# POLITECNICO DI TORINO

DEPARTMENT OF ENERGY

Master's degree in Industrial Engineering


MASTER'S THESIS IN INDUSTRIAL ENGINEERING

# ENERGY AUDIT OF THE BELLVITGE UB HEALTH SCIENCE CAMPUS THROUGH DESIGN BUILDER


| | |
|---|---|
| **Author** | **Lambert Grange Vilà** |
| **Tutor** | **Professor Vincenzo Corrado** |
| **Academic semester** | **February 2018** |

# Table of contents

# 1. Third proposal: Addition of external thermal insulation system

## 1.1. Previous considerations

The application of this third improvement proposal has been considered on the basis of the current situation of the studied building, without the implementation of the last two explained proposals. This decision is intended to show the direct effect of the measure that will be explained below, without the influence that has produced in the final energy consumption the replacement of the lighting system along with the incorporation of PV panels.

With the two previous proposals, a 70.47% reduction in energy consumption associated with interior lighting is achieved (a yearly saving of 183.928,37 kWh), which at global levels of total consumption of the building translates into a reduction of 31.15% per year.

Both proposals have been argued from a technical and economic point of view, in order to assess the feasibility of their implementation. Once the desired results have been obtained in terms of energy consumption, it has been decided to make a third additional proposal focused on complimenting the present energy audit.

## 1.2. Thermal envelope analysis

This third proposal will focus on the improvement of the present thermal envelope of the Campus.

As can be seen both in the Design Builder file and in the description of the exterior walls, thermal bridges and windows that conform it (points 5.3.1 and 5.3.2 of the memory, and points 1.1.6 and 1.2 of the annex document), its correct design is confirmed, and consequently the difficulty to find an economically viable option that would allow improving the envelope (it should be remembered we are dealing with a building with only 6 years antiquity).

Regarding windows (points 5.3.2.1 and 5.3.2.2 of the memory and 1.2.1 and 1.2.2 of the annex) two typologies were implemented.

The first of them (Aulari - M.C. - a1_a6 + F.AL.V.a1_a2) composed (analyzing it from the outside to the inside) by a 10 mm glass, 12 mm air chamber and 12 mm inner glass. It is placed in the windows of the ground and first floors.

The second typology (Aulari - C.B.F.AL.V.-a1_a10 + F.B.AL.V.-a1_a3 + E.AL.V.-a1) is composed of a 6 mm outer glass, 12 mm air chamber and 8 mm inner glass. This is located on the second, third and fourth floors.

Both provide sufficiently low solar transmission and thermal transmittance values to discard their replacement. On the other hand, the existence of the solar protection elements *brise-soleils* on both south and west façades allow to compliment from a thermal and solar point of view the performance of those glazing systems.

Analyzing the exterior walls of the Campus (point 5.3.1.6 of the memoir and 1.1.6 of the appendix) it has been studied their composition in conjunction with the corresponding values of thermal transmittance, so as to be able to determine which are the ones that can compromise to a major extent the correct insulation of the building's thermal envelope.

From this analysis, it has been concluded that the external walls that are in this situation are the following:

1. Aulari – Mur Nord Monocapa – R06
2. Aulari – Mur Nord Monocapa – R07
3. Aulari – Mur Nord Monocapa – R09
4. Aulari – Mur Nord Monocapa – FA – R10
5. Aulari – Mur Nord Monocapa – FA40 – CA10 – R07
6. Aulari – Mur Nord Monocapa – FA – Conductes
7. Aulari – Mur Nord Monocapa – FA30 – Elevators

As can be seen in the DB model, all the above-mentioned exterior walls are located on the north façade of the studied building (with the particularity that wall 2 is also located on the south façade).

As a whole, they are characterized by the fact that they are finished with a continuous monolayer cladding. The existence of such layer would allow a simple incorporation of an additional external thermal insulation system in the involved facades.

Additionally, the north façade (façade affected to a greater extent by this measure) is the exterior part of the building with the least insulation and the one that must withstand the lowest temperatures in winter.

## 1.3. Application of the proposal

In order to reduce the thermal transmittance of the above-mentioned walls and consequently enhance the thermal insulation of the enclosure, it has been decided to incorporate an external thermal insulation system to all of them.

The chosen external thermal insulation system is composed by the following layers (going from the inside to the outside of the wall):

- Expanded polystyrene EPS, thickness: 0,06m.
- Layer of cement mortar for masonry, thickness: 0,02m.
- Polyvinylchloride layer (PVC), thickness: 0,02m.

