Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 3168 – 3173

Energy Procedia

6th International Building Physics Conference, IBPC 2015

School building heritage: energy efficiency, thermal and lighting comfort evaluation via virtual tour

Paola Lassandro[a]*,Teresa Cosola[b], Antonella Tundo[c]

[a]*ITC-CNR, Construction Technologies Institute-Italian National Research Council, UOS of Bari, Via Paolo Lembo 38/b, Bari 70124, Italy*
[b]*ABITA-Bioecological Architecture and Technological Innovation for the Environment, University of Florence, San Niccolò 93, Florence 50121, Italy*
[c]*ENEA, UTEE AVEE– Italian National Agency for New Technologies, Energy and sustainable economic development –Technical Unit for Energy Efficiency, Viale Japigia n.188, Bari 70126, Italy*

Abstract

Since the Italian school buildings cause huge energy waste, it is increasingly compelling to identify, quantify and eliminate energy deficits through integrated audits and coordinated actions of energy saving and retrofit. We developed a methodology that is based on a holistic approach that correlates students' post occupancy evaluation with instrumental survey and software simulations and, at the same time, we examined an innovative use of virtual tour to make the energy audit results friendly available to school managers and community. This methodology, validated on a school building of the 20s-30s, identified energy saving and retrofitting actions according to cost levels.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Energy efficiency, sustainability, lighting comfort, thermal comfort, school building, vitual tour, education

1. Introduction

Since many existing school buildings (about 70% in Italy) were built after the First World War without complying with any specific European and national standards of energy efficiency, they consume a lot of energy. Moreover, there is not often an adequate energy and maintenance management based on an integrated audit that allows to carry out coordinated actions of energy saving. In fact, retrofitting works should be aimed not only to improve energy

* Corresponding author. Tel.: +39-080-5481265; fax: +39-080-5482533.
E-mail address: paola.lassandro@itc.cnr.it

1876-6102
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.775

performance and to increase users' comfort but they should be considered as an opportunity to make visible the audit results and to raise school community's awareness about energy saving issues.

Therefore, we used the school building as a teaching tool towards a more sustainable society [1].

2. Methodology and innovative tools

Although energy audit is usually used to evaluate the building energy behaviour, it cannot be effective enough since we need a more global approach that correlates students' post occupancy evaluation with objective data collected in situ and software simulations. Moreover, due to the complexity of putting together all the different levels of knowledge in a more integrated, comprehensive and communicable way, we studied an innovative use of ICTs tools in order to organize and make the audit results friendly available to all the stakeholders (school community, municipalities, administrators, teachers, staff members, etc.). We proposed a methodology that identifies sample areas with different use, orientation and position in the building. It is based on students' involvement from the beginning of the diagnostic process on their school building in order to take into account their thermal and lighting comfort perceptions and make them handle directly diagnostic tools during their classroom audit (the methodology will be implemented with acoustical comfort evaluation in further researches). In this way, we connected the necessity of energy retrofit not only to energy saving issues but also to students' wellbeing. Furthermore, we identified the energy saving and retrofitting actions trying to optimize the available economic resources.

This methodology identifies step-by-step different phases [2] and how to introduce them in a virtual tour:

- Phase 1: the preliminary audit also called "walk-through audit" consists of visual inspection, collecting data about building elements, thermal and lighting systems, their consumptions of the past three years, historical information, hourly profile of equipment use, maintenance schedules, occupancy hours as well as the preliminary identification of the potential energy improvements. It corresponds to a virtual walk-through audit with info-interactive hotspots that allow viewer to open boxes with preliminary information
- Phase 2: the instrumental diagnostic survey of some significant parts of building (with the participation of the users) consists of measurements and instrumental analyses on site to detect the defects of building-plants system and to evaluate the micro-climatic and lighting conditions in the sample classrooms during school hours (thermo-hygrometer data logger, anemometer, lux-meter); it includes questionnaires that students fill in about their subjective perceptions of visual-thermal comfort and about measured data related to their position in the classroom; the instrumental survey corresponds via virtual tour to coloured interactive areas outlining the borders of the thermographic images that are accessible by clicking on them and to info-hotspots allowing viewers to click on them to link to thermographic, thermal and lighting analyses; the photos and the results about the thermal and lighting labs with students are available in the virtual tour clicking on play-icons placed on the blackboards
- Phase 3: the in-depth analyses of the whole building-plants-users system consist of software simulations about thermal and lighting performances (temperature distributions during the year, heat gains and losses, daylight factor, glare and illuminance distribution etc.); after the integrated energy and lighting evaluations, some possible upgrading solutions are identified according to cost levels (low, medium and high cost); it includes the improvement of building-plants system management also through energy saving tips for students, teachers and technical staff; some hotspots are identified in the panoramic images in order to create the links to the solar animations and to the software simulations results as well as to the lighting and thermal retrofit solutions
- Phase 4: the elaboration of a new virtual tour after the energy-efficiency retrofit works

The audit through virtual tour is available on a webpage using a desktop computer (Windows, Mac) or a mobile device (smartphone, Fig.1).

