Hellenic Aid Program for Collaboration on Energy Efficiency and Renewable Energy in Athens Energy Community Countries- "SYNENERGY" - Action 2. Energy efficiency pilot project in Chisinau Moldova.

Energy study of building Block 10 of the Public Medical-Sanitary Institution the Research Institute of Mother and Child Health Care(PMSI RIMCHC) in Chisinau, Moldova.

Assessment of a series of measures for the improvement of the energy performance of the building and quantification of the effect of their implementation.

Table of Contents

1. Introduction

Under the framework of Action 2 of the Hellenic Aid Program for Collaboration on Energy Efficiency and Renewable Energy in Athens Energy Community Countries- "SYNENERGY", Center for Renewable Energy Sources and Saving (CRES) has undertaken an energy efficiency improvement pilot project in Chişinău, Moldova. The building selected for the implementation of the project is Block 10 of Research Institute for Protection of Health of Mother and Child of the Republic of Moldova (RIPHMCRM).

Because of the special character of the building, the indoor conditions are of a major importance. The specific building has being constructed at the late '70's, without any provision on thermal insulation. That lack of insulation results to an intense consumption of energy for heating and at the same time of poor indoor conditions. Improvement of the energy performance of the building envelope leads to a reduction to the energy needed for heating, improvement of the indoor conditions and pottentially reduced costs in case of reconstruction of the HVAC system.

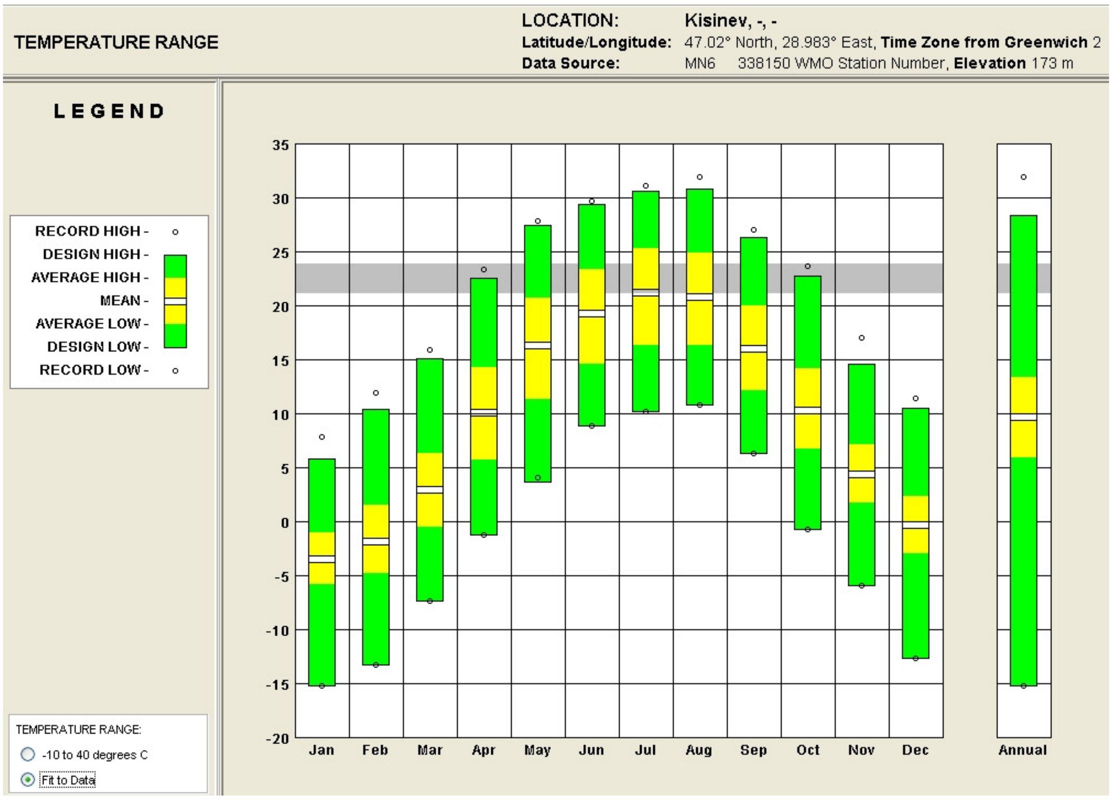
The energy and economic analysis of the energy performance of the existing building and a series of proposed measures have shown that the most efficient ones would be:

1. Thermal insulation of the flooring of the technical floor. The insulant material that shall be used is plates of extruded polystyrene XPS of high compressive strength, with thermal conductivity λ=0,035 W/(mK) and thickness d=5cm. Alternatively it can be used any material having high moisture resistance, high compressive strength and thermal resistance equivalent with the proposed one.
2. Application of an external thermal insulation composite system (ETICS) on the first and the second floor. The insulant material that shall be used is plates of expanded polystyrene EPS with thermal conductivity λ=0,038 W/(mK) and thickness d=20cm. Alternatively it can be used any material having thermal resistance equivalent with the proposed one. Special attention must be given at the application of ETICS on the reveals, heads and cills of the windows and doors.
3. Replacement of all of the windows and doors on the first and the second floor with windows and doors having thermal transmittances for the glazing $U_{glazing}$=1.20 W/(m^{2}K), for the frame U_{frame}=1.20 W/(m^{2}K) and for the opaque part of the doors U_{panel}=1.35 W/(m^{2}K). Alternatively can be used windows having a total thermal transmittance U_{window}=1.50 W/(m^{2}K) and doors U_{door}=1.50W/(m^{2}K) respectively.

The above measures shall reduce the long term energy consumption for heating from 229 kWh/m^2/year which is for the existing design, to 101 kWh/m^2/year i.e. more that 60%., and will improve dramatically the indoor conditions providing the lacking thermal comfort to the patients.

2. The climate of Chişinău

Chişinău is located at an altitude of 173m above sea level with latitude 47°02 north, and longitude 28°98 east. It has a continental climate, characterized by hot dry summers and cold windy winters. Winter temperatures are often below 0°C, although they rarely drop below −10°C. The heating degree days are 3337. In summer, the average temperature is approximately 25°C, however, temperatures sometimes reach 35°C in mid-summer in the city center. The cooling degree days are 325. Although average precipitation and humidity during summer is low, there are infrequent yet heavy storms. Spring and autumn temperatures vary between 16–24°C, and precipitation during this time tends to be lower than in summer but with more frequent yet milder periods of rain.



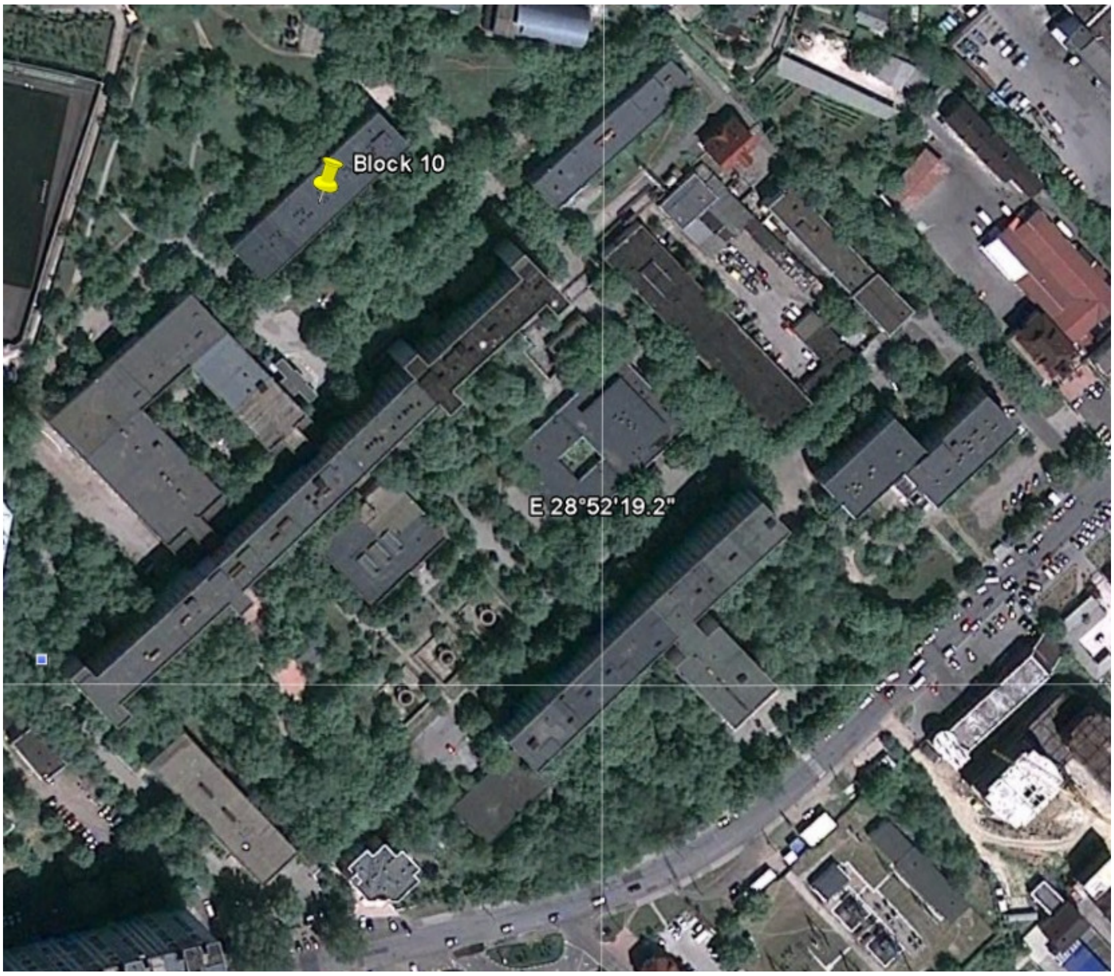
Picture 1: Temperature range in Chisinau

For the analysis that will follow there has been created a weather data file the city Chişinău with the use of the database-software Metonorm v.6 .The weather file contains hourly values of the many different climatic data including air temperature, direct normal radiation, diffuse radiation, wind direction and velocity etc.

3. Building description

3.1. General Data

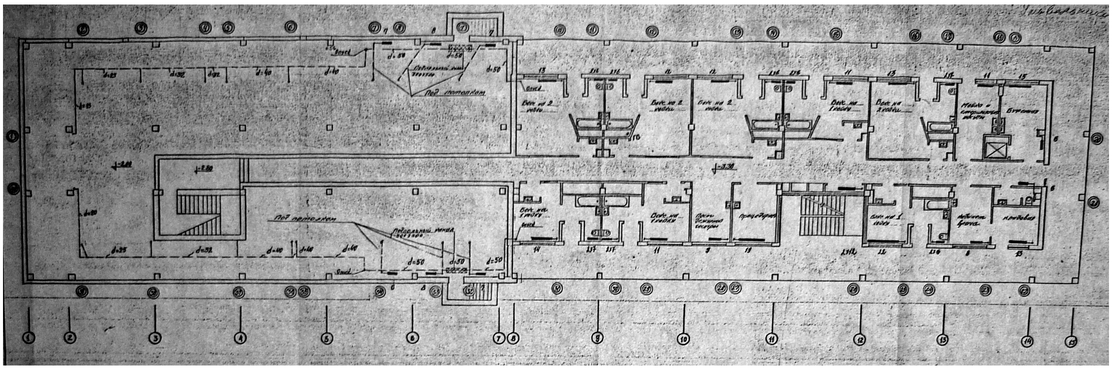
The Research Institute for Protection of Health of Mother and Child of the Republic of Moldova (RIPHMCRM) is a medical institution situated in Chisinau, Moldova. There are 19 blocks on the territory of RIPHMCRM. Block 10 has been selected for the implementation of the energy efficiency improvement pilot project in Moldova.



Picture 2: Aerial view of the Research Institute for Protection of Health of Mother and Child

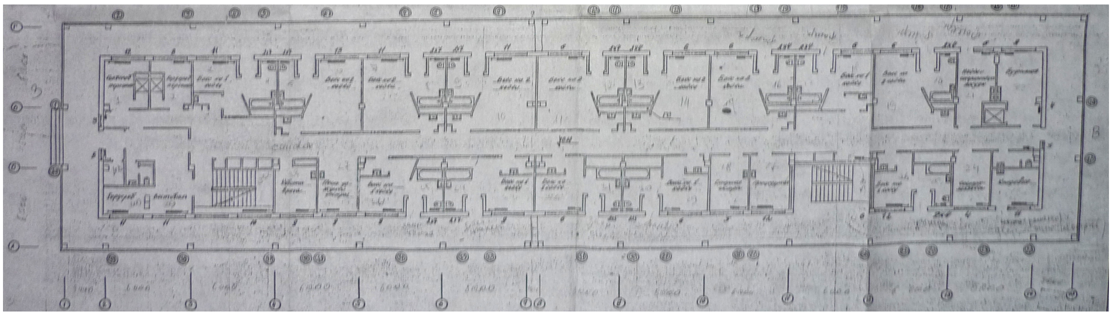
Block 10 was built in 1978 as a diagnostic and isolating block for 54 beds. Initially, at the design phase, the block's destination was hospitalization of sick children with unclarified diagnoses coming from ward sections and the reception. Single and double bed Meltzer boxes (individual boxes) have been designed on the first (-3.30m level), second (+0,00 level) and the third floor (+3.30m level) with independent, external entrances through the balconies located within the building's perimeter, and internal entrances through the floor's main corridor. A technical floor has been designed for the fourth floor (+6.60level). There are two staircases designed in the building, one external for reception of children, and one internal for the personnel.