The following is an example of the change made to one of the affected exterior walls (Aulari - Mur Nord Monocapa - R06):

| | |
|---|---|
| **General** | |
| **Name** | **Aulari - Mur Nord Monocapa - R06** |
| Source | |
| Category | Walls |
| Region | SPAIN |
| **Definition** | |
| Definition method | 1-Layers |
| **Calculation Settings** | |
| **Layers** | |
| Number of layers | 4 |
| **Outermost layer** | |
| Material | Mortero de cemento o cal para albañilería y para revoco/enlucido 10 |
| Thickness (m) | 0,0150 |
| Bridged? | |
| **Layer 2** | |
| Material | 1/2 pie LP métrico o catalán 80 mm< G < 100 mm |
| Thickness (m) | 0,1400 |
| Bridged? | |
| **Layer 3** | |
| Material | Air gap 5mm |
| Thickness (not used in thermal calcs) (m) | 0,0460 |
| **Innermost layer** | |
| Material | Placa de yeso laminado [PYL] 750 < d < 900 |
| Thickness (m) | 0,0150 |
| Bridged? | |

*Figure 1: Initial composition of the enclosure*

In Figure 1 the initially configured layers can be observed. The following Figure 2 shows how the enclosure looks once the three layers of the external thermal insulation system have been incorporated.

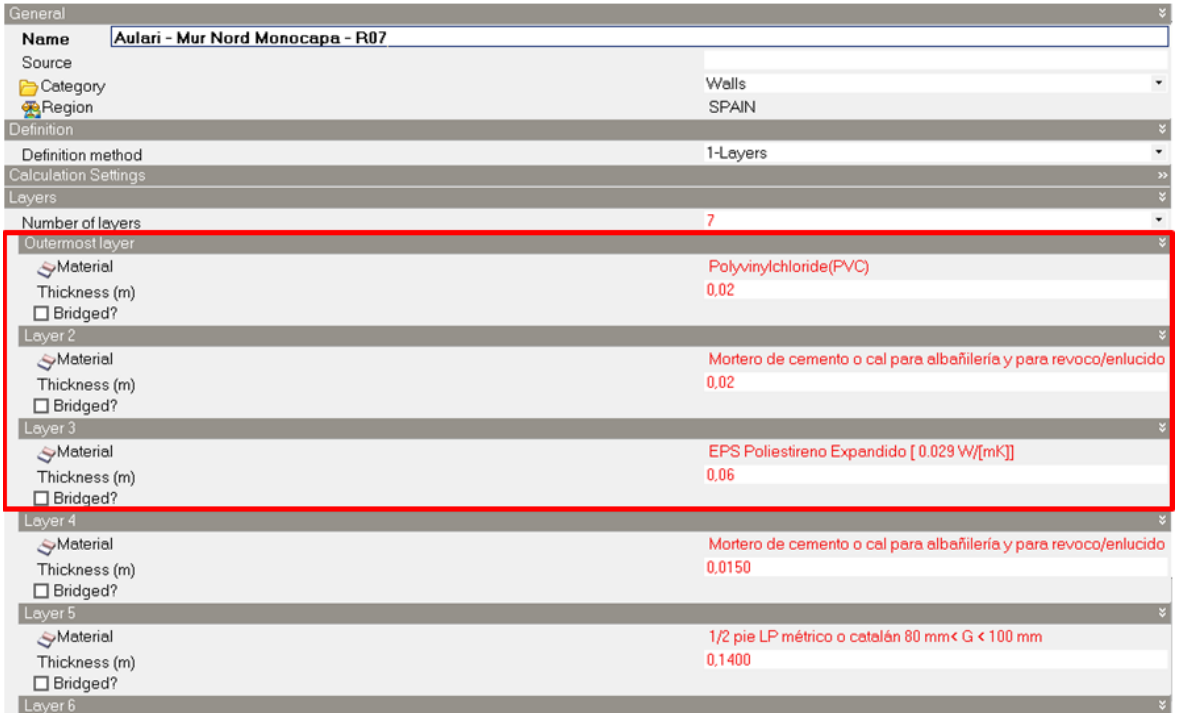


*Figure 2: Final composition of the enclosure*

Regarding the effect produced in the values of thermal transmittance, as can be seen in the following Figure 3, the introduction of such system has allowed reducing it from 1,6 W/m$^2$K to 0,35 W/m$^2$K.

