“Sustainable Campus”: a starting point for a Building Sustainable Refurbishment. Energy-Efficiency Upgrading and Thermal Comfort

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Abstract

During the last year Politecnico and Università degli Studi di Milano have been launching a project in order to transform the university area into a sustainable and quality campus, which could become a model for the rest of the city, sharing experiences and results into the International Sustainable Campus Network (ISCN).

Various interventions are needed within that project, in order to improve the quality of life, environmental, economic and social aspects, not only on a large scale but also at each building level. For this reason some activities have been already carried out and others have been planned on a number of representative buildings inside the campus. More specifically, the first aim is the assessment of the current condition in terms of thermal performance of the building envelope, heating and cooling systems functioning and indoor comfort. It has been done by micro-climate measurements, statistical surveys, energy consumptions monitoring, modelling and simulations, after having established the specific methods, standards and protocol to follow. Some BIM models have been created to support analysis and design phase.

In this study the ultimate goal is the proposal of different solutions to improve the energy efficiency and thermal comfort of the existing buildings, acting both on the envelope and on the plants. The best project alternative choice is based on the calculation of the sustainability level of each one, determined through a multi-criteria choice method, based on the existent AHP (Analytic Hierarchy Process) comparison method, able to consider simultaneously environmental, economic and social aspects, following the standards EN 15643 relating to the sustainability assessment of buildings. The best alternatives obtained have been compared with the current situation of the building, showing a large performance increase in

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terms of environment, economy, and internal performance level. These results have also been confirmed by changing into the BIM model the boundary conditions based on the best refurbishment interventions and comparing them with the actual state.

In conclusion, that evaluation system could be a tool useful during the decision phase, able to guarantee the maximum quality level and upgrading within a sustainable building framework in the project alternatives design stage.

Keywords: Sustainability, energy efficiency, thermal comfort, multi-criteria method, BIM

1. Introduction

The “Sustainable Campus” project started in 2011 and it has been promoted by two Universities in the “Città Studi” district of Milan. The aim of this project is to transform the whole area in a sustainable quarter thanks to the active participation of students, researchers and whoever lives in the district, suggesting idea and specific projects.

The project is organized into different thematic areas: “people, energy, environment, accessibility and city” and for each of them a discussion group is active. In order to achieve the general results it is important to act also at each building level. So, from a building point of view the main purposes are related to environment and energy because of the necessity to reduce its impacts in terms of emissions and resources and energy saving.

Nowadays the attention for sustainability issues has increased, along with the calculation methods to evaluate it, based on the Life Cycle Assessment (LCA) as expressed by the European guidance (2010). In recent years we are witnessing a thriving standardization by Technical Committee ISO/TC 59, Building construction, Subcommittee SC 17, Sustainability in building construction, and by CEN/TC 350, at European level, in order to define the principles and the procedures for assessing the sustainability of both products, ISO 21930 (2007), and new and existing buildings, ISO 21931-1 (2010) from environmental, social and economic point of view, related to ISO 15392 (2008) and ISO 21929-1 (2011).

On the basis of what has been outlined in the reference standards, a preliminary evaluation activity on some existing buildings has been carried out within the project “Sustainable Campus”. This project is aimed at assessing the real conditions and proposing solutions to improve the environmental performance, the life cycle cost performance, the health and comfort performance of the buildings.

2. Conditions survey

The university campus consists of a series of buildings of different construction periods and therefore they have different characteristics from plants and structures point of view. For this reason, the first step of the analysis was to select the more representative buildings on which to perform the investigation in terms of thermal performance of the building envelope, heating and cooling systems and indoor comfort, for evaluating the energy consumption and consequently the environmental, social and economic impacts. Among others a significant building ("Nave"), that will also soon undergo heavy refurbishment, has been chosen and monitored.

The “Nave” (see Figure 1) was built in the late sixties by Gio Ponti, it is a 7-storey building, which is L-shaped and divided into two blocks with different functional uses: a block for the offices, extended in the north-south direction, with a concrete bearing structure in beam and pillars and a floor area of about 732 square meters; and a second block, which extends west-east, with a mixed concrete - steel structure and a floor area of about 1242 square meters, for the classrooms. The building has a radiator heating system and no air conditioning ventilation system.