The first and the second floor were designed with 22 Meltzer boxes, a lobby, a passing point for the personnel, rooms for nurses, a room for medical treatment, buffet, a room for sterilization of utensils with an external entrance. The third floor was designed with 14 Meltzer rooms, rooms for doctors, head of department, storage of portable X-ray equipment, a photo room, a buffet, medical treatment room. There are 2 points for nurses on duty designed on each floor.



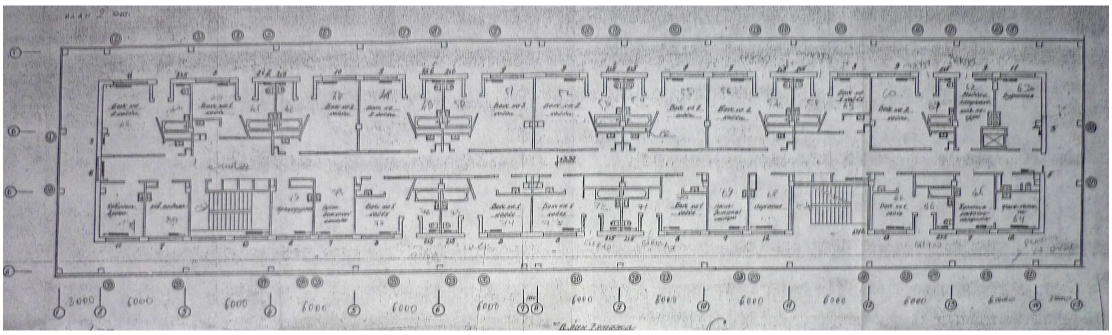
Picture 3: Ground floor plan

In 2004 the ground floor was reconstructed and was destined for children's chronicle hemo dialyses treatment section. At the present time, there are 2 sections, one for pathology and one for hemodialyses located in block 10. The block is available for 45 patients and about 20 people from personnel including temporary visitors (students).



Picture 4: First floor plan

At the present time (autumn 2009) all of external entrances for Meltzer boxes on the first floor have been canceled. After extended communication with the directorate of the hospital



Picture 5: Second floor plan

3.2. Building envelope

The building consists of four floors. The half part of the ground floor is underground and is used only for technical reason (pipes etc). The other half is used as treatment section. In the initial design the heated area of the ground floor was about 400m^2.


Picture 6: Closed external balconies on the ground floor

After the reconstruction the external corridors (gallerys) have been closed with double plastic framed windows and have become part of the heated space leading to a total heated area of about 600m^2. The height of the floor is 3.30m (from slab to slab). The first and the second floor have the same heated area equal to 827m^2 each. The height of each floor equals to 3.30m (from slab to slab,) and their external area is about 560m^2 covered with fenestration at a percent of 28%. Finally the third floor is used only for technical reasons (ventilation and heating system).

	total area m^2	heated area m^2	total volume m^3	heated volume m^3
ground floor	1295	600	1390	1980
first floor	827	827	2730	2730
second floor	827	827	2730	2730
third floor	1295	0	2850	0
building	4244	2254	9700	7440

Table 1: Building general data

3.2.1. Building construction elements


Picture 7: External view of the first floor

The load bearing structure is made of reinforced concrete and the external walls are hinged panels. The panels are 300 mm thick, made of expanded-clay concrete with lime plaster as interior finish layer, cement mortar and tiles as exterior finish layer. There is not any thermal insulation. The U value of the panels is estimated to be 1.20 W/(m^{2}K).

All of the floors slabs are made of

reinforced concrete with lime plaster as bottom finish layer and industrial floor finish for the upper part with total thickness of 35cm. The U value of the floors is estimated to be 1.94 W/(m^{2}K) and 2.60 W/(m^{2}K) depending on the heat flow direction.

Picture 8: Windows on the first and the second floor

The windows of the first and second floor consist of wooden frame and double glazing with about 15 cm cavity between the panes. The condition of windows is unsatisfactory. Taking into consideration the significant time of the hospital being in service, about 20 years, windows sealing has been partially destroyed which leads to intensification of air infiltration vis a vis the normative one and as a consequence decreases the temperature in premises, due to higher heat losses The estimated U value of the existing windows is 3.00 W/(m^{2}K).

Picture 9: Doors on the first and second floor

The doors of the first and second floor, except the four main doors located at the small sides of the building at each floor, consist of wooden frame and wooden panels with a small part of single glass. The condition of the door is unsatisfactory. The estimated U value of the door is also 3.00 W/(m^{2}K). The four main doors aforementioned are entirely wooden doors. Their U value is estimated also equal to 3.00 W/(m^{2}K).

The heated space of the ground floor has been reconstructed as mentioned before. The external balconies have been closed with double plastic frame windows with an estimated U value equal to 2.1 W/(m^{2}K).

	wall area m^2	window area m^2	doors area m^2	floor area m^2	ceiling area m^2
ground floor	105	105.0	2.3	600	600
first floor	339	114.7	39.3	827	827
second floor	339	113.4	41.6	827	827
third floor	402	-	-	1295	1295

Table 2: Area of building elements

	wall U $W/(m^2K)$	window U $W/(m^2K)$	doors U $W/(m^2K)$	floor U $W/(m^2K)$	ceiling U $W/(m^2K)$
ground floor	1.20	2.20	2.20	1.94	2.60
first floor	1.20	3.00	3.00	1.94	2.60
second floor	1.20	3.00	3.00	1.94	2.60
third floor	1.20	-	-	1.94	2.60

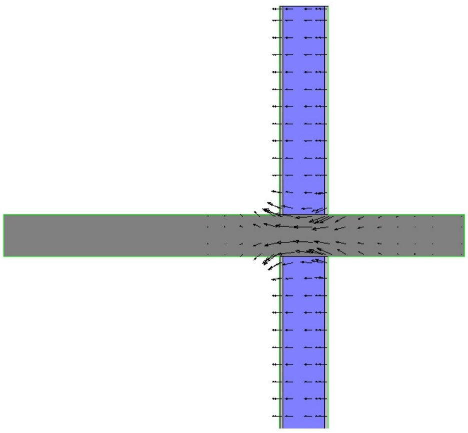
Table 3: U value of building elements

3.2.2. Thermal bridges

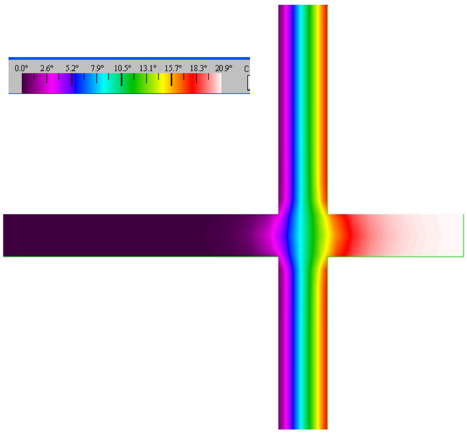
It has been detected four different types of thermal bridges. The calculation of the linear thermal transmittance has been done according to the EN ISO 10211:2007 "Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculations".

Type A: balconies

The most important thermal bridge detected in the building is the one formulated at the joint of the floor slab and the expanded clay concrete panels. The importance of the specific thermal bridge is due to its high value and the great length that it is detected.



Picture 10: Heat flows through the element

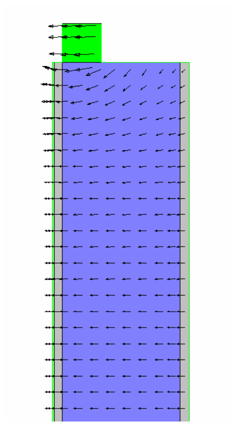


Picture 11: Temperatures inside the element

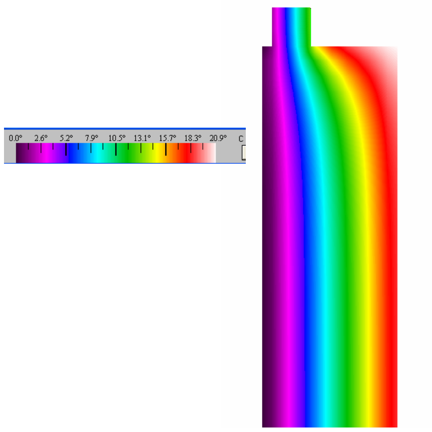
The Ψ value was calculated equal to 0.58 W/(mK) and the total length occurred is 337.4 m for the first and the second floor.

Type B: windows

The second most important thermal bridge detected in the building is the one formulated at the joint of the windows and doors and the expanded clay concrete panels. The importance of the specific thermal bridge is due to its great length that it is detected.



Picture 12: Heat flows through the element

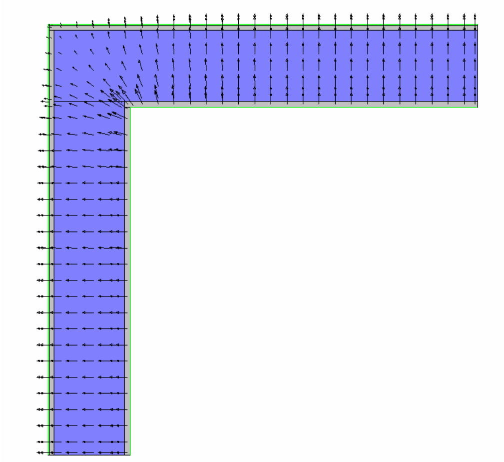


Picture 13: Temperatures inside the element

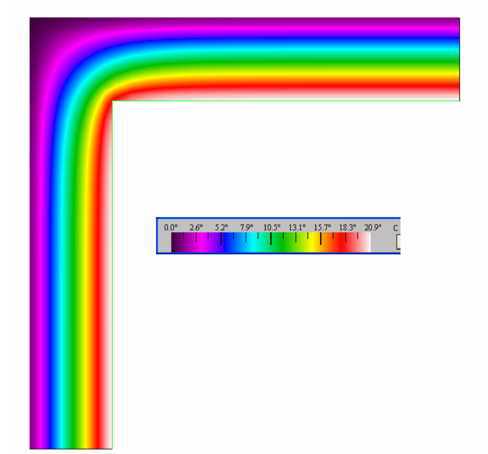
The Ψ value was calculated equal to 0.14 W/(mK) and the total length occurred is 690 m for the first and the second floor.

Type C: external corners

The third type of thermal bridges that it is detected in the building is the external corners. Hopefully this type is not so important because of its little length so they are going to be ignored in the forthcoming analysis.



Picture 14: Heat flows through the element

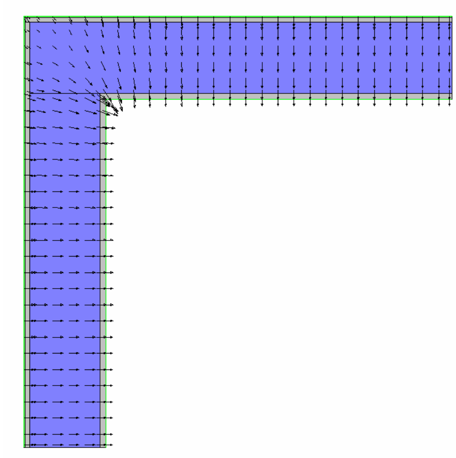


Picture 15: Temperatures inside the elements

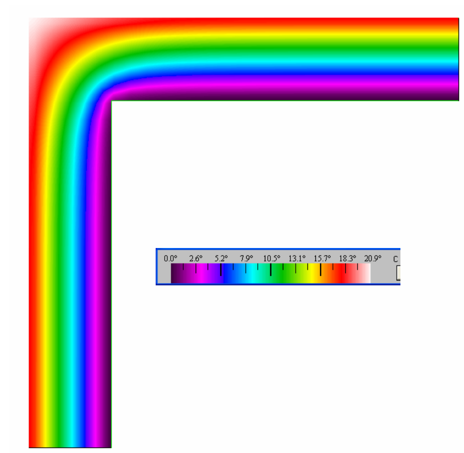
The Ψ value was calculated equal to -0.50 W/(mK) and the total length occurred is 18 m for the first and the second floor.

Type D: internal corners

The fourth type of thermal bridges that it is detected in the building is the internal corners. Hopefully this type is also not so important because of its little length so they are too going to be ignored in the forthcoming analysis.



Picture 16: Heat flows through the element



Picture 17: Temperatures inside the elements

The Ψ value was calculated equal to 0.28 W/(mK) and the total length occurred is just 6 m for the first and the second floor.

	Type a	Type b	Type c	Type d
Ψ (W/mK)	0.58	0.14	-0.50	0.28
L (m)	337	690	18	6
Ψ×L (W/K)	196	97	-9	2

Table 4: Linear thermal transmittances for the building

	walls U×A (W/K)	windows U×A (W/K)	doors U×A (W/K)	floor U×A (W/K)	ceiling U×A (W/K)
first floor	407	344	118	1604	-
second floor	407	340	125	-	2150
sum	814	684	243	1604	2150

Table 5: Areal thermal transmitances.

According to EN ISO 13789 (2008) the direct transmission heat transfer coefficient for the first and the second floor is:

$$H_{tr,dir}=\Sigma\,(U_i\times A_i)+\Sigma\,(\Psi_i\times L_i)=$$
$$=(U_{wall}\times A_{wall}+U_{window}\times A_{window}+U_{door}\times A_{door})+(\Psi_a\times L_a+\Psi_b\times L_A+\Psi_c\times L_c+\Psi_D\times L_D)=$$
$$=(814W/K+684\ W/K+243\ W/K)+(196\ W/K+97\ W/K\ -9\ W/K+2\ W/K)=$$
$$=1741\ W/K+286\ W/K=2027\ W/K$$

The direct transmission heat losses of the building due to thermal bridges are about 14% of the total direct transmission heat losses, too high too be ignored for the foregoing analysis.