| Inner surface | | Inner surface | |
|---|---|---|---|
| Convective heat transfer coefficient (W/m2-K) | 2,152 | Convective heat transfer coefficient (W/... | 2,152 |
| Radiative heat transfer coefficient (W/m2-K) | 5,540 | Radiative heat transfer coefficient (W/m... | 5,540 |
| Surface resistance (m2-K/W) | 0,130 | Surface resistance (m2-K/W) | 0,130 |
| Outer surface | | Outer surface | |
| Convective heat transfer coefficient (W/m2-K) | 19,870 | Convective heat transfer coefficient (W/... | 19,870 |
| Radiative heat transfer coefficient (W/m2-K) | 5,130 | Radiative heat transfer coefficient (W/m... | 5,130 |
| Surface resistance (m2-K/W) | 0,040 | Surface resistance (m2-K/W) | 0,040 |
| No Bridging | | No Bridging | |
| U-Value surface to surface (W/m2-K) | 2,197 | U-Value surface to surface (W/m2-K) | 0,372 |
| R-Value (m2-K/W) | 0,625 | R-Value (m2-K/W) | 2,855 |
| **U-Value (W/m2-K)** | **1,600** | **U-Value (W/m2-K)** | **0,350** |
| With Bridging (BS EN ISO 6946) | | With Bridging (BS EN ISO 6946) | |
| Thickness (m) | 0,2160 | Thickness (m) | 0,3160 |
| Km - Internal heat capacity (KJ/m2-K) | 12,3750 | Km - Internal heat capacity (KJ/m2-K) | 12,3750 |
| Upper resistance limit (m2-K/W) | 0,625 | Upper resistance limit (m2-K/W) | 2,855 |
| Lower resistance limit (m2-K/W) | 0,625 | Lower resistance limit (m2-K/W) | 2,855 |
| U-Value surface to surface (W/m2-K) | 2,197 | U-Value surface to surface (W/m2-K) | 0,372 |
| R-Value (m2-K/W) | 0,625 | R-Value (m2-K/W) | 2,855 |
| **U-Value (W/m2-K)** | **1,600** | **U-Value (W/m2-K)** | **0,350** |

*Figure 3: Comparison of the thermal properties before (left) and after applying the ext. system (right)*

Below is attached an image (Figure 4) of the area of the north façade in which it has been decided to incorporate the external insulation system (marked in red).

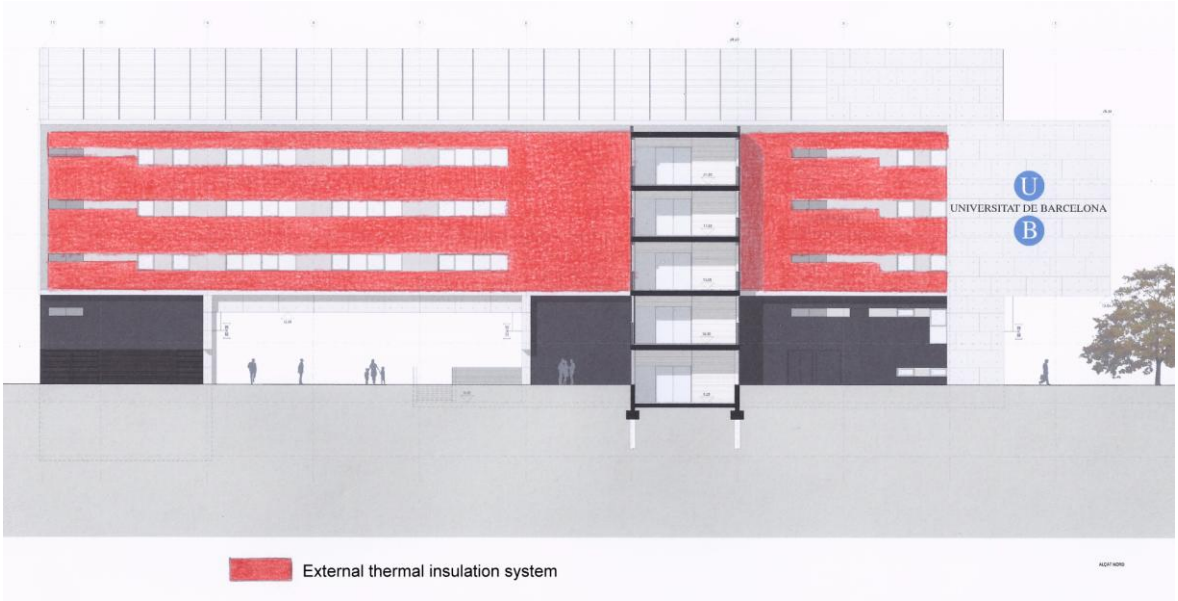


*Figure 4: Zone of the North façade where the ext. insulation syst. will be applied*

## 1.4. Obtained results

Once the relevant changes have been introduced in the Design Builder file, the corresponding simulations are carried out in both heating and cooling systems.