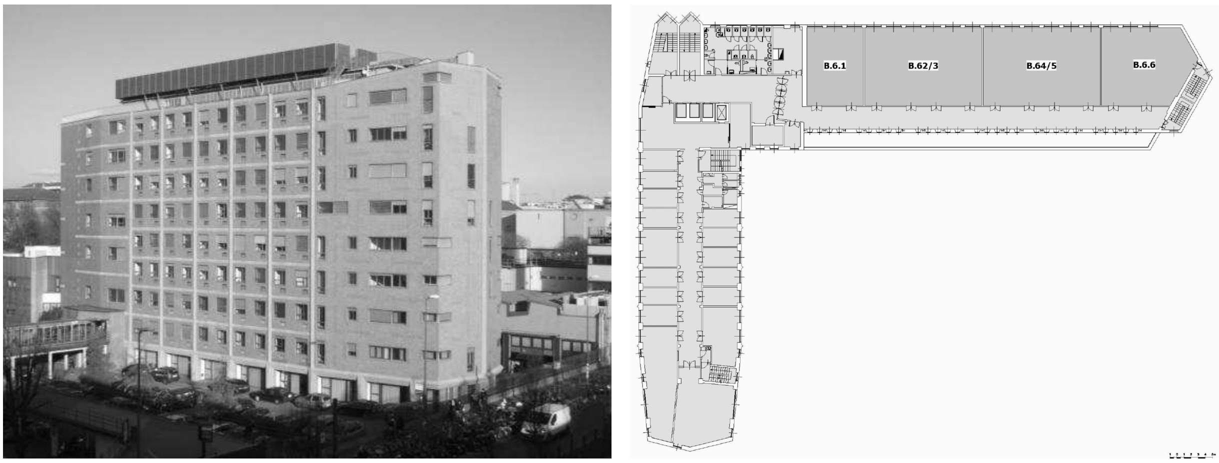


Figure 1 – “Nave” building: picture and sixth floor map.

2.1 Thermal comfort and measurement protocol

The first activity was related to the monitoring in terms of heating and cooling demand and environmental comfort: the goal of the surveys is to improve the comfort avoiding the equipment of rooms with air conditioning (not present today in those building) and to propose more efficient and energy-saving solutions that initially explore the redesign of the building envelope.

The survey of the current situation is performed by instrumental measurements, statistical surveys and calculation of indicators to evaluate the deviation from the thermal comfort ideal conditions. According to the definition, the thermal comfort is “condition of mind derived from satisfaction with the thermal environment”. An environment is considered acceptable if it meets a certain percentage of occupants. The comfort sensation is governed by the subject-environment thermal exchanges, determined by the combined thermal effect of environmental parameters including air temperature, vapour pressure, air velocity, mean radiant temperature (fixed factors) and clothing and activity level of occupants (variable factors).

A detailed measurement protocol has been drawn up with the aim to define a survey procedure which may be valid and applicable in all the cases the assessment of the actual thermal comfort in existing buildings is needed.

2.1.1 Calculation model

Two different calculation models, described in the reference standards and to be used for monitoring and displaying the indoor environment, as recommended in the Energy Performance of Buildings Directive (2010), can be applied to obtain the comfort index, depending on the data input and the boundary conditions. The two models are the Fanger Method and the Adaptive Method.

The Fanger method, as shown in UNI EN ISO 7730 (2006), allows us to calculate the Predictive Mean Vote (PMV) of a group of people related to a 7-point thermal sensation scale (+3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cool, -2 cool, -3 cold), based on measured indoor climatic parameters and with assumed typical levels of activity and thermal insulation for clothing. The other parameter, calculated on the base of PMV, is the Predicted Percentage of Dissatisfied (PPD). For different categories there is a list of recommended value to be respected. The model is mainly valid for moderate environments with conditioning system.

The Adaptive Method, as shown in ASHRAE standard (2004) is valid mainly for non-conditioned environment and represents an individual's ability to adapt to the prevailing climate (seasonal and local) depending on physiological conditions and by acting directly on the surrounding environment. The reference parameter is the Optimal Operative Temperature for which a maximum number of the occupants can be expected to feel the indoor temperature acceptable. It is calculated starting from Outdoor Air Temperature and has got upper and lower limits of acceptability, which the measured Indoor Operative Temperature should fall within. The acceptable ranges are higher than the Fanger model.