3.3. Heating system

The design of the heating system for the block 10 of RIPHMC was developed for district heating, with outdoor design temperature T_{ext}=-15^{o}C. According to the technical design, there is a one-pipe dead-ended heating system with upper distribution. At the moment of the inspection of the building, the district heating was supplied by JS «Termocom», through the existing networks of RIPHMC The elevating point is located in the basement of the building. From the basement the hot water is elevated to the technical floor and from there it is distributed to the emission system.

Picture 18: Technical floor. Distribution system.

Picture 19: First and second floor emission system.

On the first and the second floor the emission system has been implemented with the use of cast iron radiators type M-140-AO. On the ground floor the heating system has been reconstructed so as to cover the needs of the closed spaces after the floor renovation on 2004 and the earlier designed heating devices M 140 AO, have been replaced with new ones of TERMO type.

The main and rising pipes of the distribution system are metallic except of the reconstructed section, where they have been changed with new plastic coated metal ones. The return main pipes are laid under the ceiling and above the floor of the technical floor lying under the heated spaces of the first and the ground floor. The water in heat carriers is at a temperature of 85-65^{o} C. Mayevskiy valves have been installed on the upper floor heating devices to eliminate the air. In order to disconnect separate rising pipes and discharge water from them, cork and discharging valves have been designed on the joint parts to supply and return main pipes.

The thermal insulation on the main supplying pipes of the heating system is partially destroyed while the rest of it is obsolete and unsatisfactory. This leads to a certain amount of heat losses and decreases parameters of the heat carrier in the heating devices (radiators) and correspondingly leads to the violation of the temperature conditions in the premises of the hospital. According to the design project, the pipelines of the return main pipe have not been thermally insulated.

3.4. Ventilation system

The design and installation of the ventilation system has been done taking into consideration that the block 10 of the RIPHMC was constructed as isolation and diagnostic sector.

Picture 20: Exhaust air grille

The supply ventilation system has been designed as a mechanical system supplying air in the corridors. Exhaust ventilation system has been designed for each box, polybox and each ward section with artificial impulse and installation of deflectors. The frequency of air exchange has been accepted in correspondence with existing norms for similar buildings. In total there have been designed and installed 44 exhaust systems and 1 supply facility with a total capacity of 10.200 m^3/h.

Picture 21: Ventilation air-ducts in technical floor

The design has provided an automatic control of temperature of the air supply and protection of air-heaters from freezing. To heat the air in premises during the winter time, the installation has been equipped with the air-heater supplied with hot water with parameters 130–70^o C from the elevating point located in the basement of the building. During the summer the system is used as exhaust system only, with air supply temperature equal to external air temperature. The ventilator maintaining the supply system in the building has been installed on the vibro-insulated base in order to reduce the level of noise and vibration. Some flexible elements have been installed on absorbing and exhausting pipe. Air-ducts are made of thin galvanized sheet of steel.

During the inspection of existing ventilation systems of the block 10, it was found out that the supply ventilation system does not work. Ventilation channels and shafts are obsolete and can’t be used anymore. The air supply through the existing air ducts is not possible due to the strong microbiologic pollution. The system equipment is in unsatisfactory condition. At the moment the ventilation system is not used and is not subject to renovation.

3.5. Domestic hot water system

According to the design, the domestic hot water in block 10 is supplied from interdistrict heating networks. The internal hot water distribution system was designed to be of galvanized steel pipes and to be laid together with cold water pipes. It have been equipped with 34 blenders for bathrooms, 2 blenders for shower cabins and 12 wall blenders to wash the dishes. The hot water temperature is 65^{o}C and the circulation provided in the design is mechanical in both main pipes and pipe risers. The hot water for the block 10 was heated in boilers, located in CHP of RIPHMC by the use of the hot water of the district heating supplied by JS „Termocom".

Picture 22: Damaged boiler in CHP

Since 1996, there has been no district supply of hot water. All of the boilers in the CHP of RIPHMC have been of damaged and demolished. The hot water demand is partially covered by 6 water heating boilers. The internal pipeline has not been changed and is ready for operation, should there be the renewal of district hot water supply. For this, some preventive measures are required including the change of hygienic cord blenders. The hot water supply system does not have automatic control system.

3.6. Lighting system

The lighting system includes a general, a local, an emergent and a repairing system. The network voltage for general, local and emergent lighting is 220 V, and for repairing 36 V.

Picture 23: Fluorescent luminaire

The general lighting of the wards and the corridors was designed to be provided by luminaires equiped with two fluorescent lamps of 40 W each and one magnetic ballast except for premises where incandescent lamps are recommended according to the standards. The emergent lighting is provided in corridors, lobbies, staircase, nurses' rooms, ventilation shafts, while night lighting is provided in wards and semiboxes with the help of lamps, installed at the height of 0,3 m from the floor in special niches.


Picture 24: Incandescent lamps installed on a fluorescent luminaire.

In total, according to the design, there should be installed 150 luminaires with 2 fluorescent lamps each of 40 W each and 143 luminaires with one incandescent lamp each of 60W each. Taking into account that the ballasts used are magnetic the aforementioned luminaries leads to total lighting system installation of about 23kW.

During the inspection of the building it has been discovered that a great portion of the lighting system has been destroyed. In some cases simply the lamps or the ballasts have been burned out and in some cases the luminaires have been destroyed.

3.7. Internal equipment

The internal equipment that has been installed in the building, according to a previous inspection that has been conducted two years ago, is presented at the following table.

Equipment	Pieces	Unit capacity, kW	Total capacity, kW
Quartz lamps	22	0,001	0,022
Refrigirators	6	0,15 – 0,17	0,95
Electric ovens	1	2,0	2,0
Heaters	3	1,5	4,5
Drying box	1	2,0	2,0
Sterilizator	1	1,8	1,8
Electric boilers	6	2,8	8,0
Computers	1	0,45	0,45
Pumps	3	0,25 -1,46	3,17
Dialyzing chairs	1	0,6 – 0,8	0,6 – 0,8
Hymodialyses equipment	3	2,0	6,0
Total			**29,59**

Table 6: Internal equipment installed

3.8. Summary - Conclusions

The inspection of the building and its services revealed:

- The building envelope is uninsulated and the indoor conditions are far away from sufficient to provide thermal comfort to the occupants and especially to the patients. The temperature of the internal surface of the walls is much lower than the interior air temperature leading to low mean radiant temperatures and consequently to lack of thermal comfort. For instance, when the interior air temperature equals $T_{air}=22^oC$ and exterior air temperature equals to the average low of Chişinău $T_{ext}=-5.4^oC$, the temperature of the interior surface of the external walls equals to $T_{surf,wall}=17.5^oC$ and of the interior surface of the interior window pane $T_{surf,window}=11.3^oC$. At the same time the lower surface's temperatures may lead to surface vapor condensation and mould growth deteriorating the indoor air quality.

- The heating system of the building needs to be redesigned and reconstructed so as to provide a more uniform air temperature inside the premises and to be more efficient.

- The ventilation system is totally out of order. Because it is used to provide conditioned air it has to redesigned and reconstructed in agreement to the heating system.

- One major part of the lighting system is out of order. The fluorescent luminaires are out-dated, the ballasts used are magnetic consuming about 20% more than the lamp's installed power and there is a great number of incandescent lamps that should be replaced by compact fluorescent lamps consuming just a fifth of the current energy consumption for lighting.

Having in mind that the specific building is a children's hospital, the necessity to provide sufficient thermal comfort for its occupants raises dramatically. The first measure that has to be undertaken is to improve the thermal insulation of the building envelope. That will lead on the one hand to the improvement of the indoor conditions and on the other hand to the reduction of heat losses by transmission. The reduced energy needs for heating will have to be covered by a smaller and more efficient HVAC system leading to a further reduction of energy consumption and cost of renovation.

For the above reasons it has been decided, firstly to investigate the application of thermal insulation on the floor of the third floor (technical floor), the application of external thermal insulation composite system (ETICS) on the walls of the first and the second floor, and the replacement of the windows and doors of the first and the second floor with new, energy efficient ones. It has been decided that there will be no intervention on the ground floor since it has been recently (2004) renovated.

4. Energy efficiency improvement measures
4.1. Description

It has been decided that the energy efficient improvement measures that will be undertaken shall focus on the improvement of the building envelope. This strategy has two main targets:

- Improvement of the indoor environment.
- Reduction the energy needs of the building shell for heating and cooling.

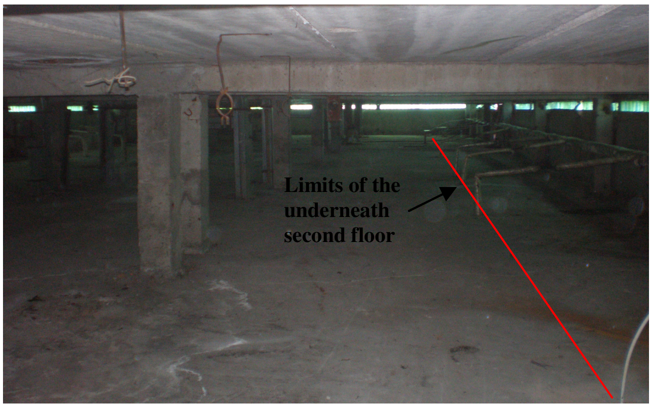
As it was already mentioned, the heating and venting system has to be redesigned and reconstructed. By the reduction of energy needs of the building envelope, the systems needed to cover the heating loads shall be smaller and more efficient than those needed for the existing envelope design.

The proposed measures are:

A. thermal insulation on the floor of the fourth floor,
B. external thermal insulation of walls of the first and the second floor,
C. replacement of windows and doors of the first and the second floor.

4.1.1. Measure A: Thermal insulation on the floor of the fourth floor

The third floor is used as a technical floor for the distribution of the heating pipes. In practice it is a non heated space that it is visited rarely. The area of the floor in touch with the heated second floor is 827m^2, while the total area of the floor is 1295m^2. The U value of the floor is about 2.60W/m^{2}K.



Picture 25: Technical floor.

For the reduction of the heat losses of the second floor during the winter and the heat gains during the summer it is proposed to add thermal insulation on the floor of the technical floor. The thermal insulation shall be in the form of insulation slabs that just will be superimposed on the floor. That way if there is any work to be done on the technical floor, the insulation can just put off and relocated after the finish of the works. The insulant material that will be used has to have high moisture resistance so as not to be destroyed in case of a water leak. Material that can be used is extruded polystyrene (XPS) and polyurethane (PUR). At the same time it has to have high compressive strength so as not to be destroyed during routine visits on the floor.

It has been decided to investigate the use of 5cm of insulating material with thermal conductivity λ=0,035W/(mK).

1. Measure B: External thermal insulation of walls

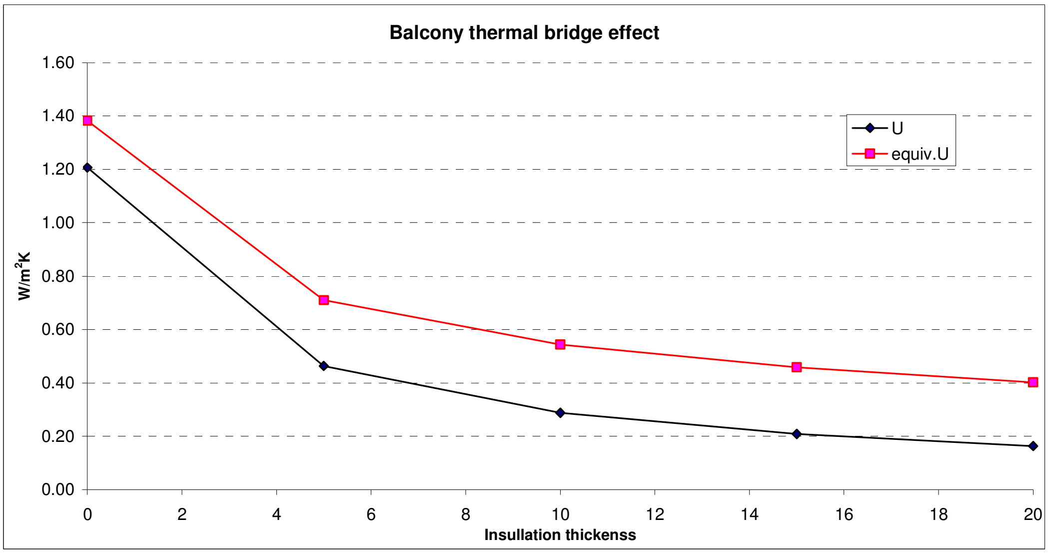
Picture 26: Application of ETICS

It has been decided to apply an external thermal insulation composite system (ETICS) on the wall of the first and the second floor. The system will be composed of insulant plates that will be fixed on the wall with adhesive material and mechanical fixing devices.
As far the thermal bridge of external and internal corners, i.e. type **C** and **D** respectively, because of the use of external insulation and of their little length they are formulated, they practically are eliminated and they are not taken into consideration in the analysis following.