Equivalent to the analyses carried out in points 7.3.4 and 7.4.3 of the memory, the values obtained from total energy consumption and the number of unsatisfied hours have been analysed.

A comparison of both sets of values with the situation prior to the implementation of this third improvement proposal is made in both systems.

### 1.4.1. Heating system

If the final energy consumption obtained through the simulation of the heating system is initially analysed, it is observed that the differences are minimal (see Figure 5, on the left, the results once the proposal has been applied, and on the right the old ones). Even the total consumption has increased.

Additionally, it can be observed how the consumption associated with fans and water systems, both directly related to the production of hot water from heat pumps BC1 and BC2, has also been raised.

However, the main factor to be taken into account from this information is that no energy savings have been obtained in heating mode with the application of this third proposal.

**End Uses**

| | Electricity [kWh] |
|---|---|
| Heating | 0.00 |
| Cooling | 0.00 |
| Interior Lighting | 236970.10 |
| Exterior Lighting | 0.00 |
| Interior Equipment | 20938.84 |
| Exterior Equipment | 0.00 |
| Fans | 88513.50 |
| Pumps | 3511.69 |
| Heat Rejection | 0.00 |
| Humidification | 0.00 |
| Heat Recovery | 20462.90 |
| Water Systems | 15407.65 |
| Refrigeration | 0.00 |
| Generators | 0.00 |
| | |
| Total End Uses | 385804.67 |

**End Uses**

| | Electricity [kWh] |
|---|---|
| Heating | 0.00 |
| Cooling | 0.00 |
| Interior Lighting | 238233.72 |
| Exterior Lighting | 0.00 |
| Interior Equipment | 21072.29 |
| Exterior Equipment | 0.00 |
| Fans | 85635.75 |
| Pumps | 3511.65 |
| Heat Rejection | 0.00 |
| Humidification | 0.00 |
| Heat Recovery | 20462.90 |
| Water Systems | 14993.21 |
| Refrigeration | 0.00 |
| Generators | 0.00 |
| | |
| Total End Uses | 383909.52 |

*Figure 5: Comparison of the obtained total annual energy consumptions (left: after applying the proposal; right: before)*

The comfort values are then analysed. These, as already explained in point 7.3.3 of the memory, are calculated following the parameters marked by the ASHRAE 55 model (using the PMV/PPD method to determine whether we are within the comfort zone or not).

As shown in Figure 6 (framed in red are the unsatisfied heating hours obtained once the proposal has been applied), the unsatisfied hours have been generally reduced compared to the previous situation (Figure 7).

It is noteworthy the decrease produced in the common area of the ground floor (going from the initial 432.25 unsatisfied hours to 384.25 hours) and the one obtained in office 4.11 of the fourth floor (going from the initial 137 unsatisfied hours to 97 unsatisfied hours per year).