2.1.2 Instrumental monitoring

In order to map and assess the building thermal fluctuations over time according to the different contextual conditions, some continuous measurements of temperature and relative humidity were carried out using mini-logger (thermo-hygrometric probes) installed in more than one room per floor (for minimum 30 days) at the middle of the inner wall and at the height of 70 cm from the floor. Other measurements were performed for monitoring the environmental parameters, as shown in ISO 7726 (1996), for the calculation of the comfort indexes, using probes sets (micro-climate station) installed in some representative rooms, also for a shorter period of time (7 days). The station is composed by: psychrometer to measure relative humidity and air temperature (dry and wet bulb), globe thermometer to measure mean radiant temperature, and hot wire anemometer measuring air speed. This micro-climatic station was installed in the centre of the room.

2.1.3 Data collection

A survey (thermal sensation questionnaire) on a cross-section of users was carried out to evaluate statistically the subjective experience and individual feeling, preferences and acceptability of the thermal environment, based on UNI EN ISO 10551 (2001). The goal is to obtain an Actual Mean Vote of thermal sensation comparable to Predicted Mean Vote calculated from direct measurements in order to validate the model. External Temperature and Humidity (outdoor climatic data) were gathered from a data base, measured by the nearest environment monitoring station in order to compare the trends of internal hourly values with the external ones and to calculate the acceptability limits for the Adaptive Model.

2.1.4 Data processing and results

The monitoring activity has been carried out for two periods in 2011-2012, in summer and winter conditions, in order to have enough values to evaluate seasonal discomfort based on the calculated indices. Thanks to the continuous measurements by mini-datalogger it was possible to see the different trend of temperature on the building area, (for instance a difference of 1 °C for each floor as shown in Figure 2).

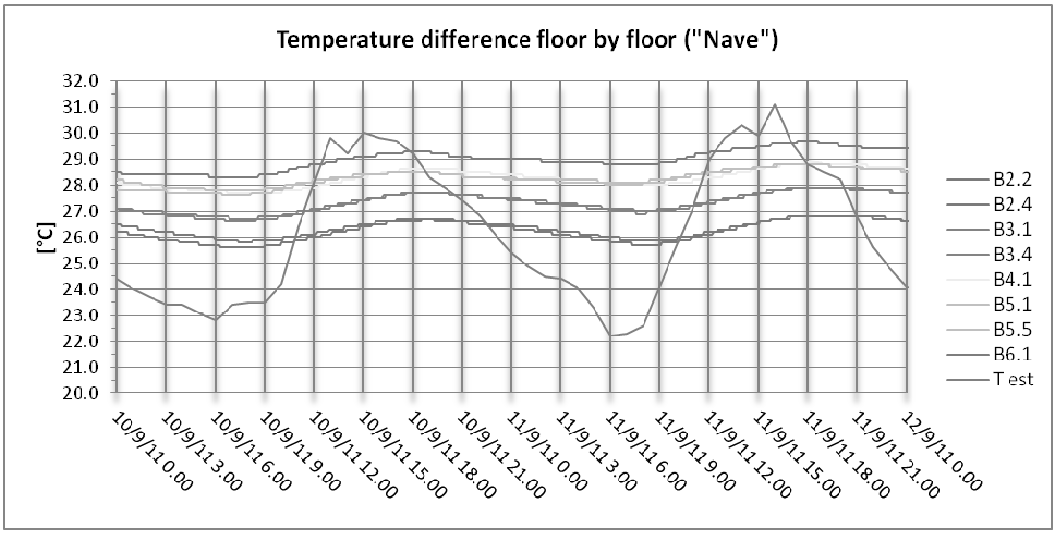
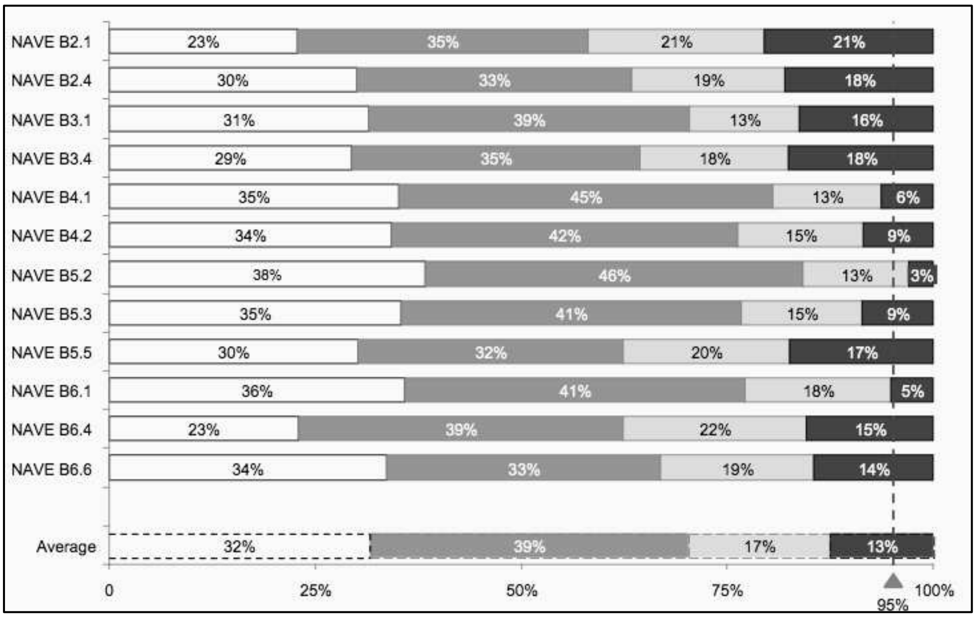


