A work-related learning project for energy efficiency evaluation and indoor comfort of school buildings

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ABSTRACT. *The students spend most of their time after homes in their classroom, where indoor air conditions, thermal and visual comfort are not often adequate. Therefore, students' health and performance may get worse. This implies the need to experiment with new tools that enable an integrated approach for school buildings' indoor environment evaluation. They are based on the innovative use of Information Communication Technology (ICT) in order to involve actively users in the improvement process of indoor comfort of their school and to manage the complexity of the information as well as to make it easily accessible to all stakeholders. Since students can play an important role in promoting energy saving actions within their family and community, it was carried out a work-related learning project that involved directly high school students to monitor their indoor comfort (CO_2 concentration, lighting and thermal measurements) from an objective and subjective point of view. The paper aims at presenting the results of the work-related learning project through a technical virtual tour, created also by drone as a tool to educate but also to help stakeholders to evaluate comfort problems and energy efficiency as well as to find possible improvement measures.*

RÉSUMÉ. *Les étudiants passent la plupart de leur temps dans la classe, où les conditions d'air intérieur, la chaleur et le confort visuel sont souvent insuffisants. Par conséquent, la santé et les performances des élèves peuvent s'aggraver.*

Cela implique la nécessité d'expérimenter de nouveaux outils permettant une approche intégrée de l'évaluation de l'environnement intérieur des bâtiments scolaires. Basés sur l'utilisation innovante des Technologies de l'Information et de la Communication (TIC), ils permettent aux utilisateurs de participer activement à l'amélioration du confort intérieur des écoles, de gérer la complexité des informations et de faciliter l'accès à toutes les parties prenantes.

Étant donné que les étudiants peuvent jouer un rôle important dans la promotion d'activités d'économie d'énergie au sein de leur famille et de leur communauté, un projet d'apprentissage lié au travail a été mis en œuvre pour permettre aux élèves des lycées de surveiller directement leur confort intérieur (mesure de la concentration de dioxyde de carbone, de la luminosité et des calories) d'un point de vue objectif et subjectif.

Cet article vise à présenter les résultats du projet d'apprentissage lié au travail par le biais d'une visite virtuelle technique, créée également par drone comme outil d'éducation, mais aussi pour aider les parties prenantes à évaluer les problèmes de confort et d'efficacité énergétique, ainsi que pour rechercher les améliorations possibles.

KEYWORDS: *energy efficiency, indoor comfort, ICT, SAPR, school building, virtual tour.*

MOTS-CLÉS: *Efficacité énergétique; Confort intérieur, TIC, SAPR, Bâtiment scolaire, Visite virtuelle.*

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1. Introduction

Although the school buildings spaces are the most important non-residential indoor environments, they often have extreme temperatures, critical relative humidity, inadequate lighting and poor air quality (Yang *et al.*, 2013).

Moreover, the high occupancy densities of school classrooms make the ambient conditions more adverse due to the increase of internal gains, odour and pollutants emissions, so that negative impacts on student performance occur.

Poor Indoor Air Quality (IAQ) is the main responsible for health problems (Chaves *et al.*, 2016), such as respiratory diseases and allergies, but also inadequate thermal and visual comfort contribute to cause fatigue, eyes irritation, headaches, lack of concentration.

Therefore, it is necessary an integrated approach in order to improve energy performance and, at the same time, indoor environmental quality.

Regrettably, many interventions do not meet the users' expectations, neither at the level of comfort nor at the level of energy savings.

Hence, the involvement of students in energy audit carried out for their school buildings is an opportunity to define and experiment with new tools that takes into account their perception of the indoor environmental quality beyond the monitoring of environmental parameters.

Furthermore, it is useful to explore the innovative use of Information Communication Technology (ICT) because it can have a greater impact especially on new generations and can make friendly available different levels of knowledge to the stakeholders. Indeed, after gathering data according to this methodology, teachers and students can become able to identify energy and comfort related brainstorm solutions (Thiyagarajan *et al.*, 2018; Tundo *et al.*, 2013).

In particular, the paper presents the results of a project, which involved the students of an Italian scientific high school and arose from the adherence of the ITC-CNR to the initiative of the Work-Related Learning Project. This kind of project (in Italian: progetto di Alternanza Scuola Lavoro) is commissioned by the Ministry of Education, Universities and Research (MIUR). It is defined by MIUR as: "an innovative teaching method which, through practical experience, helps to consolidate the knowledge acquired at school and to test students' attitudes on-field, to enrich their training and to orientate their study course and, in the future their working career, thanks to projects in line with their study plan”.