3. The case study: a school building built in the 20s-30s

We needed to validate the developed methodology on school buildings with different construction type. In this paper, we applied it to a primary school built in the 20s-30s in a small town in Southern Italy with load-bearing masonry that can be considered representative and comparable to the buildings of the same historical period.

3.1. Preliminary phase

First of all, we collected the building plans, the historical documents from the archive sources and the consumptions of the last three years (average 12,500 litters of diesel fuel per year and 8,674 kWh of electricity). Then, during the "walk-through audit" we used specific equipment to create 360-degree panoramic photography, useful for the school virtual tour. The information was collected and linked to white info-hotspots. Every hotspot was located on each investigated element of the building in order to make the viewer able to open files about technical characteristics:

- The external walls have a thickness of 70 cm with two faces of local calcareous tufa that enclose a gap filled with crushed stones (the so-called "a sacco") but they reduce their thickness to 30 cm under the windows
- The flat roof is not insulated, made of local earthenware elements called "bubbole" and double-T steel beams
- The aluminium double-casement windows with double glazing are without thermal break and blind systems
- The central heating system with a vertical distribution system is powered by diesel fuel generator with a thermal output of 184 kW; two electric boilers, located one on each floor, produce hot water. The heating terminals in the school are cast iron radiators without thermostatic valves and placed under the windows
- The school is not equipped with a controlled mechanical ventilation and a cooling system, therefore the exchange of air is obtained by opening the windows; the artificial lighting system consists of ceiling traditional luminaires with fluorescent lamps (2x36W)

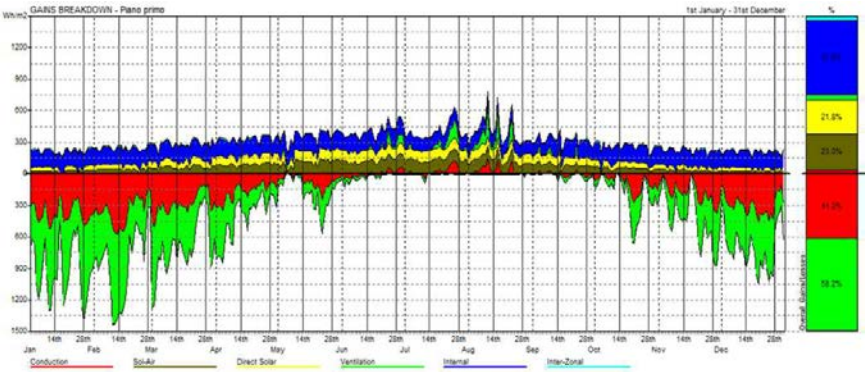
3.2. Instrumental phase

Secondly, we carried out the instrumental audit that consists of the assessment of the lighting and thermal conditions during school hours also with students' participation in the sample classrooms with different solar exposure conditions. The actual amount of natural light was measured on each desk (UNI EN 12464-1:2011, UNI 10840:2007) through lux-meter with the involvement of the students, who drew a graph about lux values versus distance from the windows. The visual comfort questionnaires were filled in by the students according to their subjective judgments comparing with the objective data. Taking into account UNI EN 12464-1 and the researches on UDI [2], we created a simplified rating scale to make this comparison more understandable to the students (ages 11-13): insufficient (lux<300), sufficient (300≤lux<500), good (lux≥500 without sun reflections on desk surfaces) and glare when sun reflections occur on desk surfaces (Fig.3), even if we know that none of the currently available metrics can summarize overall visual comfort especially about glare, because there is not a standardized method for the rating of discomfort glare from windows [3,4]. External and internal thermographic analyses (thermographic camera and FLIR ResearchIR software) were performed to detect thermal bridges, infiltrations and condensation. On the virtual tour pictures, we drew some grey polygons that outline areas where we carried out the thermographic analyses. These analyses are available by clicking on the grey polygon areas. Some red info hotspots were introduced in the virtual tour in order to link to the instrumental thermal and lighting survey results. Moreover, we added links on the blackboards to the students' laboratories results about their thermal (ASHRAE scales) and visual comfort perceptions [5,6].