Unfortunately the thermal bridges formulated at the joint of the floor slab and the walls, i.e. type **A** thermal bridge, cannot be eliminated. In contrary as the external insulation gets higher values of thermal resistance, the thermal bridge effect influence more the total transmission heat losses and their effect has to be taken into account. As a matter of fact the thermal bridge effect seems to reduce the improvement of the energy efficiency measure of external insulation as can been seen in the next table and illustrated in the next graph.

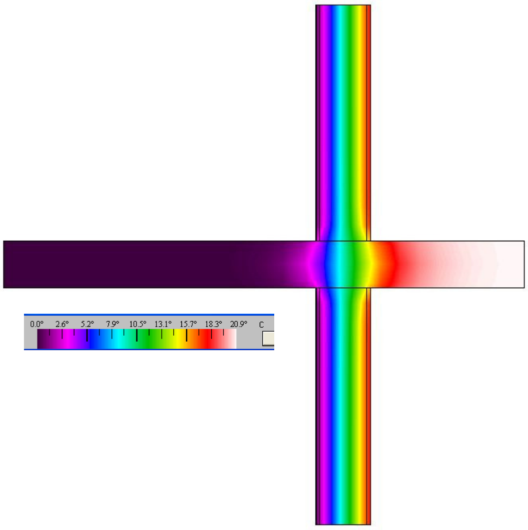
Thickness of wall insulation	U value of wall [W/m^2K]	Ψ value [W/(mK)]	Equivalent U value of wall [$W/(m^2K)$]
0	1.206	0.58	1.382
5	0.464	0.81	0.710
10	0.288	0.85	0.544
15	0.209	0.82	0.458
20	0.164	0.79	0.402

Table 7: Wall insulation and balconies thermal bridge effect

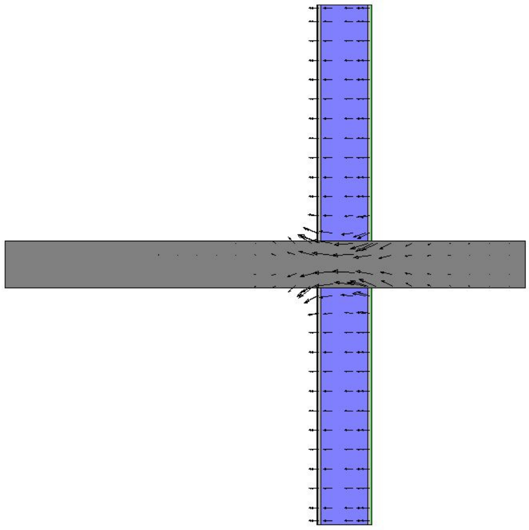


Graph 1: Wall insulation and balconies thermal bridge effect

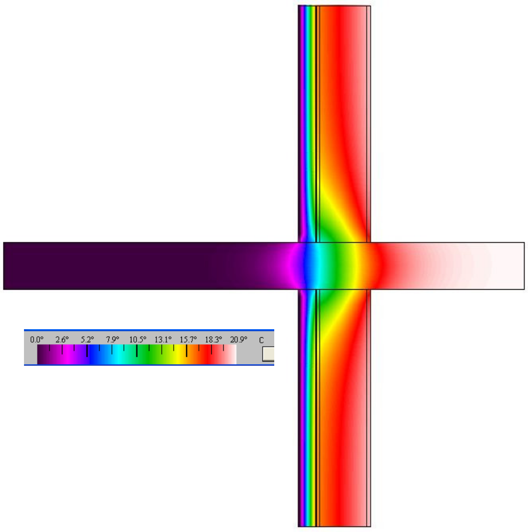
<u>**Type A thermal bridges. Balconies.**</u>



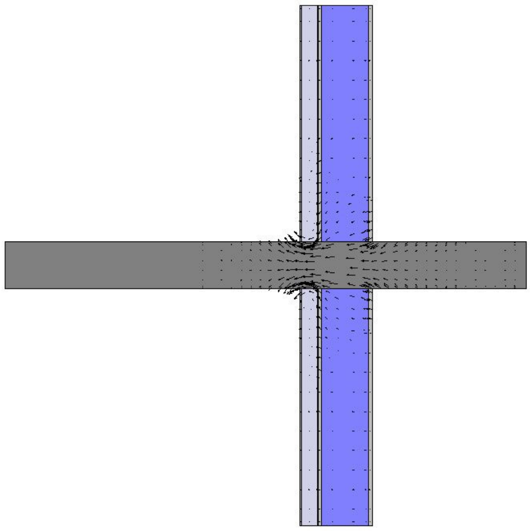
Picture 27: Temperatures with no insulation



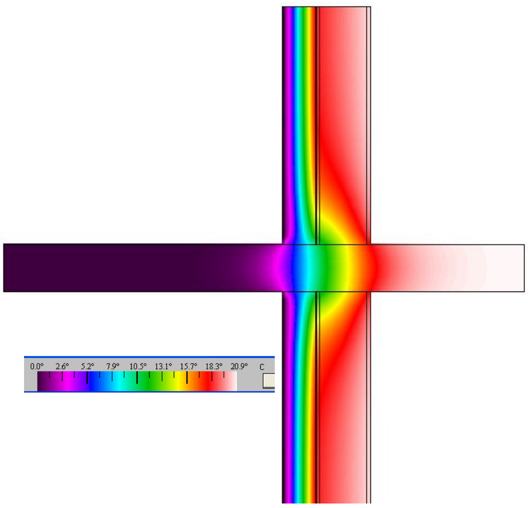
Picture 28: Heat flows without insulation



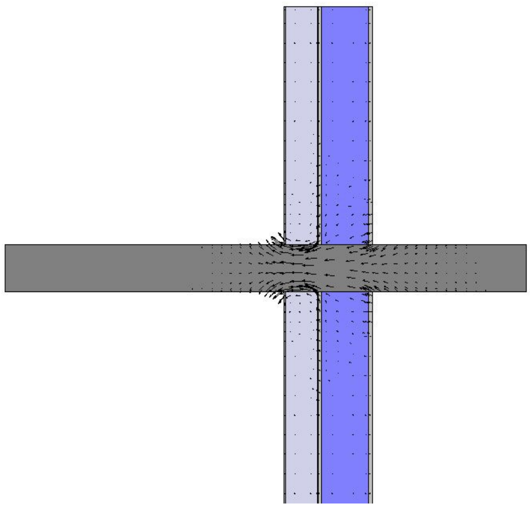
Picture 29: Temperatures with 10cm insulation



Picture 30: Heat flows with 10cm insulation



Picture 31: Temperatures with 20cm insulation

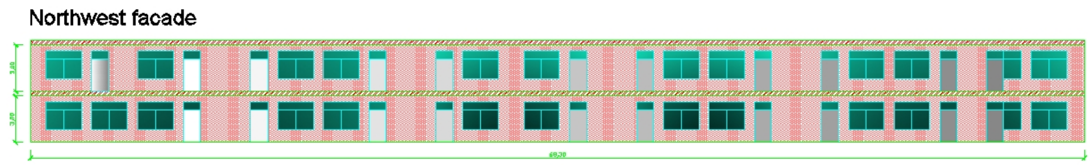


Picture 32: Heat flows with 20cm insulation

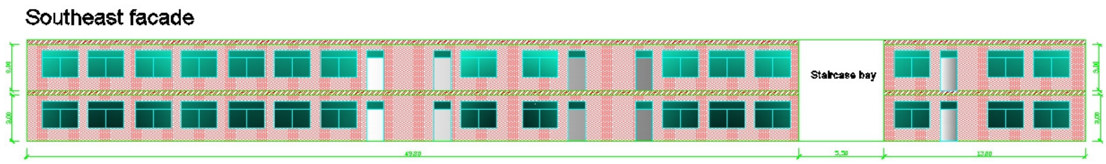
No matter of the thermal bridge effect, the interior surface temperature of the wall rises. Even with use of only 5cm of thermal insulation the surface temperature becomes T_{surf}=20.9^{o}C which is much greater than T_{surf}=17.5 occurring with the existing design. It becomes clear that the indoor conditions with the use of ETICS become much better.

There four different scenarios that will be investigated. In all cases the wall insulation material will be considered having of λ=0,038W/(mK). The four different scenarios will be the use of material with thickness of:

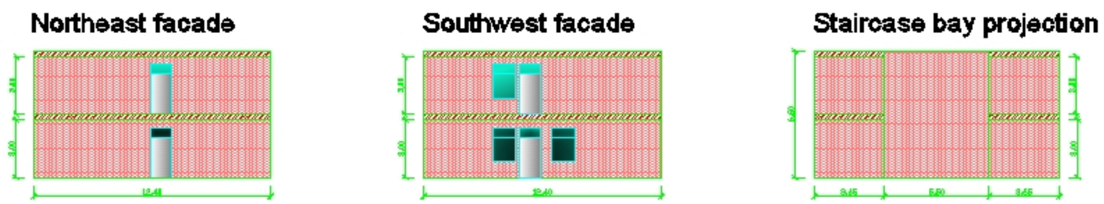
1. 5 cm
2. 10cm
3. 15cm
4. 20cm



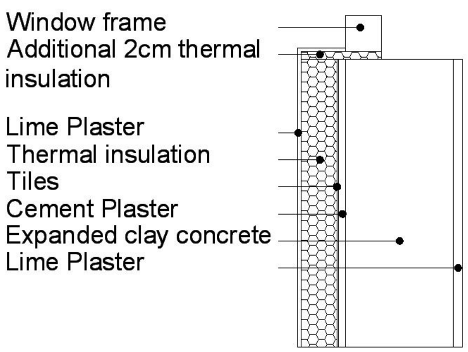
Picture 33: Application of ETICS on northwest facade



Picture 34: Application of ETICS on southwest facade



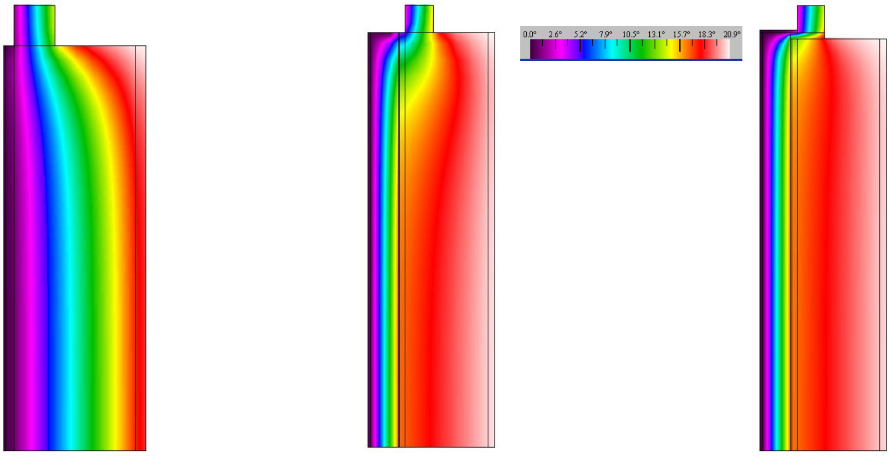
Picture 35: Application of ETICS on northeast, southwest facade and staircase bay



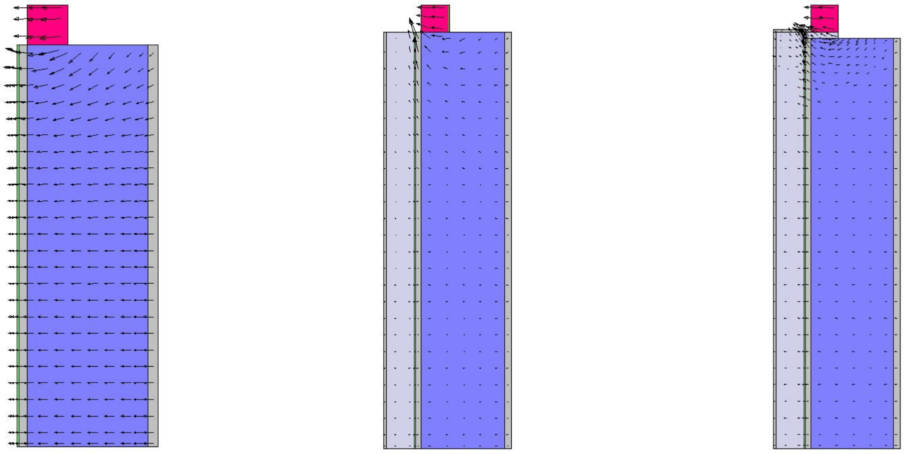
Picture 36: Window reveals, head, cill detail.

So as to reduce the effect of thermal bridges detected at the joint of the windows and the walls, i.e. type **B** thermal bridge, the insulation shall turn around the reveals, the head and the window cill so as to form a continuous layer with the windows. The thickness of the material used over the window cill, the reveals and the head of the window shall be at least 2cm.

<u>Type B thermal bridges: Windows</u>



Picture 37: Temperatures inside the element a) without thermal insulation, b) with 10cm thermal insulation on the wall, b) with 10cm thermal insulation on the wall and 2cm on the reveal



Picture 38: Heat flows from the element a) without thermal insulation, b) with 10cm thermal insulation on the wall, b) with 10cm thermal insulation on the wall and 2cm on the reveal

As can been seen at the previous images, the wall thermal insulation reduces the heat flows of the entire building element but if there is no provision to thermally insulate the reveals, the window cills and the heads, there is intense heat flows alenght the joint of the window frame and he wall. This effect can be reduced by the addition of 2cm of thermal insulation at the aforementioned points.