The activities concerned the direct participation of students in a technical team for the validation of a participatory energy audit methodology applied on Enrico Fermi Scientific High School in Bari, a city in Southern Italy. They consisted of the survey of geometric and technical features through appropriate instruments for CO_2 concentration, lighting and thermal measurements and questionnaires analysis about users’ comfort. Lastly, it was produced a technical and educational virtual tour to collect all the audit results and improvement proposals.

For this reason, the methodology application included photographic surveys with 360° cameras, aimed at creating an interactive virtual tour also at aerial level by drone – UAV (Unmanned Aerial Vehicle). This allows an engaging experience with immersive virtual navigation but, at the same time, the opportunity to dwell on focus of interest (hotspots) implemented with media contents (images, textboxes, video) about technical data and improvement suggestions.

2. Methodology and innovative tools

The methodology applied to this project is based on an ordered set of phases in order to involve students without particular expertise in the field.

The idea is to start from very simple tasks and then gradually encouraging the students to experiment complex activities, appropriate to their age and capability.

The first step of a work-related learning project for energy evaluation consists of applied theory workshop about heat transmission through building envelope, artificial and natural lighting, air quality in indoor environments and use of specific instruments and software for data processing. This phase is useful to increase the students’ skills and make them able to carry out the assigned technical tasks and to operate not only as users but also as "technicians" in on-field activities.

The second step constitutes the first level of approach to energy audit and is about inspection, data collection through direct survey and documents analysis (floor plans, construction details, technical reports and general information, obtained also from the school staff, climatic conditions, orientation and current energy consumption) (Gagliano *et al.*, 2017; Negro *et al.*, 2017). Then, sample rooms were identified with different exposure and position for further analysis. This step includes:

- The directed geometric survey with traditional methodology for the selected classrooms and indirectly one using a digital multi-images photogrammetric technique with innovative tools for the facades.
- The execution of immersive photographs, at terrestrial and aerial level, aimed at creating the virtual tour. In particular, immersive photography means a 360° image that allows a complete observation of the surrounding environment. The viewpoint of the photographer is not imposed and it is possible to navigate in

every direction and explore the surrounding space, as if users were really inside a three-dimensional environment, with simple mouse movements (Lerario *et al.*, 2010).

Further investigations are carried out from the subjective and objective point of view (the third step). Students operate primarily as users and then as technicians in order to not be influenced in their personal judgments. The sub-steps are the following:

- Analysis of thermal and visual comfort as well as air quality expressed by users (post-occupancy evaluation) through questionnaires;
- Instrumental measurements of microclimatic variables (temperature, relative humidity and air velocity), lighting conditions and CO_2 concentration (air quality analysis) in the chosen school spaces also in relation to the external environmental conditions;
- External and internal thermographic survey to identify any defects of the building-system (thermal bridges, moisture, air or water infiltrations etc.).

After post-occupancy evaluation and diagnostics phase, it is necessary to examine in depth the building with the aid of dynamic simulation software, as follow:

- Digital images processing through specific software to create a measurable 3D model;
- Modeling and simulation of the thermo-hygrometric characteristics of building envelope;
- Lighting modeling and simulation for analysis about daylight factor, medium illuminance, uniformity, glare in natural, artificial and combined light conditions;
- Elaboration of questionnaires data.

This third phase is concluded by the identification of the possible improvement solutions and actions from a thermal, lighting and air quality point of view.

Finally, it is created a virtual tour as a tool to manage the results of the previous steps and to make them easily legible and sharable on a webpage. It consists of immersive images linked together thanks to the presence of sensitive areas, called "hotspots" or arranged on a special interactive and integrated map-layout. Moreover, additional information (in the form of texts, documents, images, drawings, videos, web pages etc.) are linked to specific hotspots in different color for each project step and to interactive polygonal area on the building.

3. The case study: a school building built at the end of the 90s

The case study is the school building attended by the class that participated to the Work-Related Learning Project. This is a high school (students age 14-19). The school building dates back to 1998 and is divided into three levels above ground with a reinforced concrete structure, masonry brick walls and concrete and hollow tile floors.

The transparent closures are double glass sliding windows in aluminum with inside mounted venetian blinds.

The heating system uses electric convector heaters. An electric heat pump split system, used for cooling, is installed in the secretaries' and head-teacher's rooms. The school is not provided by a controlled mechanical ventilation system and, thus, the air change is obtained by opening the windows. A photovoltaic system of 126 crystalline panels (504 m^2) is installed on the roof. The school building is illuminated by natural light source through a system of sliding windows in every classroom, staff's offices, school corridors and laboratories. The artificial lighting system is composed of ceiling neon lights.

