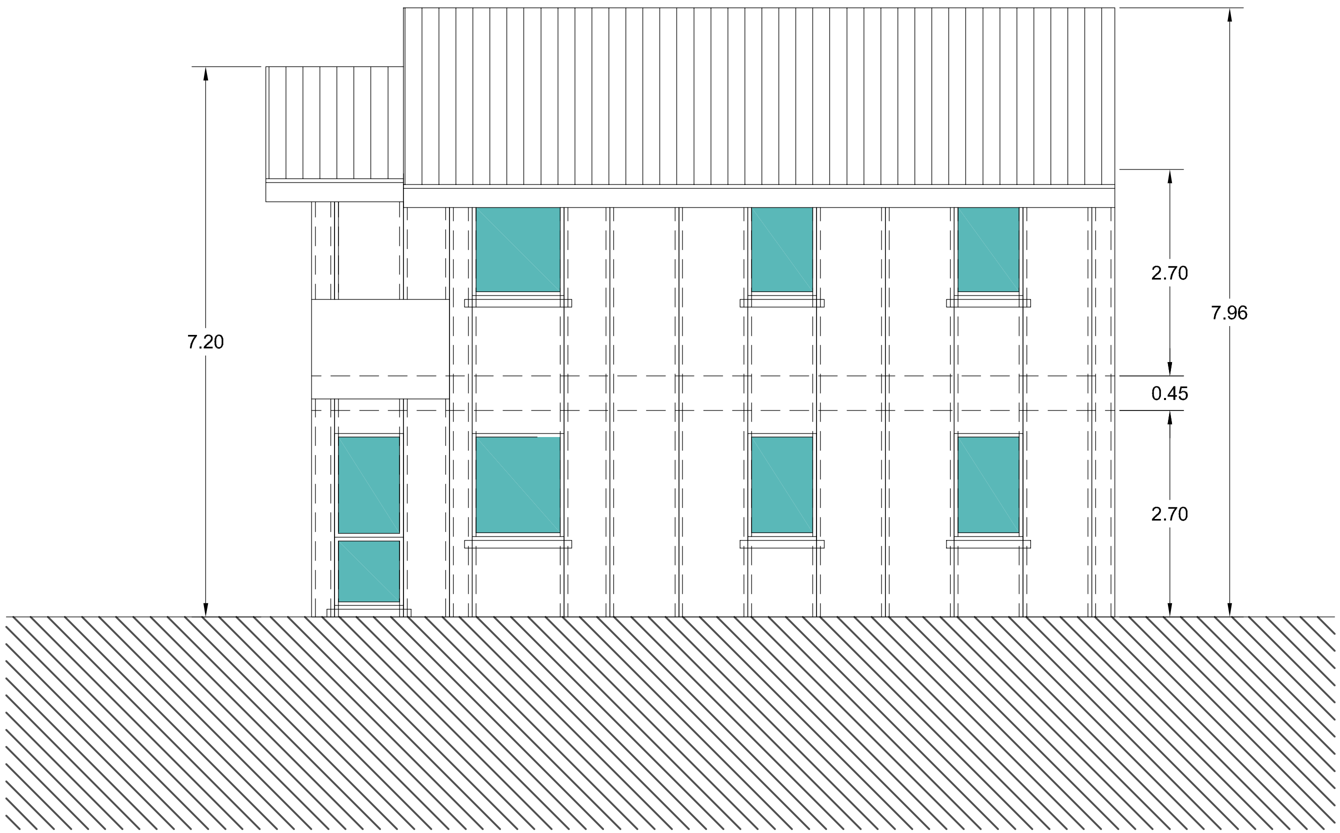
DESCRIPTION	DATE	SCALE
SECTIONS	October 2012	1:50
	STUDENT DAL CASON ALBERTO	