For example using 10cm of thermal insulation with no provision for the reveals, the window cills and the heads, will lead to linear thermal transmittance Ψ=0,41 W/(mK). By the use of 2cm of insulant at the reveals, the window cills and the heads, that value become Ψ=0,22 W/(mK). Recalling that the total length that this type of thermal bridge is detect is about L=690m, leads to the fact that the transmission heat losses become about 152W/K with the use of this additional insulation against 283W/K without.

4.1.2. Measure C: Replacement of windows and doors

Picture 39: Existing window

It has been decided to replace all of the windows and doors of the first and the second floor with new more efficient ones. As it was revealed during the inspection, the window frames are wooden and there seem not to have done any maintenance work for many years. The glazing is double 3mm pane with a 10cm cavity. The glass used is of a poor quality. The air permeability of the window is high, leading to cold draft inside the premises and consequently poor indoor conditions. The main window typology is incapable to provide the natural ventilation needed during the summer period. The existing window thermal transmittance is estimated equal to U_{window}= 3.00 W/(m^2K)

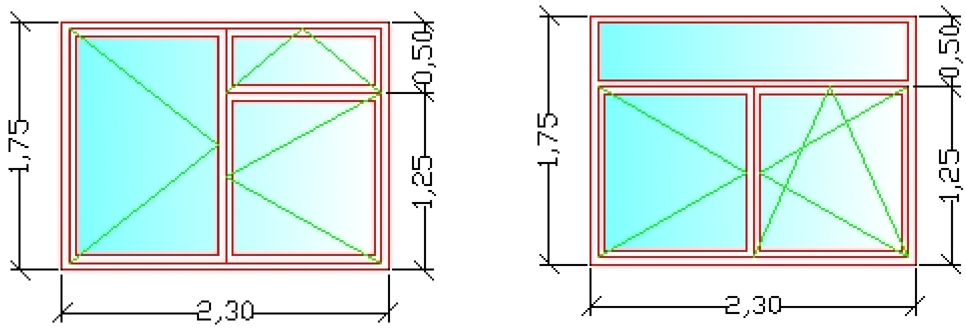
Picture 40: Existing doors

The wooden doors are in even worst condition. The door joints sealants seem to be totally destroyed and because of poor quality of the wood used, the joints have been broaden leading to high air permeability.
The existing doors thermal transmittance is estimated to be U_{door}=3.00 W/(m^2K).

It has been decided to investigate the use of thee different type of windows that arise from the combination of different frames and glazing. The window typology is changed as illustrated in the image following in the next page. In the new typology there is an upper fixed part used only for daylighting. The lower part of the window consists of two parts from which the one is dual action so as to ensure the mild natural ventilation of the rooms.

The first type (typeA) of window considered, is composed by a frame with thermal transmittance U_f=2.50 W/m^2K and glazing with thermal transmittance U_g=2.60 W/(m^2K) (double glazing with 15mm cavity filled with argon). The total thermal transmittance of the window, is calculated according to EN ISO 10077-1 (2006): “Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General”. The calculated window thermal transmittance for the frame area being 25% of the whole window area is U_{window}=2.6 W/(m^{2}K).

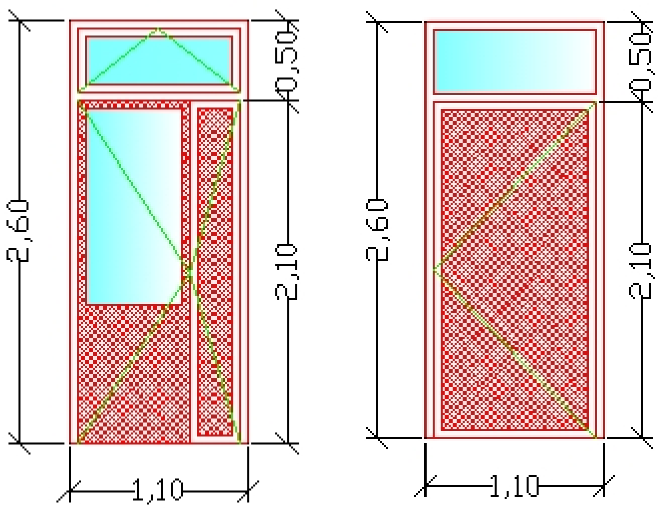
The second type (type B) of window is composed by a frame with thermal transmittance U_f=2.00 W/m^{2}K and glazing with thermal transmittance U_g=1.40 W/(m^{2}K) (double glazing with one pane low-e glass and with 15mm cavity filled with air). The calculated window thermal transmittance for the frame area being 25% of the whole window area is U_{window}=1.70 W/(m^{2}K).



Picture 41: Old (left) and new (right) window typology

Finally, the third type (type C) of window is composed by a frame with thermal transmittance U_f=1.50 W/m^{2}K and glazing with thermal transmittance U_g=1.20 W/(m^{2}K) (double glazing with one pane low-e glass and with 15mm cavity filled with argon). The calculated window thermal transmittance for the frame area being 25% of the whole window area is U_{window}=1.48 W/(m^{2}K).

At the same time it has been decided to investigate the use also of three different types of doors that arise from the combination of different frames, glazing and panel. For the three door types the door is considered to be composed by an upper fixed glazed part used only for daylighting and a lower opaque one covered with a panel. The panel that is used consists of two panes of aluminum with a cavity of 2cm filled with an insulant material. The thermal transmittance of the panel is U_{panel}=1.35 W/(m^{2}K).



Picture 42:Old (left) and new (right) door typology

The first type of the doors (type A) considered, is composed by a frame with thermal transmittance U_f=2.50 W/m^{2}K, glazing with thermal transmittance U_g=2.60 W/(m^{2}K) (double glazing with 15mm cavity filled with argon) and a panel with thermal transmittance U_{panel}=1.35 W/(m^{2}K). The total thermal transmittance of the door, is

calculated according to EN ISO 10077-1 (2006): "Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General". The calculated door thermal transmittance for the frame area being 25% of the whole door area is U_{door}= 2.00 W/(m^2K).
The second type of doors (type **B**) considered, is composed by a frame with thermal transmittance U_f=2.00 W/(m^2K), glazing with thermal transmittance U_g=1.40 W/(m^2K) (double glazing with one pane low-e glass and with 15mm cavity filled with air) and a panel with thermal transmittance U_{panel}=1.35 W/(m^2K) The calculated door thermal transmittance for the frame area being 25% of the whole door area is U_{door}=1.70 W/(m^2K).

Finally the third type of doors (type C) is composed by a frame with thermal transmittance U_f=1.50 W/(m^2K), glazing with thermal transmittance U_g=1.20 W/(m^2K) (double glazing with one pane low-e glass and with 15mm cavity filled with argon) and a panel with thermal transmittance U_{panel}=1.35 W/(m^2K) The calculated door thermal transmittance for the frame area being 25% of the whole door area is U_{door}=1.50 W/(m^2K).

Scenario		U_{frame} W/(m^2K)	$U_{glazing}$ W/(m^2K)	U_{panel} W/(m^2K)	U_{window}/U_{door} W/(m^2K)
1	Window	2.5	2.6	1.35	2.6
	Door				2.0
2	Window	2.0	1.4	1.35	1.7
	Door				1.5
3	Window	1.5	1.2	1.35	1.5
	door				1.5

Table 8: Window and doors investigated

The thermal bridges occurring at the joint of the wall and the window frame (i.e. type **B** thermal bridges) that have been arisen for different frames and different wall insulation thickness have been analytically calculated. As can been seen from the next table, the thermal transmittance of the frame has a minor effect on the linear transmittance of the element.

Thermal insulation thickness [cm]	Linear transmittance Ψ [W/mK]		
	U_{frame}=2.5 W/m^2K	U_{frame}=2.0 W/m^2K	U_{frame}=1.5 W/m^2K
0	0.142	0.145	0.149
5	0.306	0.301	0.298
10	0.226	0.222	0.218
15	0.196	0.192	0.187
20	0.183	0.179	0.171

Table 9: Linear thermal transmittance for different frames and insulation thickness

The direct thermal transmission that is derived for the different wall thermal insulation thicknesses and different types of windows and doors that will be investigated are calculated according to EN ISO 13789(2007): 'Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method" and is presented in the following table. As can been seen from the table the higher the thermal insulation applied the higher the effect of the thermal bridges. From that it is getting clear the importance of taking into account the thermal bridges for assessing the energy performance of the building.

Thermal insulation thickness [cm]	Σ U*A W/K	Σ Ψ*L W/K	$H_{transmittion}$ W/K	Thermal bridge effect
0	1627	294	1921	**15%**
5	1120	485	1606	**30%**
10	1001	441	1441	**31%**
15	947	413	1359	**30%**
20	916	392	1308	**30%**

Table 10: Direct thermal transmission. Type A windows and doors.

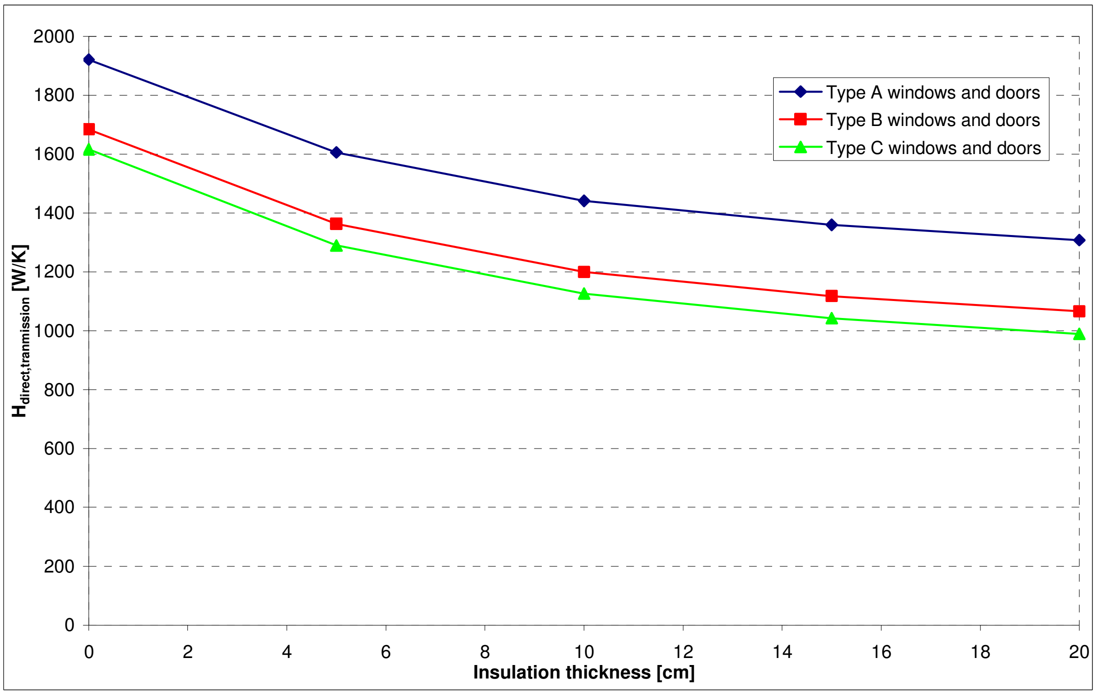
Thermal insulation thickness [cm]	Σ U*A W/K	Σ Ψ*L W/K	$H_{transmittion}$ W/K	Thermal bridge effect
0	1388	296	1684	**18%**
5	881	482	1363	**35%**
10	761	438	1200	**37%**
15	707	410	1118	**37%**
20	677	389	1066	**37%**

Table 11: Direct thermal transmission. Type B windows and doors.

Thermal insulation thickness [cm]	Σ U*A W/K	Σ Ψ*L W/K	$H_{transmittion}$ W/K	Thermal bridge effect
0	1317	299	1616	**19%**
5	810	480	1290	**37%**
10	690	436	1126	**39%**
15	636	406	1043	**39%**
20	606	384	990	**39%**

Table 12: Direct thermal transmission. Type C windows and doors.

In the next graph it is shown the direct thermal transmittance of the building for different wall insulation thicknesses and types of windows



Graph 2: Direct thermal transmittance of the building for different wall insulation thicknesses and types of windows

4.2. Evaluation of the proposed measures

4.2.1. Methodology

The evaluation of the proposed measures is been conducted in four steps. Firstly there is done the assessment of the existing design long term energy performance of the building. Secondly there is done the assessment of the long term energy performance of the building after each measure has been undertaken. Thirdly there is done the economic analysis of the financial gains due the measures against the cost of the investment. Finally the best possible energy efficient improvement measures are selected.

For the first and the second step, i.e. assessment of the long term energy consumption of the existing design and the different designs proposed, it has been used the european methodology following the EN ISO 13790 (2008): "Energy performance of buildings - Calculation of energy use for space heating and cooling", and more specifically the use of dynamic simulation method in accordance to the aforementioned european standard. The simulation software used for the calculations of the energy performance of the building is EnergyPlus version 3.1.0. For the analysis of the occurring thermal bridges, THERM version 5.2 has been used.