3.1. Applied theory workshop

The applied theory workshop is divided into four different sessions that deal with the following topics:

- Geometric survey and digital multi-images photogrammetric technique;
- Thermal physical parameters (heat, temperature, humidity, air velocity), heat transmission through building envelope and subjective factors in thermal comfort assessment (metabolism, clothing and activities);
- Artificial and natural lighting on natural light and energy saving, positive and negative effects of solar radiation;
- Air quality with a particular focus on CO_2 emissions in indoor and outdoor environments, their effects on comfort and climate change and possible building retrofitting solutions to reduce them (Lassandro *et al.*, 2017).

In each session, the students were involved in learning experiments, using survey instruments, to acquire the know-how useful for the next phases also with a gaming approach. For instance, multi-images 3D models of some students were created; the CO_2 concentration was measured changing the conditions in the classroom, i.e. during sedentary or physical activities, after lighting candles or in presence of plants.

3.2. Building analysis and proposals

The activities were dedicated to documentation collection (Figure 1) and geometric, photographic and instrumental survey in order to carry out the analysis of the building.

Figure 1. Documentation study activity

3.2.1. Geometric survey and preliminary analysis

The geometric survey was the basis of subsequent activities of instrumental investigations, software simulation and data collection of microclimatic and lighting conditions in the identified areas. The sample classrooms were chosen with different exposure as showed in Figure 2.

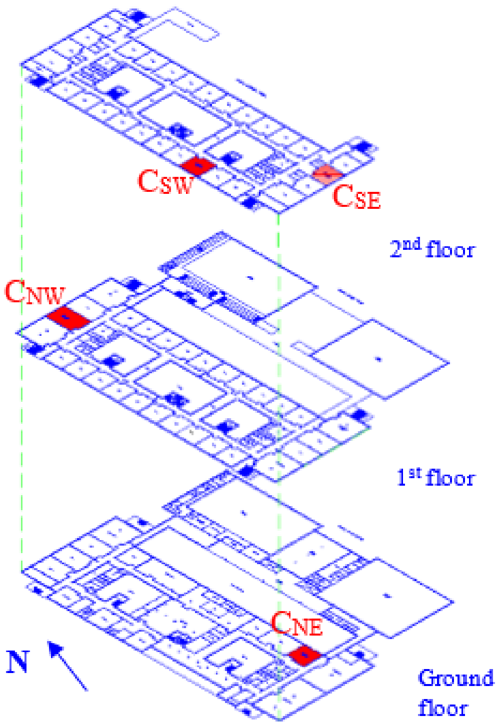


Figure 2. Sample classrooms

Some survey forms for preliminary audit were set up to help students in gathering all the necessary information for the project purposes (Figure 3), e.g. walls, windows and furnishings measurements, lighting devices and convector heaters positions, distance between each desk and the windows, the features of opaque surfaces and their reflectance etc.

The photographic survey campaign for both analysed indoor and outdoor environments was performed, for the ground shooting, with a camera for 360° images, Ricoh Theta S. The camera is characterized by two 180 ° lenses (fish-eye) each one, for the execution of immersive images aimed at creating a virtual tour of the building exterior (Figure 4) and of the selected environments.

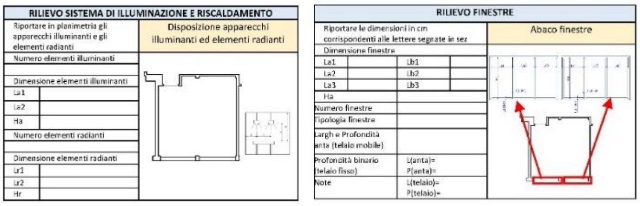


Figure 3. Geometric survey of the classroom

a *b*

Figure 4. a) Survey with multi-camera pole; b) Immersive photo, equirectangular projection