A4



west

DESCRIPTION	DATE	SCALE
WEST FACE	October 2012	1:100
	STUDENT	
	DAL CASON ALBERTO	



south

DESCRIPTION	DATE	SCALE
SOUTH FACE	October 2012	1:100
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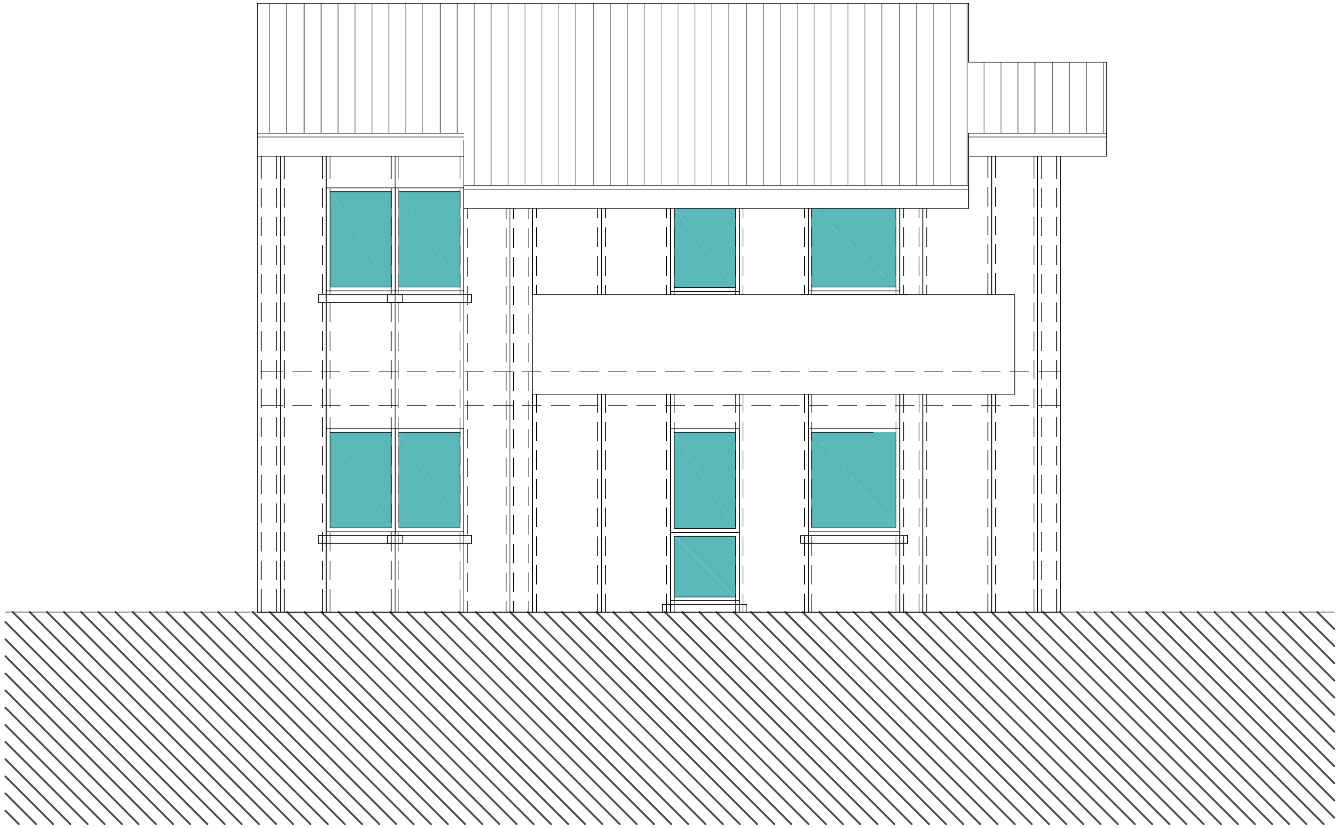
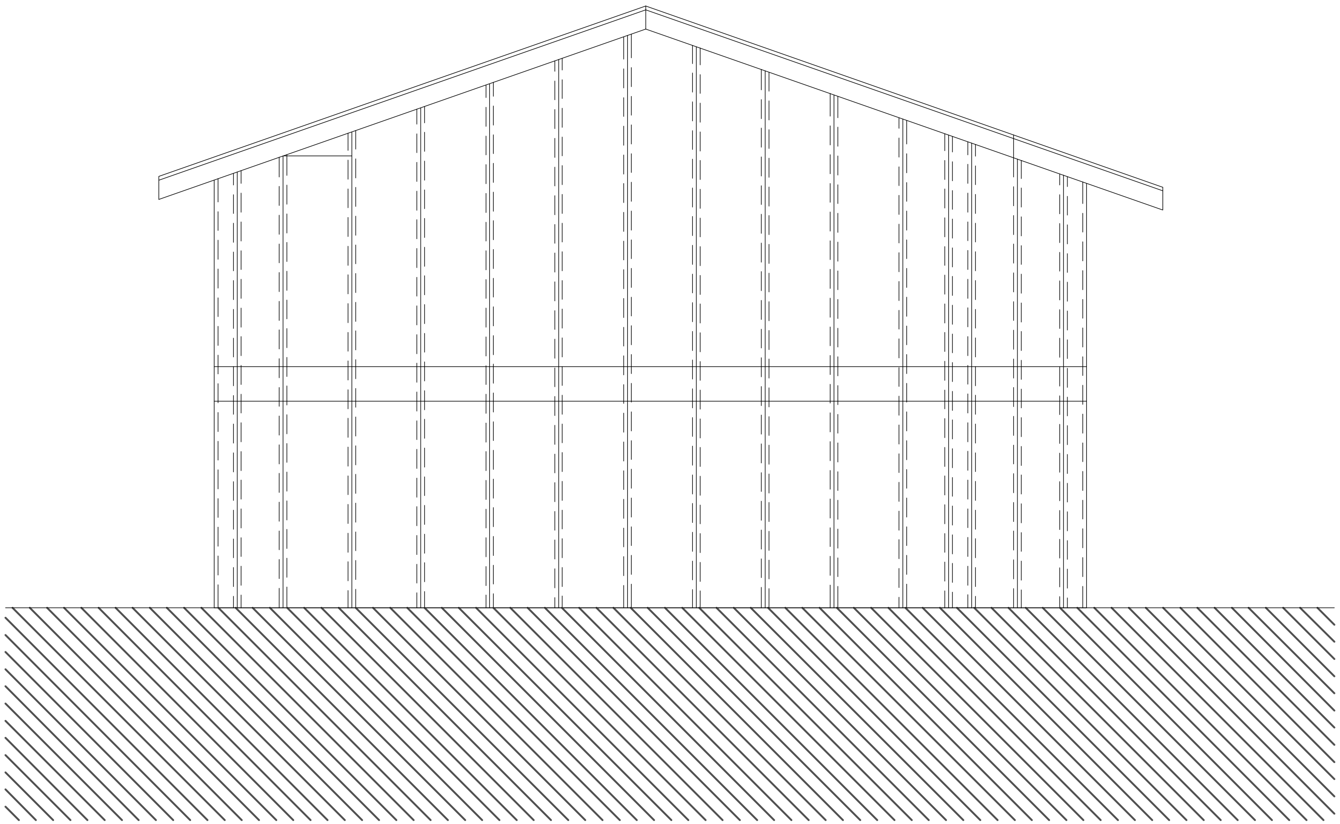


north

DESCRIPTION NORTH FACE	DATE October 2012	SCALE 1:100
	STUDENT DAL CASON ALBERTO	



east

DESCRIPTION	DATE	SCALE
EAST FACE	October 2012	1:100
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