4.2.2.Assumptions for the calculations

The existing design of the building shall be compared with the proposed design in terms of energy consumption. This comparison has to be done assuming that the indoor environmental conditions cover at least the minimum requirements. For that reason, for the calculation of energy consumption for heating and cooling for all the designs, the following assumptions have been made:

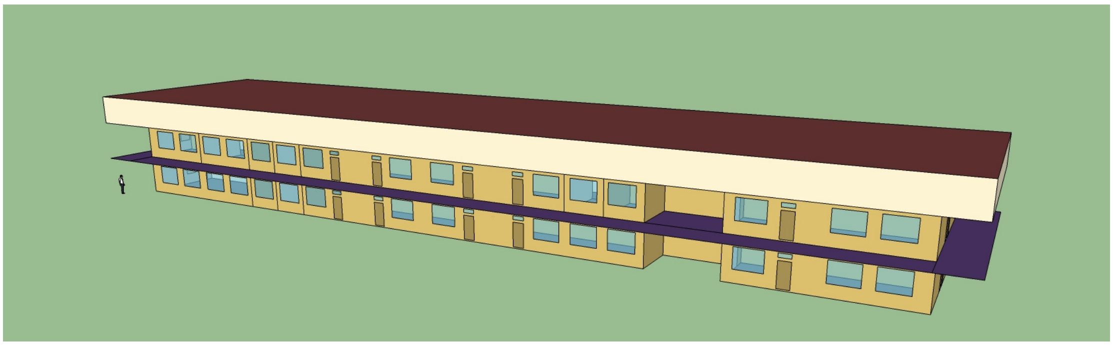
- The building is considered that it is heated 24 hours per day, 7 days per week during the heating period.
- The thermostat of the heating system is considered to be constantly set at 22^{o}C for the rooms and 20^{o}C for the corridors according to the annex G of EN ISO 13790.
- The building is considered that it is conditioned 24 hours per day, 7 days per week during the cooling period.
- The thermostat of the cooling system is considered to be constantly set at 24^{o}C for the rooms and 26^{o}C for the corridors according to the annex G of EN ISO 13790.
- The quantity of fresh air needed at the rooms is considered constantly equal to 0.030 m^3/h per person for hygiene reasons.

Apart from the above assumption, it has been assumed also that:

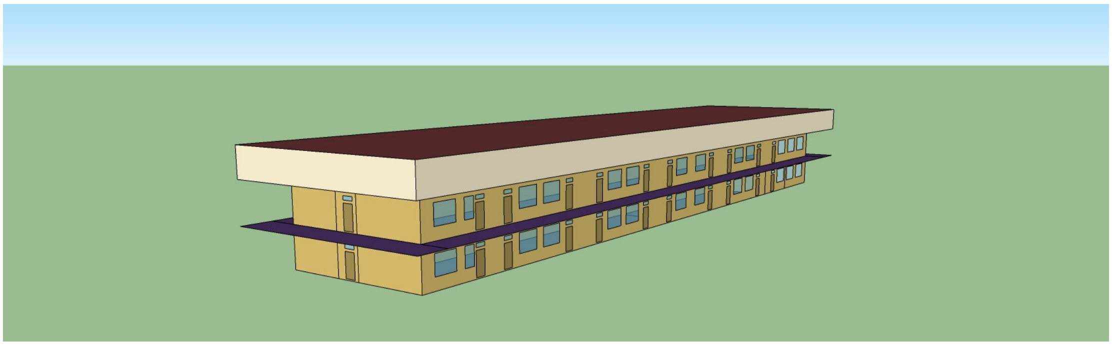
- The installed long term equipment in the building is about 4 W/m^2.
- The metabolic heat generation of the occupants is equal to 80 W per person and that there is no mechanical work produced.
- There are about 2 occupants in each room.

4.2.3.Simulation of the building

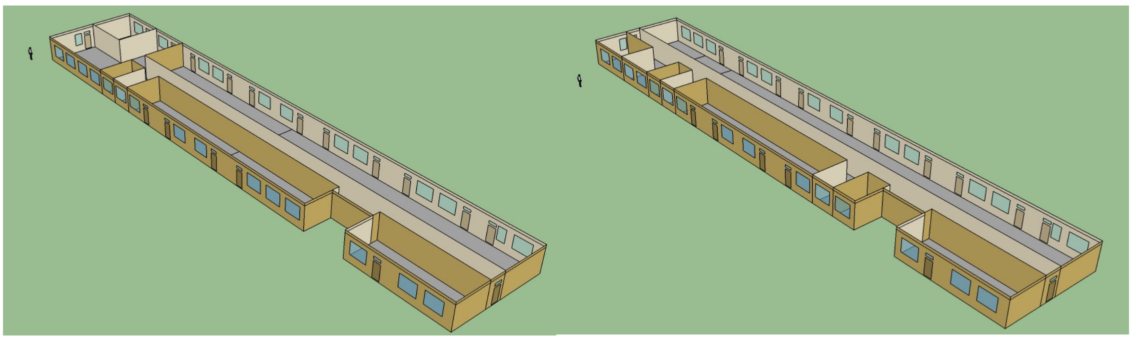
For the calculation of the thermal performance of the building it has been created a 3D model of the building envelope. The building was divided into 14 thermal zones, 13 heated and 1 non heated. More specifically the fist floor was divided into 5 main zones and 1 circulation zone. The second floor was divided into 6 main zones and 1 circulation zone. Finally the technical floor was perceived as non heated zone. In the next pictures the 3D model created for the analysis is illustrated.



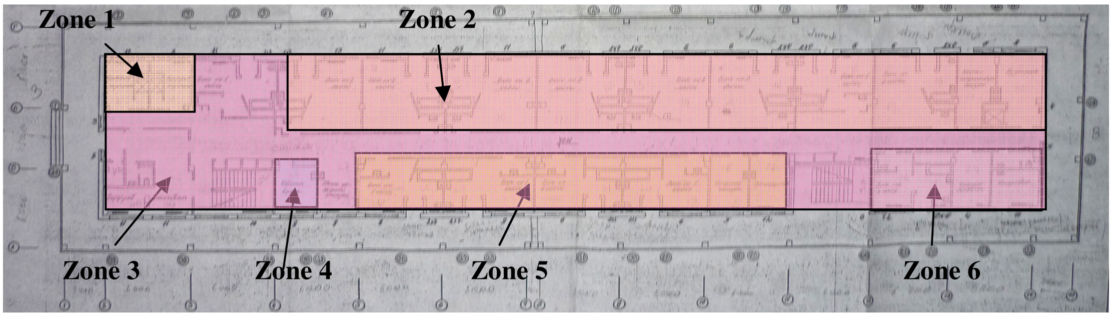
Picture 43: Building's 3D model. South southwest view.



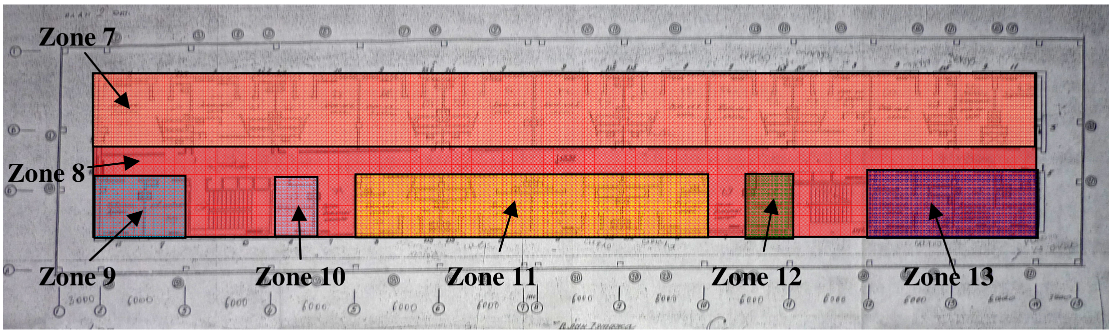
Picture 44: Building 3D model. North view.



Picture 45: First and second floor zoning.



Picture 46: First floor's deviation into thermal zones.



Picture 47: Second floor's deviation into thermal zones.

The thermal characteristics of the materials composing the building elements have been received according to the EN ISO 10456 (2007): "Building materials and products - Hygrothermal properties -Tabulated design values and procedures for determining declared and design thermal values" and their geometrical characteristics according to the design".

Name	Expanded Clay Concrete	Ceramic porcelain tiles	Plaster lime sand	Plaster cement sand	Brick	Panel	Concrete	Equivalent Material	EPS	ETICS Plaster	XPS
Thickness [m]	0.3	0.01	0.025	0.02	0.1	0.02	0.35	0.3	variable	0.01	variable
Conductivity [W/mK]	0.5	1.3	0.8	0.8	0.52	0.038	2.0	variable	0.038	0.8	0.035
Density [kg/m3]	2000	800	800	800	800	25	2000	2000	25	800	25
Specific Heat [kJ/kg]	1000	1000	1000	1000	1000	800	1000	1000	1000	1000	1000
Thermal Absorptance	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Solar Absorptance	0.7	0.7	0.4	0.4	0.7	0.4	0.7	0.7	0.7	0.4	0.7
Visible Absorptance	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Table 13: Thermal and geometrical characteristics of building element materials.

The composition of the building elements have been considered according to the design of the building and can be seen at the next table.

Name	External Walls Lower	External Walls Upper	External Walls_TF	Internal Walls	Glazing	Panel	Slab	Technical Floor Slab
Outside Layer	Ceramic porcelain tiles	Ceramic porcelain tiles	Ceramic porcelain tiles	Plaster lime sand	Variable	Panel	Concrete	Variable
Layer 2	Plaster cement sand	Plaster cement sand	Plaster cement sand	Brick 10cm	Variable	-	-	Concrete
Layer 3	Expanded Clay Concrete	Equivalent Material	Expanded Clay Concrete	Plaster lime sand	Variable	-	-	-
Layer 4	Plaster lime sand	Plaster lime sand	Plaster lime sand	-	-	-	-	-
Layer 5	Variable	-	-	-	-	-	-	-
Layer 6	ETICS Plaster	-	-	-	-	-	-	-

Table 14: Building elements

The HVAC system has been simulated according to the EN ISO 13790(2008), i.e. as an ideal system with ellipsis of hysteresis and an adequate capacity. The efficiency of the distribution and emission part of the heating system has been considered equal to 0.85 and the SEER of the cooling system equal to 3. For the ventilation system it has been considered that there is not a recovery system present.

4.2.4.Results of the simulation of existing design

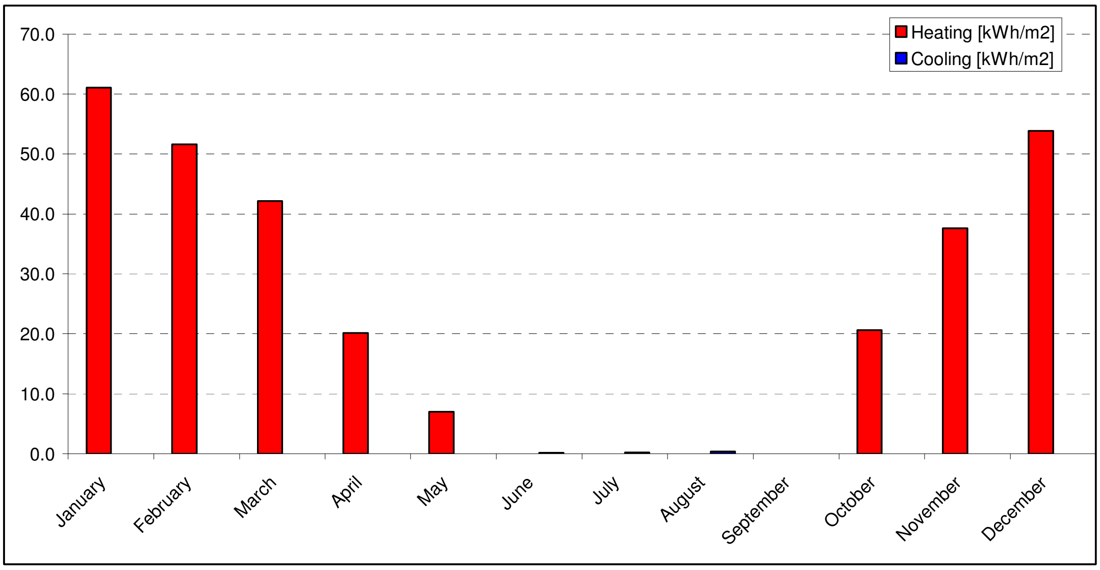
As a result of the simulation of the building it emerges that the energy needs for cooling is negligible. As a matter of fact these needs can be covered entirely with passive cooling techniques, e.g. natural ventilation by the use of the dual action windows. For the above reason the foregoing analysis will take into account only needs and consumption for heating. As can been seen at the next tables and graph the buildings needs for heating are pretty intense.