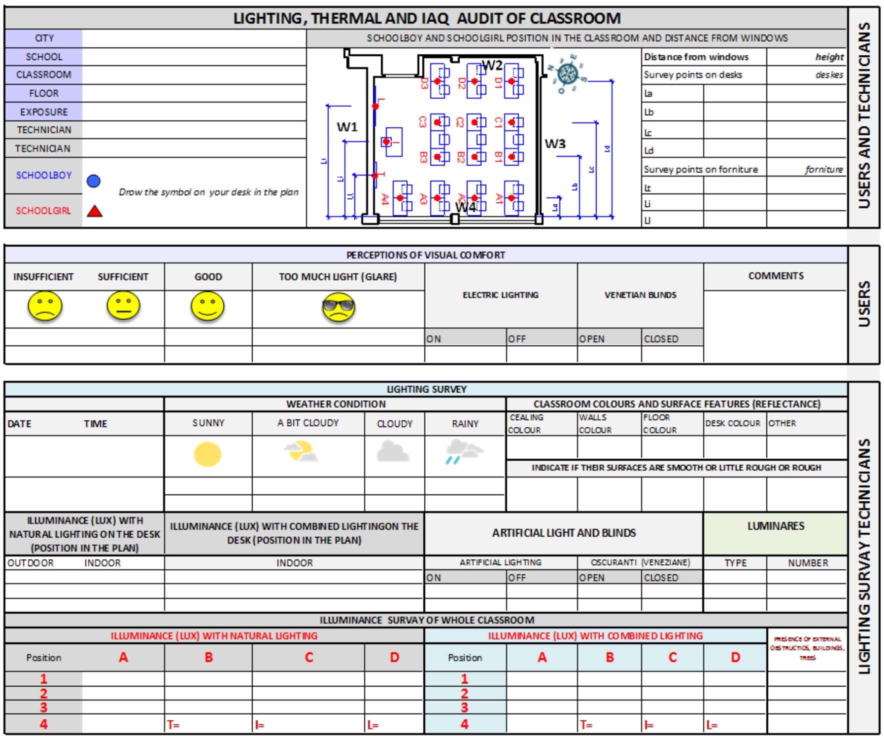
3.2.2. Questionnaires

Some questionnaires about thermal and visual comfort and air quality sensations were distributed to students of selected classrooms. They filled in the part of form focused on their subjective perceptions, after having indicated general information about them (gender, class, school name) and their position in the classroom.

As regard visual comfort, they specified their perceptions as insufficient, sufficient, good and too much light (if glare occurs according to their observation and opinion). The definition of the range of visual comfort for comparison of perceptions and measured value is critical, as it depends on the visual task and on the luminance all around. It was determined on the basis of EN 12464-1 (UNI EN 12464-1, 2011) and studies on UDI, Useful Daylight Illuminance (Ierardi *et al.*, 2017). Many researches set the highest threshold at 2000 lux and the lower limit at 100 lux for comfort in the offices (Nabil and Mardaljevic, 2006; 2015). Nevertheless, in this case of school building, 300 lux threshold was considered as sufficient and the range 300-3000 as good in order to make the students mindful of standard requirements and glare problems. In fact, more recent researches assert that illuminance level above 3000 lux is considered excessive and thus the daylight glare probability increases (Mardaljevic *et al.*, 2012; Moreno *et al.*, 2015).

Their thermal comfort was expressed according to the ASHRAE scale (2013) (very cold, cold, slightly cool, neutral, slightly warm, hot, very hot) that corresponds to 7-points Fanger scale. Moreover, the students indicated their clothes and the activities carried out the hour before.

The last audit form concerned the sensations related to indoor air quality such as tiredness, lack of air, unpleasant odors (bad smell), humidity and air currents (Figure 5).



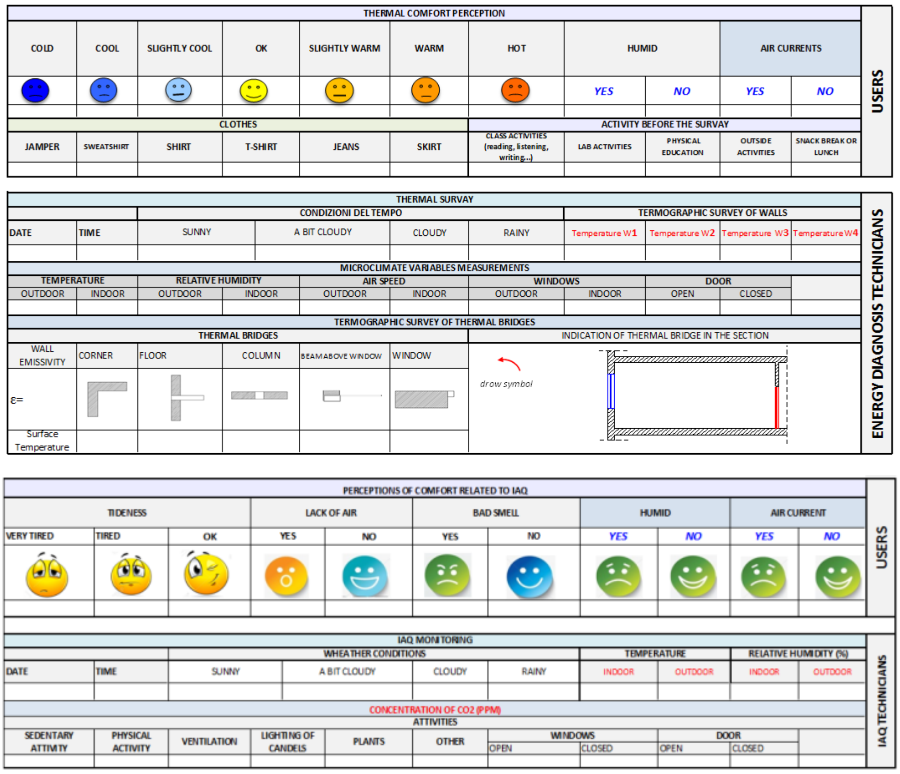


Figure 5. Questionnaires about visual, thermal comfort and air quality and instrumental audit with students' participation