**Time Setpoint Not Met**

| | During Heating [hr] | During Cooling [hr] | During Occupied Heating [hr] | During Occupied Cooling [hr] |
|---|---|---|---|---|
| 0GROUNDFLOOR:COMMONAREAGR.FL. | 2666.75 | 1765.50 | 384.25 | 299.00 |
| 0GROUNDFLOOR:SALADEGRAUS | 906.25 | 2296.25 | 26.25 | 422.00 |
| 0GROUNDFLOOR:OFFICEGR.FL. | 519.50 | 3706.25 | 2.50 | 1494.75 |
| 0GROUNDFLOOR:RECEPTION | 1089.50 | 2880.00 | 7.25 | 1088.50 |
| 1FIRSTFLOOR:CLASSROOMS1.11.2 | 721.50 | 3334.25 | 8.00 | 756.00 |
| 2SECONDFLOOR:CLASSROOM2.1 | 1933.75 | 2939.25 | 33.00 | 748.25 |
| 2SECONDFLOOR:COMPUTERLABS2.12.2 | 1148.00 | 3434.75 | 39.25 | 818.50 |
| 2SECONDFLOOR:CLASSROOMS2.22.32.4 | 715.75 | 3977.50 | 2.25 | 1128.75 |
| 2SECONDFLOOR:CLASSROOM2.5 | 472.25 | 4270.00 | 7.50 | 1194.75 |
| 2SECONDFLOOR:CLASSROOMS2.62.72.8 | 595.00 | 3876.25 | 9.75 | 1017.25 |
| 2SECONDFLOOR:COMPUTERLAB2.3 | 892.25 | 3897.25 | 21.50 | 982.75 |
| 3THIRDFLOOR:LABORATORY3.1 | 899.25 | 4028.25 | 20.75 | 1032.75 |
| 3THIRDFLOOR:LABORATORIES3.93.10 | 619.25 | 4029.50 | 24.25 | 944.50 |
| 3THIRDFLOOR:LABORATORIES3.23.4 | 616.00 | 4425.25 | 11.25 | 1197.00 |
| 3THIRDFLOOR:LABORATORIES3.53.8 | 555.00 | 4443.50 | 12.75 | 1164.00 |
| 4FOURTHFLOOR:OFFICES4.14.2 | 969.00 | 4426.00 | 40.50 | 1242.25 |
| 4FOURTHFLOOR:OFFICES4.34.10 | 966.00 | 4432.75 | 35.00 | 1265.75 |
| 4FOURTHFLOOR:OFFICE4.11 | 1553.00 | 4150.00 | 97.00 | 1157.25 |
| 4FOURTHFLOOR:CLASSROOMS4.14.2 | 999.00 | 3871.75 | 10.50 | 1023.75 |
| 4FOURTHFLOOR:CLASSROOMS4.34.4 | 540.00 | 4429.50 | 10.00 | 1226.50 |

*Figure 6: Obtained comfort results after applying the 3rd Proposal*

**Time Setpoint Not Met**

| | During Heating [hr] | During Cooling [hr] | During Occupied Heating [hr] | During Occupied Cooling [hr] |
|---|---|---|---|---|
| 0GROUNDFLOOR:COMMONAREAGR.FL. | 2837.50 | 1650.00 | 432.25 | 278.25 |
| 0GROUNDFLOOR:SALADEGRAUS | 938.75 | 2267.00 | 26.50 | 415.00 |
| 0GROUNDFLOOR:OFFICEGR.FL. | 535.75 | 3650.50 | 2.75 | 1465.25 |
| 0GROUNDFLOOR:RECEPTION | 1161.50 | 2799.00 | 8.00 | 1057.50 |
| 1FIRSTFLOOR:CLASSROOMS1.11.2 | 776.00 | 3265.00 | 8.50 | 736.00 |
| 2SECONDFLOOR:CLASSROOM2.1 | 2087.25 | 2754.75 | 37.50 | 701.00 |
| 2SECONDFLOOR:COMPUTERLABS2.12.2 | 1513.50 | 3079.00 | 52.25 | 737.00 |
| 2SECONDFLOOR:CLASSROOMS2.22.32.4 | 882.75 | 3753.50 | 5.00 | 1045.50 |
| 2SECONDFLOOR:CLASSROOM2.5 | 564.00 | 4015.75 | 9.00 | 1079.75 |
| 2SECONDFLOOR:CLASSROOMS2.62.72.8 | 762.25 | 3667.00 | 14.50 | 944.50 |
| 2SECONDFLOOR:COMPUTERLAB2.3 | 1108.50 | 3677.75 | 27.75 | 912.00 |
| 3THIRDFLOOR:LABORATORY3.1 | 1061.75 | 3860.75 | 23.25 | 958.75 |
| 3THIRDFLOOR:LABORATORIES3.93.10 | 800.75 | 3690.00 | 26.75 | 805.75 |
| 3THIRDFLOOR:LABORATORIES3.23.4 | 777.50 | 4202.25 | 13.50 | 1088.00 |
| 3THIRDFLOOR:LABORATORIES3.53.8 | 715.00 | 4202.25 | 14.50 | 1059.75 |
| 4FOURTHFLOOR:OFFICES4.14.2 | 1335.50 | 4226.25 | 54.00 | 1188.25 |
| 4FOURTHFLOOR:OFFICES4.34.10 | 1340.50 | 4179.75 | 41.50 | 1197.25 |
| 4FOURTHFLOOR:OFFICE4.11 | 1871.50 | 3956.75 | 137.00 | 1111.75 |
| 4FOURTHFLOOR:CLASSROOMS4.14.2 | 1275.50 | 3667.25 | 16.00 | 944.50 |
| 4FOURTHFLOOR:CLASSROOMS4.34.4 | 659.75 | 4141.50 | 13.50 | 1081.50 |

*Figure 7: Obtained comfort results before applying the 3rd Proposal*

Therefore, although there was no energy saving in the total consumption of the building, the comfort values have been improved.