Date/Time	Heating [MJ]	Cooling [MJ]	Heating [kWh]	Cooling [kWh]	Heating [kWh/m^2]	Cooling [kWh/m^2]
January	278336	0	77316	0	46.7	0.0
February	235120	0	65311	0	39.5	0.0
March	191102	0	53084	0	32.1	0.0
April	89862	0	24962	0	15.1	0.0
May	30997	0	8610	0	5.2	0.0
June	0	2643	0	734	0.0	0.0
July	0	4466	0	1241	0.0	0.9
August	0	7007	0	1947	0.0	1.7
September	22064	0	6129	0	3.7	0.0
October	92093	0	25581	0	15.5	0.0
November	170711	0	47420	0	28.7	0.0
December	246200	0	68389	0	41.3	0.0
Total	**1362206**	**15427**	**378390**	**4285**	**228.8**	**2.6**

Table 15: Energy needs for heating and cooling

Date/Time	Heating [MJ]	Cooling [MJ]	Heating [kWh]	Cooling [kWh]	Heating [kWh/m^2]	Cooling [kWh/m^2]
January	327454	0	90960	0	55.0	0.0
February	276612	0	76837	0	46.5	0.0
March	224826	0	62452	0	37.8	0.0
April	105719	0	29367	0	17.8	0.0
May	36467	0	10130	0	6.1	0.0
June	5833	0	1620	0	1.0	0.0
July	0	1489	0	414	0.0	0.3
August	0	2336	0	649	0.0	0.4
September	25957	0	7210	0	4.4	0.0
October	108345	0	30096	0	18.2	0.0
November	200836	0	55788	0	33.7	0.0
December	289647	0	80458	0	48.6	0.0
Total	**1602595**	**5142**	**445165**	**1428**	**269.1**	**0.9**

Table 16: Energy consumption for heating and cooling

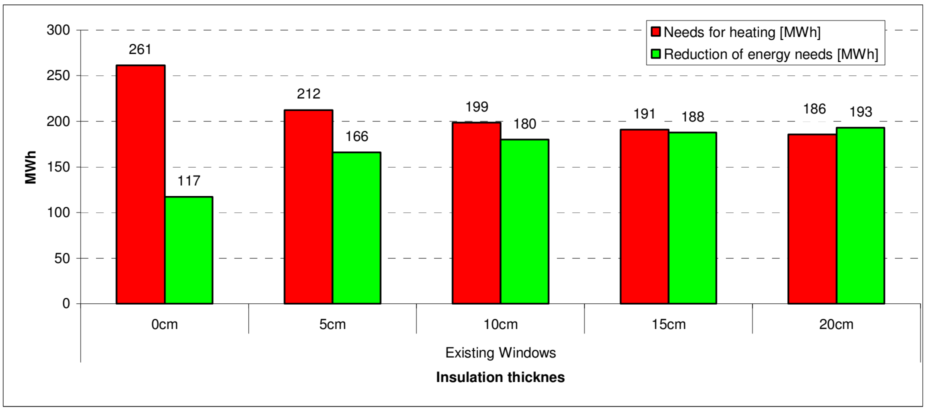


Graph 3: Energy consumption for heating and cooling of the building.

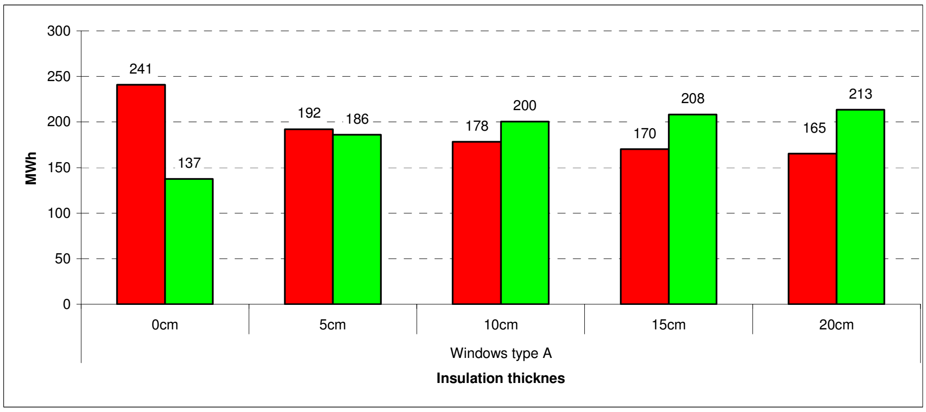
4.2.5.Results of the simulation of proposed measures

The results of the simulation of the different proposals as analyzed at the previous chapters can be seen at the next table and graphs following. The positive effects of the measures are obvious. With just 5cm insulation on the technical floor, replacement of the fenestration with type A windows and doors, and 5cm external insulation, the energy needed for heating is almost the half of that needed with the existing design. For the proposed measures, the maximum energy savings can be as high as 63%.

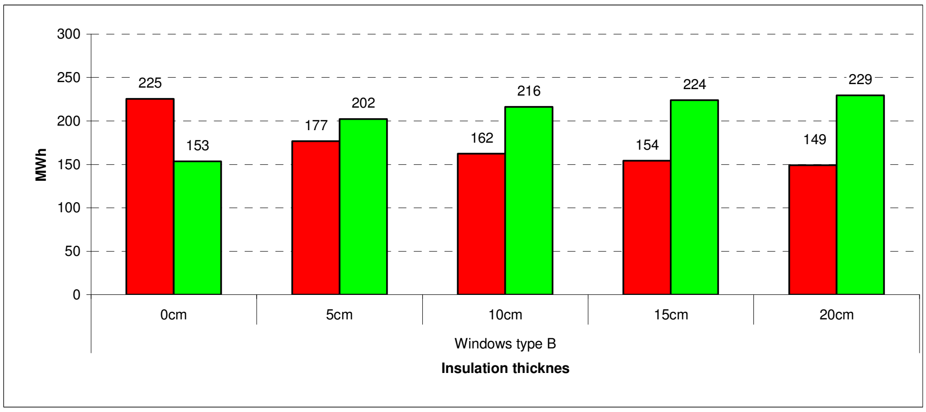
Type of windows	Insulation thickness	Needs for heating [MWh]	Reduction of energy needs [MWh]	Percent of reduction %
Existing Windows	0cm	261374	117016	30.9%
	5cm	212448	165942	43.9%
	10cm	198537	179853	47.5%
	15cm	190794	187596	49.6%
	20cm	185508	192882	51.0%
Windows type A	0cm	240924	137466	36.3%
	5cm	192219	186171	49.2%
	10cm	178174	200216	52.9%
	15cm	170379	208011	55.0%
	20cm	165067	213323	56.4%
Windows type B	0cm	225182	153208	40.5%
	5cm	176514	201876	53.4%
	10cm	162280	216110	57.1%
	15cm	154387	224003	59.2%
	20cm	149028	229362	60.6%
Windows type C	0cm	217563	160827	42.5%
	5cm	169214	209176	55.3%
	10cm	154785	223605	59.1%
	15cm	146791	231599	61.2%
	20cm	141322	237068	62.7%



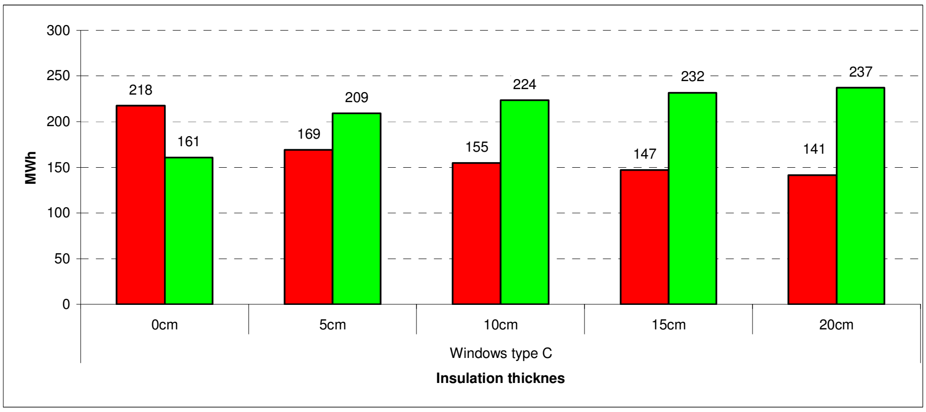
Graph 4: Energy needs and energy savings for different thickness of insulation existing fenestration



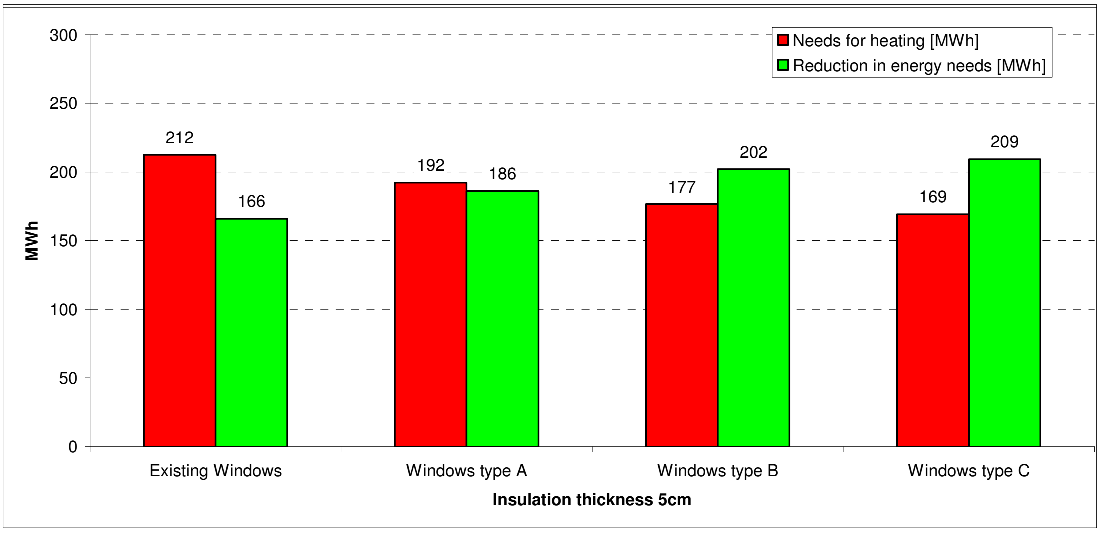
Graph 5: Energy needs and energy savings for different thickness of insulation with fenestration type A



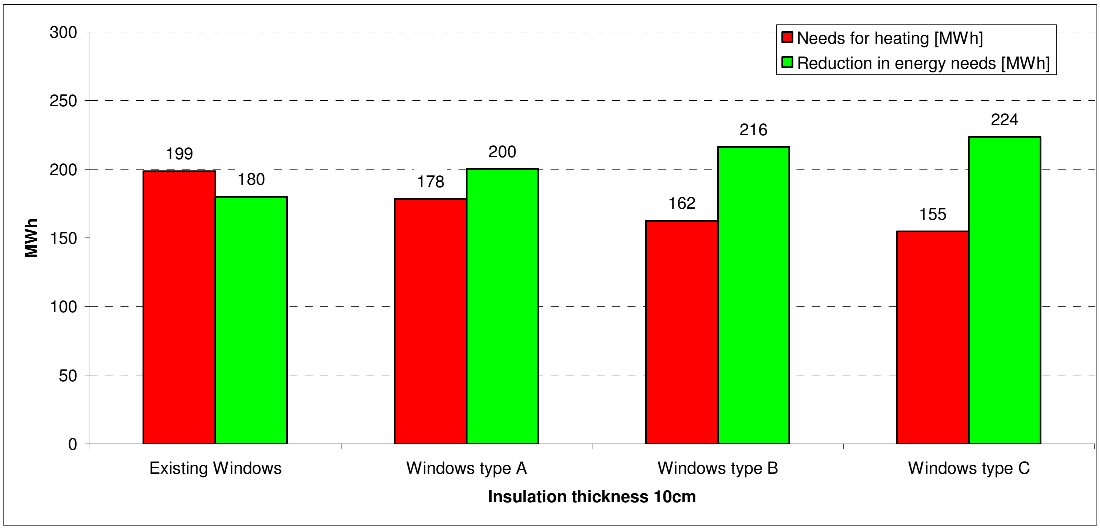
Graph 6: Energy needs and energy savings for different thickness of insulation with fenestration type B.



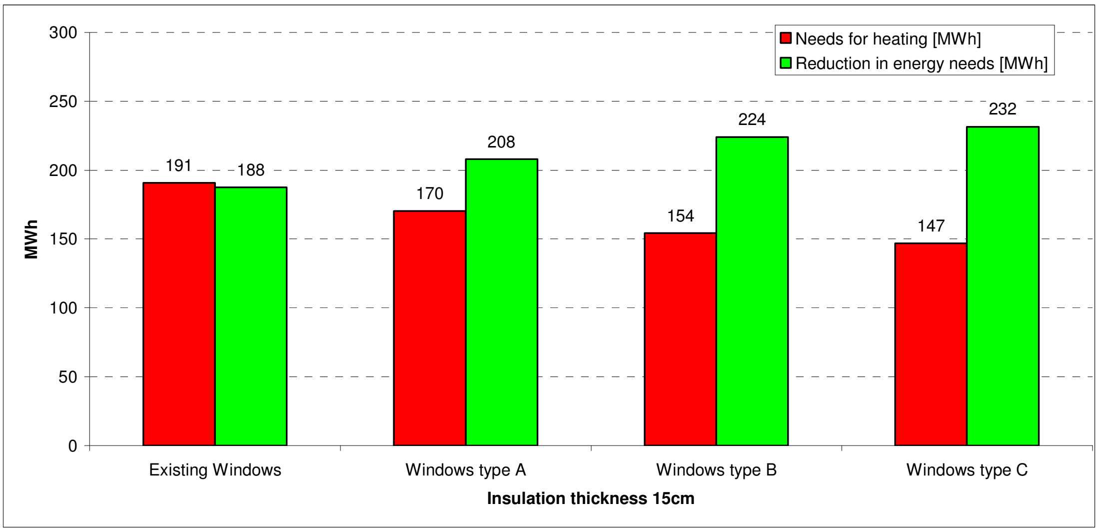
Graph 7: Energy needs and energy savings for different thickness of insulation with fenestration type C.