3.2.3. Instrumental audit

After filling out the questionnaires about subjective sensations, the students carried out instrumental measurement about microclimatic variables through thermo-hygrometer and nanometers (UNI EN 15758: (2010) and UNI EN 16242: (2013)). A thermographic campaign of the classrooms and facades was performed directly by students to investigate the defects and thermal bridges, measuring the surface temperatures and indicating the thermal bridges positions in plan and section.

Concerning visual comfort, the lux-meter was the equipment used for measuring lighting conditions (both daylight and combination of natural and artificial light) on desks, blackboard and TV monitor in relation to the visual tasks and the requirements of UNI EN 12464-1: 2011.

The students monitored the CO_2 concentration during lesson hours and, at the same time, recorded the number of occupants in the classroom and if the doors and windows were open or closed, correlating CO_2 data to users and natural ventilation (Figure 5).

3.2.4. Simulations and proposals

A measurable 3D model of the school building was created through the post-processing step with Autodesk 123D Catch-free and Agisoft PhotoScan Professional Edition software. In order to have a complete model, the photographic images taken during the drone flight were matched with the terrestrial ones.

Concerning modeling and simulation of the thermo-hygrometric characteristics of building envelope, the students carried out simulations about the school building envelope. A software was chosen to suit the level of knowledge and the age of the students, e.g. Termus G.

Lighting modeling and simulations with Relux were carried by students both to verify daylight factor, medium illuminance, uniformity, glare (in natural, artificial and combined light conditions) and to propose new solutions. All questionnaires answers were elaborated to create some survey reports on occupants' comfort perceptions. The possible improvement solutions were found through brainstorming sessions with students.

Figure 6. Virtual Tour, panoramic group and plan with hot spot A.S.L (Alternanza Scuola Lavoro).

Figure 7. Virtual Tour, thermographic image

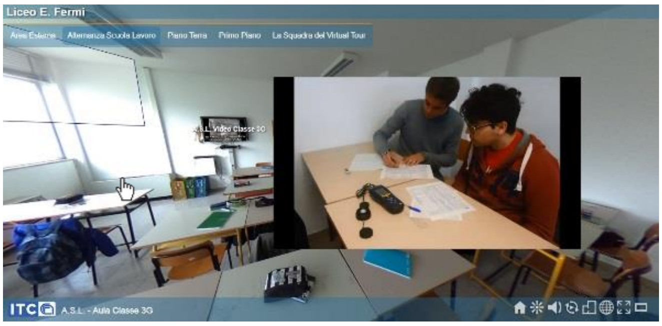


Figure 8. Virtual Tour, video addition

3.2.5. Technical virtual tour

For the case study of high school E. Fermi, a virtual tour made by ITC-CNR with a previous project already existed, and the new virtual tour developed during the activity of “Alternanza Scuola Lavoro” project has integrated perfectly with the existing one. Thus, it was possible to complete the virtual tour with some immersive images.

The new 360° photos, were inserted in the Virtual Tour, in a group, called “Alternanza Scuola Lavoro”, in which the information concerned the topics has been included (Figure 6).

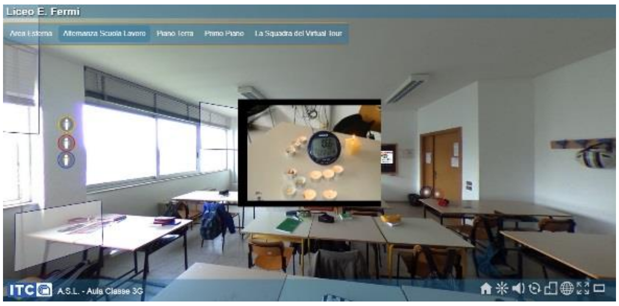


Figure 9. Virtual Tour, video of CO_2 evaluation activity

Photographs of some areas, identified inside the classroom and on the facade were taken with a thermographic camera in order to highlight the areas of thermal dispersion and analyse the construction features of the building such as the structure of the hollow tile floor identified by a different colour.

The thermographic images were inserted into the immersive photos of the environments in such a way that they can be called back when the mouse cursor is over images, through semitransparent panels. This procedure allows a direct correspondence between the element analyzed and the respective thermographic image (Figure 7).

At the same time, both the images of the main phases of the activities: lux (Figure 8), CO_2 (Figure 9) and thermographic surveys and the results of the various phases of the audit (preliminary, instrumental, software and proposal simulation) were integrated within the Virtual Tour. They are detectable through specific icons that call back texts and links for a complete and immediate communication of the whole project.