Fig. 1. Thermographic image accessible by clicking on the highlighted grey area and instrumental audit box linked to the red info-hotspot, visualization on smartphone (http://demo.ba.itc.cnr.it/mariotto_en/).

3.3. Software simulations

After the energy studies of the building envelope layers including the moisture analysis and the thermal inertia characteristics, we carried out the energy simulation using MC11300 software. The determined energy class was the class G with the overall energy performance equal to 35.81 kWh/m³year (3.5 times higher than the legislative benchmark) and with CO_2 emissions equal to 11.789 kg/m³year. Moreover, we simulated by ECOTECT software the temperature distributions, the discomfort degree hours and the gains breakdown (Fig.2) due to the building envelope behaviour (without considering the heating system) as well as the analysis of direct and diffuse solar radiation. The lighting sample classroom evaluations were simulated by RELUX software to obtain the daylight factor and the average illuminance and luminance distribution in different conditions with the natural, artificial and combined lighting. The software simulation results are available in the virtual tour through the green info-hotspots. Special play-icon identifies the hotspots linked to solar and thermal animations in different seasons and time of day (Fig.3).



Gains breakdown – First floor

From: 1st Jan to 31st Dec		
Category	Losses %	Gains %
Fabric	41.2	2.1
Sol-air	0.0	23.0
Solar	0.0	21.8
Ventilation	58.2	3.4
Internal	0.0	47.0
Inter-Zonal	0.6	2.7

Fig. 2. Gains breakdown analysis.

Fig. 3. Lighting lab with students' participation, daylight and illuminance distributions and retrofitting solution (LED lighting combined with daylight) about NE classroom, perception votes diagram, blinds system design about SE classroom and solar animations (via virtual tour)

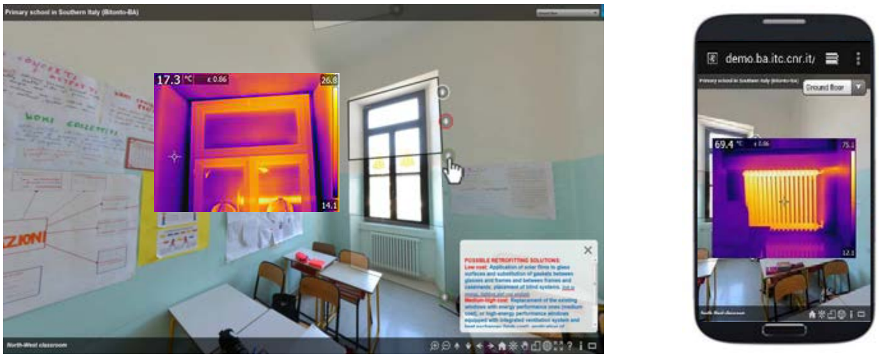


Fig. 4. The retrofitting solutions linked to the green info-hotspots; virtual tour visualizations on smartphone about radiator thermography.

3.4. Results and possible retrofitting solutions

Since the school belongs to historical building heritage built in load-bearing masonry, the audit results confirmed that this construction type building has good envelope quality. In fact, the envelope performance simulations showed that in winter there is a temperature difference of about 5°C between inside and outside that increases up to 7°C in summer. This positive effect is due to the external walls thickness (70 cm) that causes a thermal lag of 9.3 h and in few words a better energy performance in comparison with different building construction types (concrete constructions). The data, collected through the questionnaires filled by students, showed that the thermal comfort perceptions were ok for 64%, slightly warm for 21% and slightly cool for 14%, during winter even if in some days they feel slightly warm/warm but anyway they cannot operate in reducing indoor temperature for the thermostatic valves lack on the radiators. However, the lowest comfort levels are recorded near the thermal bridges under the windows due to the reduction of the wall thickness (30 cm). The uninsulated flat roof has the waterproofing system in bad maintenance conditions that cause water seepage problems into the classrooms. Another peculiarity of this construction type is that it does not allow a horizontal continuous series of windows and thus the amount of lighting is not homogeneous even if the considerable height of the windows allows the entrance of the light more in depth. These results were obtained by RELUX simulations, instrumental measurements on site and students' perceptions [7] (Fig.3). Moreover, the artificial lighting system is not sufficient according to the lighting standards (UNI EN 12464-1) also integrated with the natural light in the days with bad weather conditions.

The green info hotspots include the different retrofitting intervention alternatives according to cost levels (low, medium and high cost), payback times, and the achievable performance improvements (Fig.4).