Figure 2 – Trends of temperatures in summer conditions

In summary an evident discomfort is shown in summer conditions in case of application of Fanger Model with much higher values than limits for the category III of existing buildings (PMV > 0,7 and PPD > 15%) during the occupation hours, from 8:00 a.m. to 6:00 p.m. In the case of Adaptive Model the results are not so critical considering the physiological, psychological or behavioural adjustment of building occupants to the interior thermal environment in order to avoid discomfort. In winter condition, with the heating system turned on, there are no critical values of discomfort. In fact, PMV and PPD values are slightly above the acceptability limits in the "Nave" building. The Figure 3 represents an example of "footprint", seen as the percentage distribution of hours that the building falls within each of the four categories based on PMV-PPD reference limits and gives us an overall evaluation of the thermal environment. This evaluation is an useful tool for "mapping" the building and highlighting the most critical area where an intervention is necessary.



PMV Range	-0.2 < PMV < 0.2	-0.5 < PMV < 0.5	-0.7 < PMV < 0.7	PMV > 0.7, < -0.7
Building Categories	I	II	III	IV
Colour				

Figure 3 – "Footprint" of PMV value for the monitored rooms in winter conditions

2.2 Thermal Comfort related to Energy Consumption

Simultaneously to the comfort assessment some fact-finding analysis on the building envelope were performed in order to reconstruct the technical solution and evaluate its thermal performance (Figure 4).