Figure 10. SAPR Ispire 1, flight on the school building

An important innovation concerned the inclusion, within the Virtual Tour, of immersive images also realized at a height of about 30 m by a flight with a SAPR (drone). Thus, it was possible to capture the whole building and contextually to photograph the area of the roofs where there are photovoltaic panels, not accessible in any other way (Figures 19-20) for safety problems.

The SAPR used is INSPIRE PRO 1 of the DJI with a 12 megapixel ZENMUSS X3 camera (Figure 10). This allows to obtain high resolution images and, at the same time, using the stabilized camera, to perform the images necessary for the realization of the photos immersive, maintaining the position of the drone in stable attitude even at high altitude and in the presence of wind (Figure 11).

For a deeper analysis of the photovoltaic panels, the digital photogrammetric survey of the covering was also carried out, performing a number of shooting, from a closer distance, such as to allow three-dimensional survey of the entire surface. (Figure 12).

Figure 11. Virtual tour, view from drone

Figure 12. 3D model of the building, view of the roof

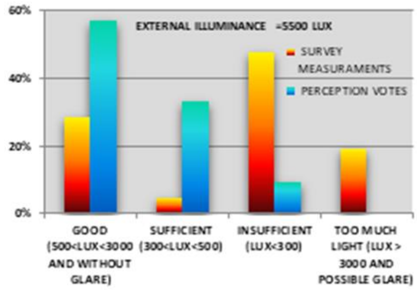
4. Results

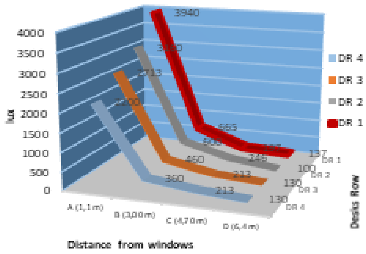
Because the school building was built with concreate frame, the instrumental audit on the facade showed the presence of important thermal bridge in correspondence of the external beams and columns with a surface temperature from 6 °C up to 10°C in winter when the heating system is on. The thermographic analysis carried out inside the classroom showed the presence of thermal bridges at the connection between the wall and windows especially in the corner (intersection among window, floor and column) with a temperature difference up to 4 °C. The surface temperatures on the wall under the windows are lower of around 1.2 °C. In fact, the results of the questionnaire highlighted the worst thermal comfort for the students with the desk near the windows, especially in the northeast class on the ground floor.

However, the school does not present any particular thermal comfort problems during the winter as the heating system generally maintains temperatures from 19 to 20 ° C, even if there are differences in the four sample classes. In particular, in the C_{NE} classroom the temperature of 17 °C was reached in winter, whereas the temperature of 24 ° C was reached in C_{SW} due to overcrowding.

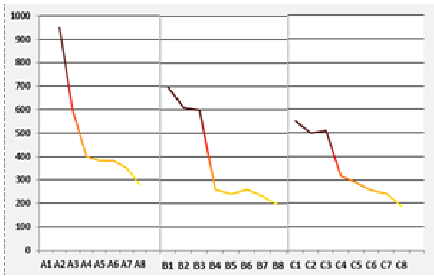
The results of questionnaires distributed in the sample classrooms showed that the students’ thermal comfort perceptions were ok for 19%-37%, slightly cool for 30%-52%, slightly warm for 0-10%, warm for 0-5% during winter.

As known, the amount of daylight varies throughout the day depending on climate condition and exposure of classroom, but anyway some considerations about results of the analysed period can be made. All the sample classrooms are with side windows. Therefore, the students recorded significant light decreases on the desks as they moved away from the windows. For instance, in the C_{SO} classroom the analysis of the illuminance level with natural light (lux ext. = 5500), showed a very high lighting variation between the areas close to the windows and the areas close to the opposite wall (differential of lighting of 3810 lux) (Figure 13 a, b).