However, their decrease cannot be considered of great importance for two reasons. On one hand, the initial values of unsatisfied hours were sufficiently adequate and on the other hand,

the greatest reduction has taken place in the common area of the ground floor, which is a circulation area where no academic activity takes place and consequently the demand for comfort in this area is lower.

### 1.4.2. Cooling system

Following the same process performed in the heating system, the analysis of the obtained results in the cooling system is carried out.

Initially if the values of total annual consumption are compared, it can be observed in the Figure 8 (on the left side after applying the proposal and on the right side the initial situation) as well as in the heating system, the consumption has not been affected by the incorporation of the external thermal insulation system.

In this case, the reason for its increase may be due to the fact that the improvement of the thermal envelope produces a higher concentration of thermal load in the different areas to be air-conditioned, and this load must be counterbalanced with an increase in the cooling consumption.

**End Uses**

| | Electricity [kWh] |
|---|---|
| Heating | 0.00 |
| Cooling | 123662.96 |
| Interior Lighting | 236970.10 |
| Exterior Lighting | 0.00 |
| Interior Equipment | 20938.84 |
| Exterior Equipment | 0.00 |
| Fans | 59049.44 |
| Pumps | 7315.06 |
| Heat Rejection | 1841.96 |
| Humidification | 0.00 |
| Heat Recovery | 20048.20 |
| Water Systems | 0.00 |
| Refrigeration | 0.00 |
| Generators | 0.00 |
| | |
| Total End Uses | 469826.56 |

**End Uses**

| | Electricity [kWh] |
|---|---|
| Heating | 0.00 |
| Cooling | 119952.32 |
| Interior Lighting | 238233.72 |
| Exterior Lighting | 0.00 |
| Interior Equipment | 21072.29 |
| Exterior Equipment | 0.00 |
| Fans | 57313.50 |
| Pumps | 7352.66 |
| Heat Rejection | 1841.96 |
| Humidification | 0.00 |
| Heat Recovery | 20048.20 |
| Water Systems | 0.00 |
| Refrigeration | 0.00 |
| Generators | 0.00 |
| | |
| Total End Uses | 465814.65 |

*Figure 8: Comparison of the obtained total annual energy consumptions (left: after applying the proposal; right: before)*

Observing the obtained values of unsatisfied hours (check Figure 9 corresponding to the comfort results once the third proposal has been applied), the hypothesis previously described is corroborated. There has been an increase of unsatisfied hours in periods of occupation to be cooled.

This generalized increment in spite of not being transcendent in terms of magnitude, is indicative of the thermal tendency that would produce the application of the external thermal insulation system during the summer period.

**Time Setpoint Not Met**

| | During Heating [hr] | During Cooling [hr] | During Occupied Heating [hr] | During Occupied Cooling [hr] |
|---|---|---|---|---|
| 0GROUNDFLOOR:COMMONAREAGR.FL. | 3266.00 | 795.00 | 763.50 | 1.50 |
| 0GROUNDFLOOR:SALADEGRAUS | 974.00 | 1441.00 | 12.50 | 2.75 |
| 0GROUNDFLOOR:OFFICEGR.FL. | 644.50 | 1286.50 | 44.50 | 0.00 |
| 0GROUNDFLOOR:RECEPTION | 1516.75 | 782.00 | 124.25 | 0.00 |
| 1FIRSTFLOOR:CLASSROOMS1.11.2 | 768.50 | 2006.00 | 0.75 | 28.25 |
| 1FIRSTFLOOR:DATAXRACKSX1STFL. | 2838.25 | 2273.50 | 518.25 | 108.00 |
| 2SECONDFLOOR:CLASSROOM2.1 | 2083.00 | 1606.75 | 41.75 | 0.25 |
| 2SECONDFLOOR:COMPUTERLABS2.12.2 | 1192.50 | 1467.25 | 24.75 | 3.50 |
| 2SECONDFLOOR:CLASSROOMS2.22.32.4 | 777.25 | 2189.25 | 1.50 | 65.25 |
| 2SECONDFLOOR:CLASSROOM2.5 | 493.75 | 2389.75 | 1.75 | 78.25 |
| 2SECONDFLOOR:CLASSROOMS2.62.72.8 | 622.50 | 2113.25 | 3.25 | 16.00 |
| 2SECONDFLOOR:COMPUTERLAB2.3 | 918.00 | 1813.25 | 10.75 | 23.50 |
| 3THIRDFLOOR:LABORATORY3.1 | 956.50 | 2388.00 | 14.00 | 55.50 |
| 3THIRDFLOOR:LABORATORIES3.93.10 | 655.25 | 2370.00 | 16.75 | 20.50 |
| 3THIRDFLOOR:LABORATORIES3.23.4 | 654.00 | 2760.50 | 5.25 | 125.75 |
| 3THIRDFLOOR:LABORATORIES3.53.8 | 599.00 | 2655.00 | 6.50 | 53.00 |
| 4FOURTHFLOOR:OFFICES4.14.2 | 1339.00 | 2343.00 | 142.50 | 58.50 |
| 4FOURTHFLOOR:OFFICES4.34.10 | 1339.75 | 2083.25 | 124.75 | 26.25 |
| 4FOURTHFLOOR:OFFICE4.11 | 1980.25 | 2212.25 | 276.00 | 87.75 |
| 4FOURTHFLOOR:CLASSROOMS4.14.2 | 1061.00 | 2264.25 | 3.75 | 24.25 |
| 4FOURTHFLOOR:CLASSROOMS4.34.4 | 562.50 | 2800.75 | 9.25 | 81.00 |
| 4FOURTHFLOOR:DATAXRACKSX4THFL. | 885.75 | 3333.75 | 167.00 | 155.75 |