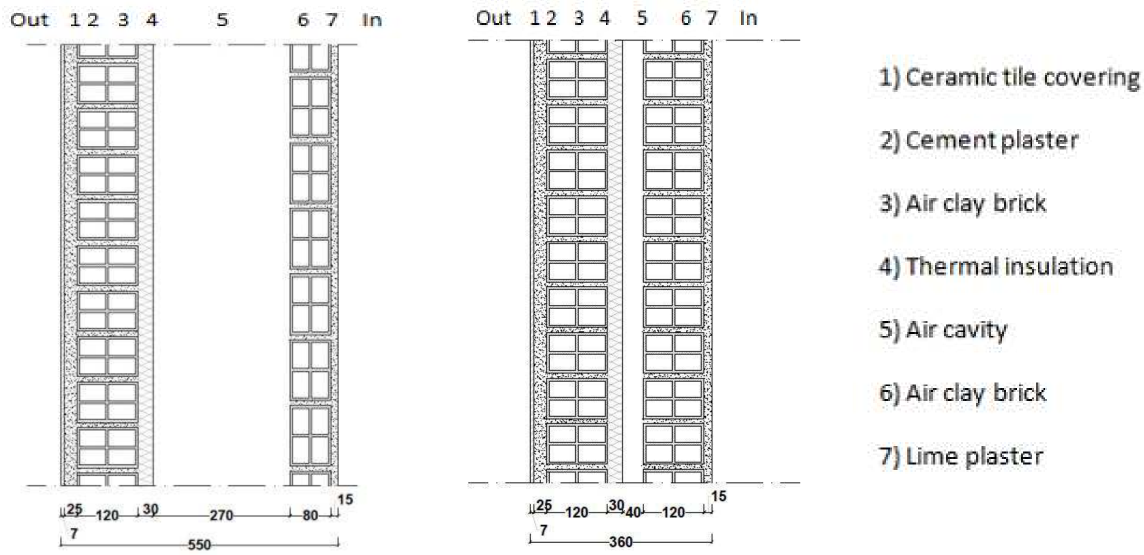


Figure 4 – Main sections of the South facing wall

At the same time, energy monitoring on the heating plants has been initiated, using probes such as temperature detectors and flow-meters. This activity may allow us to make a comparison among the thermal comfort level, the real energy demand and energy consumptions. For instance, through the thermal comfort measurements in winter condition, it was possible to learn that there are acceptable levels of comfort and sometimes the value is upper than the superior limit (too warm). This means that the heating system is oversized and mismanaged. In fact there is a poor regulating and controlling system. In order to ensure comfort and decrease the energy consumption some solution are needed and simulations should be performed in order to evaluate the advantages.

2.3 Simulations and BIM modelling

The building "Nave" energetic assessment has been done through a fully interoperable BIM model (Figure Figure 5), useful both for energetic analysis and for managing the project alternatives in the refurbishment design phase. This BIM model has been also inserted inside the much bigger 3D model of the Politecnico di Milano Campus to assess its interoperability.

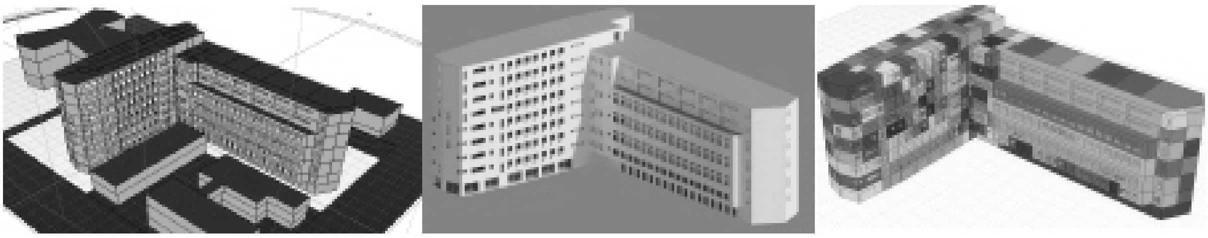


Figure 5 – BIM model of the case study

The model contains data about surfaces, volumes, thermal zones, time schedules (both for plants and users habits), technologies and plants; all gathered from the survey previously done. The simulations results show numerically what has been already noticed during the assessment of the building: there is a great consumption caused mainly by the lacks of the regulation systems of the heating plant and the low insulation level of the envelope, both opaque and transparent. The overall consumption of the heating system, evaluated with the BIM model, is around 130 kWh/m^2 y. The results will be fully checked next fall because the Politecnico is currently implementing a new system of consumption monitoring.

3. Multi-criteria method

After the inspections and analysis of the current state of the building, both in term of internal comfort and degradation of the components, some project alternatives for a sustainable refurbishment have been proposed and evaluated. To do this, a multi-criteria decision support system has been created to help the designers during the decision phase. The multi-criteria method allows evaluating interventions of different categories, regarding both plants and building components, sorted in groups or alone. A large amount of parameters has been evaluated, starting from the International Standards and other research projects with the same theme Open House (2011), Akadiri (2011). These parameters are divided into three major categories, as written in the UNI EN 15643 (2010). In this study the social sustainability has been converted into the internal performance, measured in terms of internal comfort perceived by the occupants. All the parameters, divided in the three major categories of sustainability, can be seen in the Table 1Table 1. The method is built according to the AHP selection process Kaklauskas, Zavadskas, Raslanas (2005) and Sonmez, Ontepeli (2009). The first phase consists in the creation of the hierarchic scale, made by three levels.