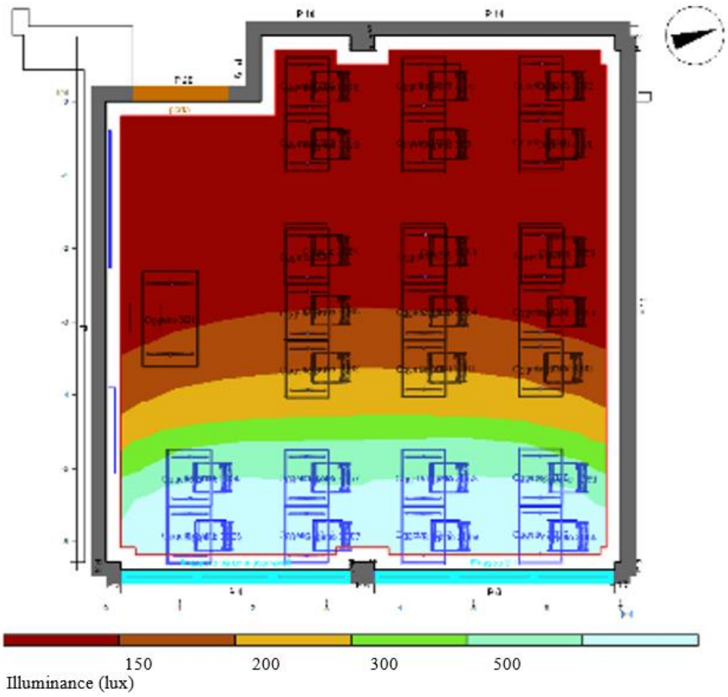

60%
40%
20%
0%
EXTERNAL ILLUMINANCE =5500 LUX
SURVEY MEASURAMENTS
PERCEPTION VOTES
GOOD (500<LUX<3000 AND WITHOUT GLARE)
SUFFICIENT (300<LUX<500)
INSUFFICIENT (LUX<300)
TOO MUCH LIGHT (LUX > 3000 AND POSSIBLE GLARE)


4000
3500
3000
2500
2000
1500
1000
500
0
lux
3940
DR 4
DR 3
DR 2
DR 1
Desks Row
Distance from windows

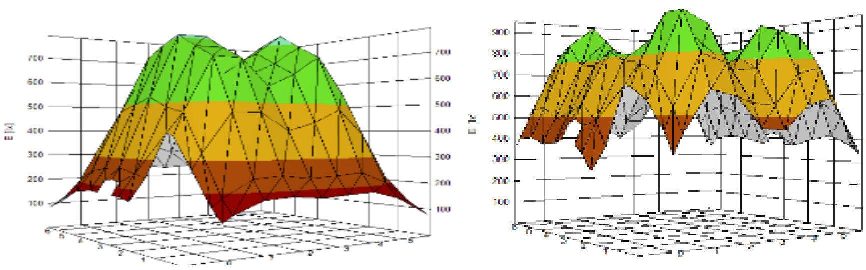
a *b*


1000
900
800
700
600
500
400
300
200
100
0
A1 A2 A3 A4 A5 A6 A7 A8
B1 B2 B3 B4 B5 B6 B7 B8
C1 C2 C3 C4 C5 C6 C7 C8

c *d*


150
200
300
500
Illuminance (lux)

e



f *g*

Figure 13. Diagram of illuminance measurements vs perception vote (a) and natural light distribution (b) in CSW; graph with combination of natural and artificial lighting (c); natural lighting software simulations (d, e) and artificial lighting simulation (g) and improvement proposal (g) in CNE

The C_{NE} classroom with trees near the windows was the one where the most critical situation was detected. In particular, for the analysed period in the morning the average percentage of students' desks with the illuminance values less than 300 lux (down up to very low value) was more than 60%. For instance, in C_{NE} the reduction reached 15 lux on the most distant desks from the window when the external illuminance was equal to 2560 lux. Even in the other classrooms the values in lux on the desks fell below the normative values, but it is found that the students in the range from 25-30% perceive as sufficient illuminance values below 300 lux. This is in line with UDI (Useful Daylight Illuminance) studies that asserts that daylight illuminances in the range of 100-500 lux can be considered effective by occupants in daylight offices.

There are also problems with direct solar reflection on the row of desks near the window, especially in C_{SE} (lux>3000).

The results obtained by RELUX simulations confirmed that U (Uniformity) <0.6 even with the artificial light for the four sample classrooms (Figure 13 c, d, e),

Considering the CO_2 concentration measurements, the air changes through natural ventilation resulted not sufficient (in fact also the indoor temperature remained quite constant), and thus the air quality is low (UNI 10339, 1995; ANSI/ASHRAE, Standard 62.1, 2013; UNI EN 15251, 2008).

From the analysis of the CO_2 levels monitoring within the four sample classes in conditions of closed door and closed windows, values above the acceptable threshold (<1000 ppm (Khatami *et al.*, 2013) were found with a maximum peak from 3100 to 3300 ppm in the presence from 26 (C_{SW}) to 31 (C_{SE}) occupants and with outdoor CO_2 equal to 402 ppm. However, what is even more alarming is that the average value settled at 2000 ppm, far above the comfort levels. The average minimum value in the analysed period were around 1000 ppm even in conditions of transversal ventilation in the classroom because the facing windows in the corridor were often closed. It reached 551 ppm, close to the good value for comfort (<500 ppm), in the C_{NW} because it is 70 square meters' classroom and although there were 30 occupants, the traversal ventilation allowed to drop the CO_2 concentration (Table 1). Instead, 503 ppm of CO_2 was reached in C_{SW} during the applied theory workshop, only when a transverse ventilation was triggered opening completely the two windows, the door and even the two front windows in the corridor for more than 12 minutes (Figure 14).