*Figure 9: Obtained comfort results after applying the 3rd Proposal*

Time Setpoint Not Met

| | During Heating [hr] | During Cooling [hr] | During Occupied Heating [hr] | During Occupied Cooling [hr] |
|---|---|---|---|---|
| 0GROUNDFLOOR:COMMONAREAGR.FL. | 3410.75 | 726.50 | 817.50 | 0.00 |
| 0GROUNDFLOOR:SALADEGRAUS | 1010.50 | 1426.25 | 14.25 | 2.00 |
| 0GROUNDFLOOR:OFFICEGR.FL. | 675.75 | 1271.25 | 46.50 | 0.00 |
| 0GROUNDFLOOR:RECEPTION | 1651.75 | 755.00 | 140.75 | 0.00 |
| 1FIRSTFLOOR:CLASSROOMS1.11.2 | 832.50 | 1959.25 | 1.00 | 23.25 |
| 1FIRSTFLOOR:DATAXRACKSX1STFL. | 2972.25 | 2247.50 | 594.50 | 105.50 |
| 2SECONDFLOOR:CLASSROOM2.1 | 2233.25 | 1519.75 | 52.50 | 0.00 |
| 2SECONDFLOOR:COMPUTERLABS2.12.2 | 1601.50 | 1315.50 | 39.00 | 0.50 |
| 2SECONDFLOOR:CLASSROOMS2.22.32.4 | 947.25 | 2071.75 | 2.50 | 41.50 |
| 2SECONDFLOOR:CLASSROOM2.5 | 613.75 | 2217.50 | 5.50 | 45.25 |
| 2SECONDFLOOR:CLASSROOMS2.62.72.8 | 807.50 | 2007.50 | 4.50 | 7.75 |
| 2SECONDFLOOR:COMPUTERLAB2.3 | 1147.50 | 1710.75 | 18.00 | 12.25 |
| 3THIRDFLOOR:LABORATORY3.1 | 1130.50 | 2242.75 | 16.25 | 31.50 |
| 3THIRDFLOOR:LABORATORIES3.93.10 | 867.50 | 2119.00 | 23.00 | 5.25 |
| 3THIRDFLOOR:LABORATORIES3.23.4 | 832.50 | 2569.00 | 9.00 | 73.50 |
| 3THIRDFLOOR:LABORATORIES3.53.8 | 791.50 | 2467.75 | 13.25 | 23.50 |
| 4FOURTHFLOOR:OFFICES4.14.2 | 1759.25 | 2089.75 | 211.50 | 26.25 |
| 4FOURTHFLOOR:OFFICES4.34.10 | 1776.50 | 1864.00 | 180.00 | 12.50 |
| 4FOURTHFLOOR:OFFICE4.11 | 2370.50 | 2005.75 | 369.75 | 57.25 |
| 4FOURTHFLOOR:CLASSROOMS4.14.2 | 1339.50 | 2099.00 | 8.00 | 11.75 |
| 4FOURTHFLOOR:CLASSROOMS4.34.4 | 713.25 | 2624.25 | 10.50 | 36.00 |
| 4FOURTHFLOOR:DATAXRACKSX4THFL. | 1125.25 | 3097.50 | 190.75 | 145.25 |

*Figure 10: Obtained comfort results before applying the 3rd Proposal*

## 1.5. Material execution budget and economical analysis

Once the thermal and energetic situation of the building is known with the application of the third proposal, an economic study is carried out to determine the total price of its implementation.