The project alternatives are in the bottom of the hierarchic scale, out of the three levels. In this study the normalization method with equally distributed scale has been used, both for parameters that need to be maximized or minimized. In this method a weighting system able to consider the relative importance among parameters seemed to be convenient, so a pair comparison among the elements of the second and third level of the hierarchic scale was conducted; the comparison was performed among elements of the same category (the three fields of sustainability) to get three series of weights. First of all, the relative importance of the field of sustainability has been calculated, with the following results: a) environmental sustainability 55%, b) economical sustainability 21% and c) internal performance 24%. Then the relative importance of the parameters has been calculated with the same method. The results are shown in the Table 1~~Table 1~~.

Table 1 – Parameters relative importance and references in the UNI EN 15643

Sust.	**Category from UNI EN 15643**	**Building phase (from A to C)**	**Parameters evaluated**	**Weight [%]**
Environmental	UNI EN 15643-2 §6.2 - Indicators for resource use (environmental aspects)	B6	Consumption of energy primary	37%
		B1	Consumption of energy and resources	23%
		B7	Water consumption	17%
		from A1 to C4	Embodied energy	11%
	UNI EN 15643-2 §6.2 - Indicators for environmental impacts (LCIA impact categories)	from A1 to C4	CO_2 emissions	13%
Economical	UNI EN 15643-4 §5.4.2.1 - Economics impacts and aspects at the Product Stage	A4 - A6	Construction cost	33%
	UNI EN 15643-4 §5.4.3.1 - Economic impacts and aspects at the Use Stage	B6	Cost of energy primary	27%
	UNI EN 15643-4 §5.4.3.1 - Economic impacts and aspects at the Use Stage	B1	Cost of energy and resources	19%
	UNI EN 15643-4 §5.4.2.2 - Economic impacts and aspects at the Use Stage	from B2 to B5	Maintenance cost	13%
	UNI EN 15643-4 §5.4.2.3 - Economic impacts and aspects at the End of Life	from C1 to C4	Disposal cost	7%
Social	UNI EN 15643-3 §6.2.2.3 - Health and Comfort	B1	Thermal comfort	46%
		B1	Acoustic comfort	24%
		B1	Internal Air Quality	19%
		B1	Internal visual comfort	12%

The evaluation of the parameters was carried on by an online survey sent to a great amount of people, consisting mainly of professionals, professors, students of Architecture and Engineering. After the comparison, the alternatives could be analysed by collecting the data and calculating the related parameters. The method really helps in the decision phase because it allows the comparison at the third and the second level of the hierarchy scale; so the user can compare both the final and the partial ranking (environment, economy and internal performances) to better understand which solution fits best the objectives.

4. Solutions for a sustainable refurbishment

Several possible solutions have been designed to solve the major criticalities encountered in the inspection phase (thermal losses of the envelope, plants regulation systems and electric high consumptions mainly). These alternatives have been studied also because there is the possibility to concretely implement these solutions inside the activity of the project "Campus Sostenibile". For each alternative all the fourteen parameters described above have been calculated with different techniques, depending on the degree of precision required and the data available. The phase after the calculation of the various parameters is represented by the correct application of the multi-criteria method, as described in §3**Error! Reference source not found.**. So, the alternatives have been normalized and weighted using the weights of the Table 1~~Table 1~~ to get the rankings, that can be seen as sustainability indexes of the alternatives. Five alternatives have been selected among the fortyfour according to these criteria: the most sustainable alternatives overall and the necessary alternatives (which means alternatives connected to components with really low performances, not depending on the improvement of sustainability). The selected alternatives are listed in the Table 2~~Table 2~~.

Table 2 – Sustainability indexes for the selected alternatives

#	COMPONENT	CODE	ENVIRONMENTAL S.	ECONOMIC S.	INTERNAL PERFORMANCE	GLOBAL S.
1	Windows	A.01	0.3647	0.1251	0.0838	0.5737
2	Illumination	A.02	0.3728	0.1481	0.0471	0.5681
3	Heating system	A.03	0.2515	0.1430	0.0192	0.4138
4	Concrete panels	A.04	0.1844	0.1285	0.0192	0.3322
5	Concrete-framed glass panel	A.05	0.1788	0.1269	0.0192	0.3250

The first three alternatives bring serious improvements to the building; on the other hand, the last two are necessary because the concrete panels and the concrete-framed glass panel show really low performances and they require prompt replacement. The five alternatives have been aggregated to make a final comparison with the current situation of the building. The Table 3~~Table 3~~ shows a large performance increase in terms of environment and economy, and also a good upgrade in the internal performance level. The initial cost is obviously high but the five selected interventions should be distributed during years.