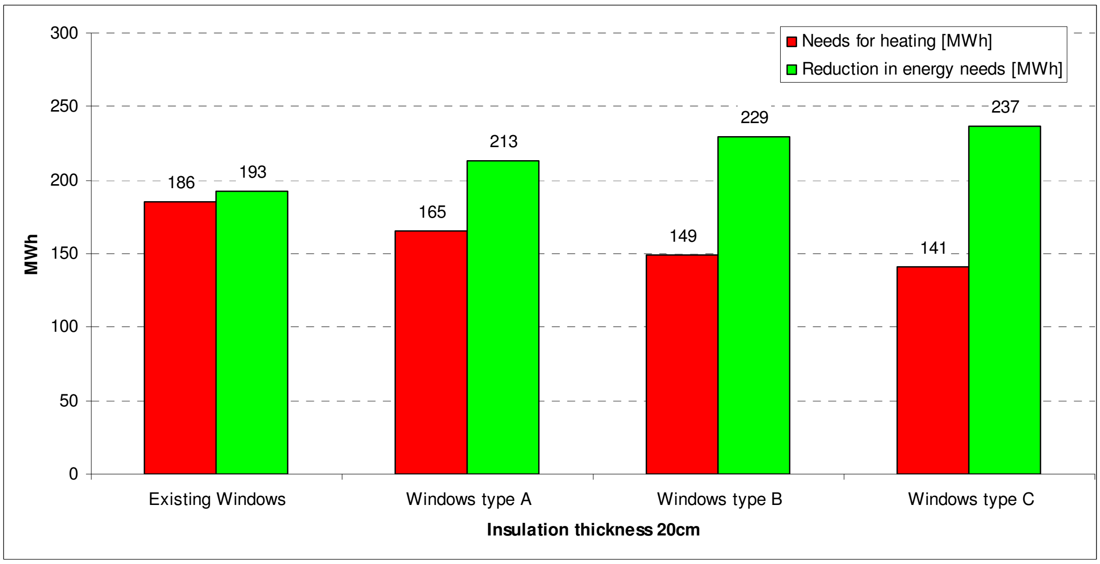
Graph 8: Needs for heating and energy savings for 5cm of wall thermal insulation



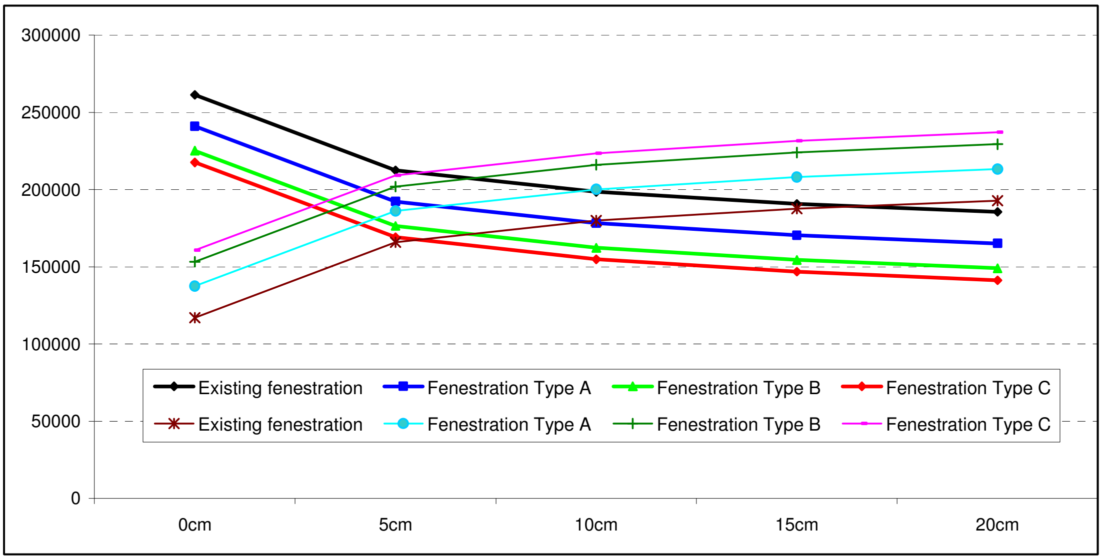
Graph 4: Needs for heating and energy savings for 10cm of wall thermal insulation



Graph 10: Needs for heating and energy savings for 15cm of wall thermal insulation



Graph 11: Needs for heating and energy savings for 20cm of wall thermal insulation

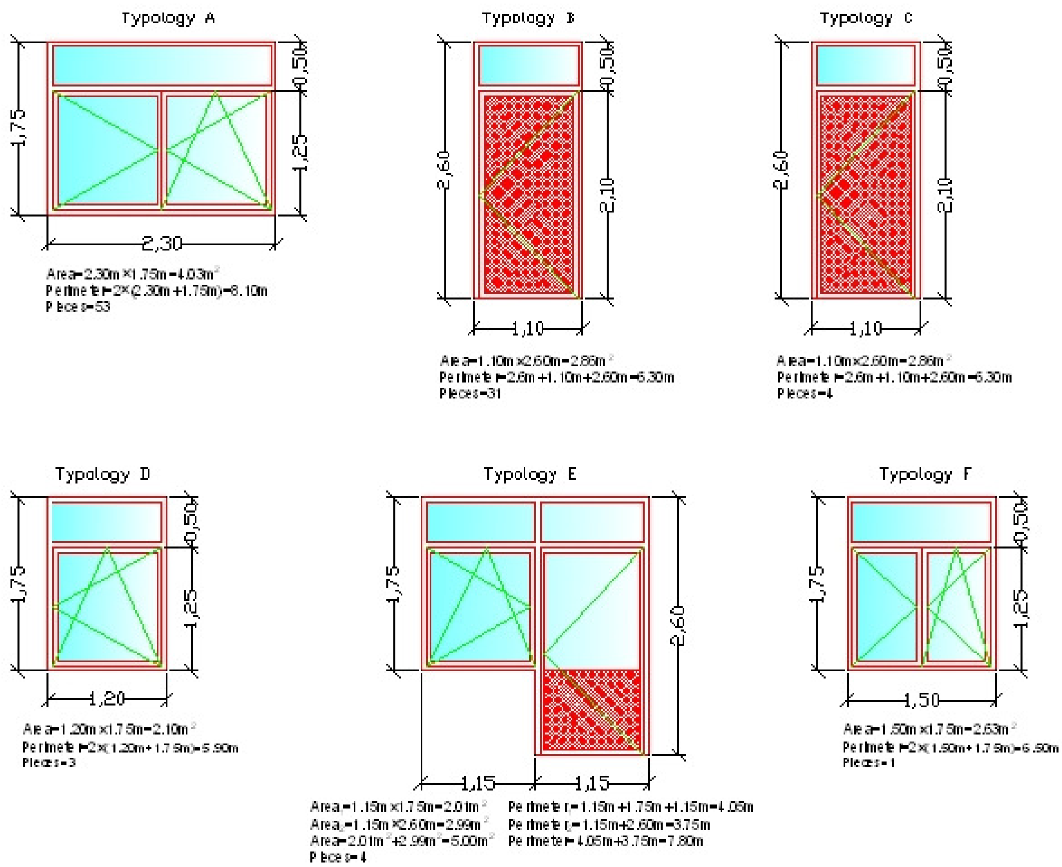


Graph 12: Energy need and energy savings for the proposals.

4.2.6.Economic data

A market research that has been conducted so as to estimate the average cost of the proposals. In the next tables the results of the market research along with the estimation of the interventions proposed are shown.

As analytically explained on chapter 2.1.3 there are three different types of fenestrations that will be investigated. In the building there are five different typologies as illustrated in the next picture.



Picture 48: Fenestration typologies

The cost of the replacement of fenestration can be seen in the next table.

	Type A fenestration		Type B fenestration		Type C fenestration	
	Areal cost [€/m^2]	Cost [€]	Areal cost [€/m^2]	Cost [€]	Areal cost [€/m^2]	Cost [€]
Typology A	238	50771	253	53971	268	57171
Typology B	246	21810	261	23140	276	24470
Typology C	238	2723	253	2894	268	3066
Typology D	238	1499	253	1594	268	1688
Typology E	242	2421	257	2571	272	2721
Typology F	238	625	253	664	268	704
Total	-	**79850**	-	**84835**	-	**89820**

Table 17: Fenestration costs.

The cost of the application of ETICS can be seen in the next table.

Thickness of ETICS	Area applied [m^2]	Unit cost [€/m^2]	Total cost [€]
5cm	682	40	**27280**
10cm	682	44	**30008**
15cm	682	48	**32736**
20cm	682	50	**34100**

Table 18: ETICS cost

The cost of the application of floor insulation of the technical floor can be seen in the next table.

Thickness of insulation	Area applied [m^2]	Unit cost [€/m^2]	Total cost [€]
5cm	830	30	**24900**

Table 19: Floor insulation cost

The cost of district heating has been estimated equal to 0.022 €/kWh.
The interest rate that will be assumed for calculating the net present value is 4% and the period of interest 50 years.

4.2.7.Economic analysis of the proposed measures

For the evaluation of the proposed measures, the economic benefits of its use have been assessed. In the next table can be seen analytically the costs of the proposed measures.

Fenestration	ETICS insulation thickness	Cost of floor insulation [€]	Cost of ETICS application [€]	Replacement of fenestration [€]
Type A	5cm	24900	27280	79860
	10cm	24900	30000	79860
	15cm	24900	32735	79860
	20cm	24900	34100	79860
Type B	5cm	24900	27280	84835
	10cm	24900	30000	84835
	15cm	24900	32735	84835
	20cm	24900	34100	84835
Type C	5cm	24900	27280	89820
	10cm	24900	30000	89820
	15cm	24900	32735	89820
	20cm	24900	34100	89820

Table 20: Cost of investigated measures.

In the next table there are shown the total investment cost, the annual savings, the simple payback period and the net present value of each intervention.

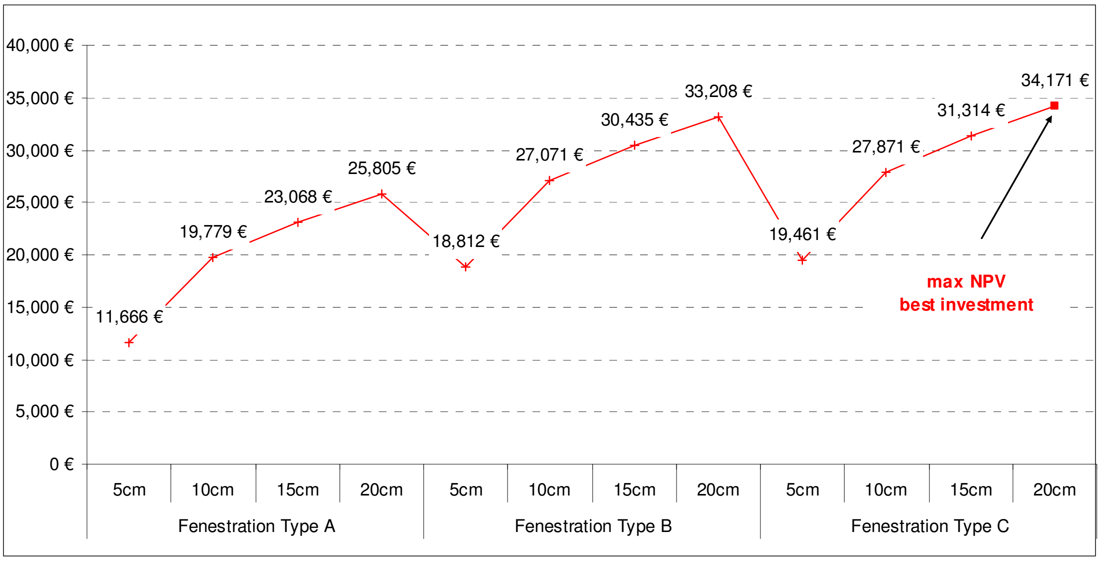
Fenestration	ETICS insulation thickness	Total investment [€]	Yearly savings [€]	Simple payback period [years]	Net Present Value of investment [€]
Type A	5cm	132040	5585	23.6	11,666 €
	10cm	134760	6006	22.4	19,779 €
	15cm	137495	6240	22.0	23,068 €
	20cm	138860	6400	21.7	25,805 €
Type B	5cm	137015	6056	22.6	18,812 €
	10cm	139735	6483	21.6	27,071 €
	15cm	142470	6720	21.2	30,435 €
	20cm	143835	6881	20.9	33,208 €
Type C	5cm	142000	6275	22.6	19,461 €
	10cm	144720	6708	21.6	27,871 €
	15cm	147455	6948	21.2	31,314 €
	20cm	148820	7112	20.9	34,171 €

Table 21: Financial indexes of proposals

From the economic analysis of the various measures proposed it arises that the most beneficial intervention would be:

1. insulation of the floor of the technical floor with 5cm XPS,
2. application of ETICS with 20cm EPS,
3. replacement of the fenestration with type C fenestration, i.e. frame with U_{frame}=1.5 W/(m^{2}K), glazing with $U_{glazing}$= 1.20 W/(m^{2}K) and panel with U_{panel}=1.35 W/(m^{2}K).

The total cost of investment is estimated to 148.820€ and the simple payback period 20.9 years.



Graph 13: NPV of investments.

5. References

1. EN ISO 13790:2008 "Energy performance of buildings - Calculation of energy use for space heating and cooling"
2. EN ISO 6946:2007 "Building components and building elements - Thermal resistance and thermal transmittance - Calculation method"
3. EN ISO 13789:2007 "Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method"
4. EN ISO 10456:2007 "Building materials and products - Hygrothermal properties -Tabulated design values and procedures for determining declared and design thermal values"
5. EN ISO 10211:2007 "Thermal bridges in building construction - Heat flows and surface temperatures - Detailed calculations"
6. EN ISO 10077-1:2006 "Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General"
7. EN 15251:2007 "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics"
8. EN ISO 13370:2007 "Thermal performance of buildings - Heat transfer via the ground - Calculation methods"