We analysed, in progressive way, some low cost solutions of energy retrofitting ($C < 5€/m^2$):

- Heating system: application of thermostatic valves on the heating elements and zonal thermostats
- Shading system: placement of curtains and light shelves, deciduous trees (n.6) and application of solar films
- Lighting system: replacement of the obsolete luminaires with new ones (2x36W, P_{max}= 58W, Luminous efficacy =77lm/W, Luminous efficiency= 75%) only in the classrooms
- Users' behaviours: saving energy tips for students, teachers and technical staff in order to save energy and improve comfort conditions
- External walls: application of radiators reflective panels behind radiators
- Windows: substitution of gaskets between glasses and frames and between frames and casements

The medium cost ($5€/m^2 \leq C < 50€/m^2$) and high cost ($C \geq 50€/m^2$) interventions are (Table 1):

- Heating system: replacement of the old heat generator with a higher energy efficiency one (medium cost), or radiant ceiling panel system with gas condensing modulating boiler (high cost) and solar panels (high cost)
- Shading system: integrated and motorized shading system (medium cost) or connected to a building automation system (high cost)

- Lighting system: replacement of the existing luminaires with LED ones with automatic adaptive dimming system and presence detectors (medium cost) or with centralized building automation lighting system (high cost)
- External walls: application of thermal insulation panels on the walls under the windows and the repositioning of the heating elements (medium cost)
- Roof flat: application of waterproofing and insulation layers (medium cost)
- Windows: replacement with high-energy performance windows (medium cost) or also equipped with integrated ventilation system and heat exchanger connected to a building automation system (high cost)

Table 1. Intervention alternatives according to cost levels (low, medium and high cost), achievable performance improvements and energy class.

Type of intervention	EPI kWh/m3 year	Energy Class	Energy saving %
Heating system: application of thermostatic valves on the heating elements and zonal thermostats (low cost)	24.98	F	30.2
External walls: application of radiators reflective panels behind radiators (low cost)	31.51	G	12.0
Replacement of the old heat generator with a higher energy efficiency one (medium cost)	18.18	E	49.2
High energy efficiency heat generator equipped with radiant ceiling panel system and solar panels (high cost)	0.65	A+	98.2
External walls: application of thermal insulation panels on the walls under the windows (medium cost)	35.25	G	1.6
Roof flat: application of waterproofing and insulation layers (medium cost)	30.59	G	14.6
Windows: Replacement of the existing windows with high-energy performance ones (medium cost)	34.04	G	4.9

4. Conclusion

This research work demonstrates that the innovative use of virtual tour integrated with the different phases of a more comprehensive audit methodology can support the decision-making process. Moreover, since it can be calibrated and used in relation to the different stakeholders necessities, it is a flexible tool that implements communication. The use of digital web tools showed a more effective involvement of students that were motivated to carry out sustainable behaviors. The energy audit through virtual tour is an innovative tool that, due to the replicability of the energy retrofitting solutions categories, can be transferred to other school buildings especially with the same construction type and implemented with further evaluations about acoustic comfort and indoor air quality.

Acknowledgements

The authors wish to thank Salvatore Capotorto for the technical support in the virtual tour development. The authors are grateful to the involved students and teachers and to Bitonto Municipality for promoting this research.

References

[1] Calice C, Clemente C, De Santoli L, Fraticelli F. Guidelines for the retrofit of the school building stock for sustainable urban regeneration of the city of Rome. Ponte 2012; 4: 27-35

[2] Nabil A, Mardaljevic J. Useful Daylight Illuminances: a replacement for daylight factors. J Energy and Buildings, 2006; 38: 905-913

[3] Carlucci S, Causone F, De Rosa F, Pagliano L. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. Renewable and sustainable energy reviews 2015; 47:1016-1033

[4] Reinhart C, Rakha T, Weissman D. Predicting the Daylit Area – A comparison of students assessments and simulation at eleven schools of architectures. J of the illuminating engineering society of North America 2014; 4: 193-206

[5] Lassandro P, Tundo A. Energy audit and comfort evaluation of a school building with the students' participation. In: Tadeu A, Ural O, Ural D, Abrantes V, editors. Proceeding of the 40th IAHS World Congress on Housing: Sustainable housing construction, 2014 December 16-19, Funchal (Madeira, Portugal). p. 1-10

[6] Chaves F, Vieira A. C. V. Indoor air quality and thermal comfort in an educational building – case study. In: Tadeu A, Ural O, Ural D, Abrantes V, editors. Proceeding of the 40th IAHS World Congress on Housing: Sustainable housing construction, 2014 December 16-19, Funchal (Madeira, Portugal). p. 120-130

[7] Amasuomo JOM, Alio AN. Students' Perception of Daylight Illumination in the School Workshop as a Determinant for Effective Students' Task Performance in Workshop Practice. J Education and Learning 2013; 2:201-207