Table 3 – Comparison with the actual situation

PARAMETER	CURRENT STATE	SELECTED ALTERNATIVES	Δ [%]
EPH [kWh_{term}/m^2 y]	141.59	33.55	-76.31%

EPC [kWh_{term}/m^2 y]	36.15	33.6	-7.06%
ELECTRICITY [kWh_{elet}/m^2 y]	63.94	52.43	-18.00%
CO2 [kg CO_2/m^2 a]	45.15	27.04	-40.11%
EE [MJ/m^2]	1,137	1,399	23.07%
INITIAL COST [€]	0	604,882	-
MAINTENANCE COST [€]	2,774,435	2,492,588	-10.16%
EP_H COST [€]	2,433,234	576,534	-76.31%
EP_C COST [€]	299,687	278,535	-7.06%
ELECTRICITY COST [€]	2,955,131	2,423,208	-18.00%
LCC [€]	8,690,734	6,375,746	-24.66%
THERMAL COMFORT [degreehour hot]	97,147	103,869	6.47%
THERMAL COMFORT [degreehour cold]	404,564	385,182	-5.03%
ACOUSTIC COMFORT [dB]	39.33	45.21	-13.01%
IAQ [PPD]	54.90%	54.90%	0.00%
VISUAL COMFORT [PPD]	30%	10%	-66.67%

The good piece of news is that two of the previously analyzed alternatives (windows replacement and implementation of the illumination system) are actually in the construction phase. The other alternatives will be evaluated in the next months.

4.1 Model validation and thermal comfort comparison

A comparison between the thermal indexes obtained by the monitoring activity and the ones obtained by simulation with the BIM model has been carried out in order to validate the model itself. As shown in Figure 6 the courses are very similar, so it is possible to highlight that the created model approximizes well enough the building actual condition.

Moreover, thanks to comparison with the PPD value obtained changing into the BIM model the boundary conditions based on the alternatives of refurbishment interventions, it is clear that the thermal index remains within the ranges but a decrease of energy consumption occurs.

PPD_A_Sim
PPD actual value obtained
by modelling and simulation

PPD_P_Sim
PPD expected value after refurbishment
obtained by modelling and simulation

PPD_A_Measured
PPD actual value obtained
by direct measurement

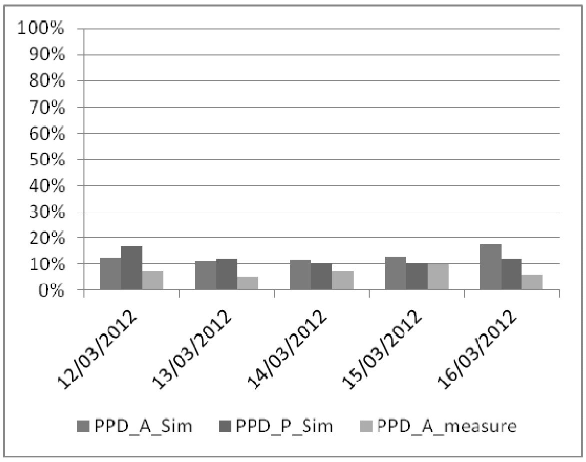


Figure 6 – Comparison among PPD values obtained by measurements and by simulation (actual and expected values after the refurbishment)

5. Conclusion

Through this case study has been demonstrated the applicability of the principles and methods for assessing the sustainability in construction sector in case of existing buildings, starting from the actual situation.

The thermal comfort assessment, performed according to a measurement protocol developed ad hoc, is a useful tool and it is aimed at assessing the actual sustainability level from the environmental and social point of view. Thanks to its wide applicability and the creation of standardized “comfort report forms”, the protocol could be used also after the refurbishment in order to evaluate the changes and the new level of comfort. Also other assessments are needed for the other environmental comfort and health forms (visual, acoustic, indoor air quality), as well as local discomfort as expressed in UNI EN ISO 15251 (2007).

The use of a multi-criteria method during the assessment of different project alternatives really helps in an objective definition of the sustainability level; this must be combined with a precise evaluation of the current state of the building. Another interesting issue is that a method like this can be easily updated with the evolution of the legislation and the related requirements.

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