The affected surface taking into account all the involved exterior walls is: **406,68 m$^2$.**

From this point onwards, as in the other two previous improvement proposals, it has been used the established prices of the price bank (called BEDEC) created through the ITEC (*Intituto de Tecnología de la Construcción de Catalunya* or Institute of Construction Technology of Catalonia). In this price bank there are introduced all the quotes that can be found in any construction project.

The investment budget for this third proposal is structured in 2 sections: implementation of the external thermal insulation system, and safety and health. No taxes have been incorporated in the current quotation.

As can be seen in the following page, the needed investment to carry out this third proposal is **29.411,75 €**. In this case, the depreciation calculation cannot be done because there are no energy savings in the building.

| | | | | | |
|---|---|---|---|---|---|
| | | ***EXTERNAL THERMAL INSULATION SYSTEM*** | | | |
| **Ref.** | | **Concept** | **Units** | **Price** | **Total** |
| 01/01 | | Assembly and dismantling of fixed metal tubular scaffolding consisting of 70 cm frames and height <= 200 cm, with adjustable bases, tube crossbeams, locking tubes, working platforms at least 60 cm wide, access ladders, side railings, skirting boards and polyamide protection net, placed throughout the exterior face of the façade, including all standardised signalling elements and transport with a maximum total travel of 20 km. | 406,68 $m^2$ | 8,82 €/$m^2$ | 3.586,92 € |
| 01/02 | | Daily depreciation of the aforementioned fixed metal tubular scaffold | 406,68 $m^2$ | 3,60 €/$m^2$ | 1.464,05 € |
| 01/03 | . | External thermal insulation system (SATE) with external insulation for thin covering support, with expanded polystyrene (EPS) sheet, 60 mm thick, 0,029 W/mK of thermal transmittance, with a smooth face and straight edge, mechanically fixed with cement mortar (20 mm) for current use (GP). Externally finished with a Polyvinylchloride layer (PVC) of thickness 20 mm. | 406,68 $m^2$ | 57,12 €/$m^2$ | 23.229,56 € |
| | | ***TOTAL PHOTOVOLTAIC SYSTEM*** | ..... | | **28.280,53 €** |

| | | | | | |
|---|---|---|---|---|---|
| ***3*** | | ***SAFETY AND HEALTH*** | | | |
| **Ref.** | | **Concept** | **Units** | **Price** | **Total** |
| 02/01 | | Application of the safety and health plan in the worksite, according to the safety and health study of the project and current regulations. | 1,00 | 1.131,22 € | 1.131,22 € |
| | | ***TOTAL SAFETY AND HEALTH*** | ..... | | **1.131,22 €** |

***INVESTMENT OF PROPOSAL 3***

| **Ref.** | **Concept** | **Total Cost** | **Percentage** |
|---|---|---|---|
| 01 | EXTERNAL THERMAL INSULATION SYSTEM | 28.280,53 € | 96,15% |
| 02 | SAFETY AND HEALTH | 1.131,22 € | 3,85% |
| | ***MATERIAL EXECUTION BUDGET*** ..... | **29.411,75 €** | 100,00% |
| | **Useful building area** | **4.554,00 $m^2$.** | |
| | **Investment cost / m2 of useful area** | **6,46 €/$m^2$** | |

## 1.6. Conclusions

Once the energy and economic viability of this third improvement proposal has been analysed, the following conclusions can be extracted:

1. Its implementation would not produce any savings in the annual energy consumption (both in the heating system and in the cooling system has been even increased).

2. In terms of comfort, its application would produce an improvement during the winter months (mainly located in the common area of the ground floor), while in the summer it would cause an increase of the number of unsatisfied hours during occupation.

3. From an economic point of view, it would imply an investment of 29,411.75 €, which despite being the lowest of the three presented proposals, would not generate any amortization due to the fact that there has been no energy saving in the building.

It is for this set of conclusions that the implementation of this third proposal would be very difficult. In any case, it should be assessed whether it is worthwhile to invest the specified amount to obtain an improvement in thermal conditions in winter (together with a worsening in summer) with the main disadvantage of not generating any energy savings, which is the main objective of this energy audit.