Table 1. CO_2 concentration (ppm): Average of the daily Maximum, Average and Minimum values in the analysed period

			CO2 concentration		
Classroom	Area (m2)	Occupants	Max	Avg.	Min.
CSW	49,30	28	3202	2205	1158
CSE	48,80	30	3347	1996	1031
CNE	48,50	30	2861	1924	971
CNW	70,00	28	2726	798	551

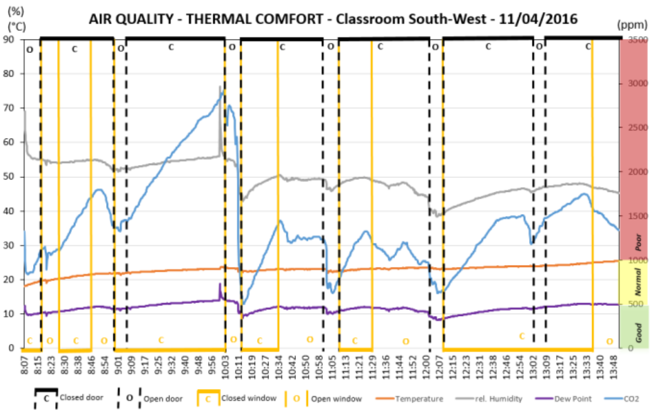
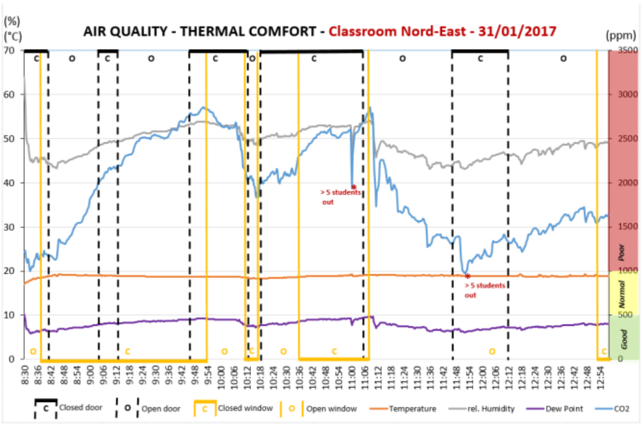
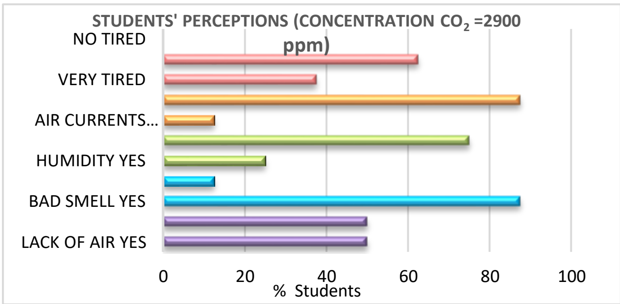


Figure 14. CO_2 concentration monitoring in CSW

Under conditions of high CO_2 concentrations (about 3000 ppm) and according to the questionnaire results, the students were tired (58.6% -62.5%) and very tired (37.5% -41.4%) with higher "very tired" percentages in the classes with higher occupant density. Surely their state is not only linked to the concentration of CO_2, but the lack of air and the bad smells, found by 50-90% and 80-87.5% of the students respectively, have confirmed that the lack of air exchange influenced the their state of well-being. Moreover, the insufficient daylight and right temperatures probably contributed to increase their fatigue (Figure 15).



a



b

Figure 15. CO_2 concentration monitoring (a), students' perceptions (b) in CNE

Students, prepared on technical issues and made aware of these problems, have proposed improvements in the brainstorming sessions according to the following cost brackets per floor area, proposed by researchers (Marrone *et al.*, 2018): low cost (c <10 € / m^2), medium cost (10 € / m^2 ≤ c <100 € / m^2) and high cost (c ≥ 100 € / m^2):

- Building envelope: Realization of exterior thermal insulation systems to eliminate thermal bridges and improve the energy performance of the school building (high cost);

- Windows and blinds:

Application of low emissive solar films and replacement of gaskets between glass and frame; addition of special gaskets or brushes between fixed frame and movable window frame (low cost);

Removal of the Venetian blind system and application of robust and easy to operate curtains (such as roller blind made of polyester and nylon cloth) that provide a suitable daylight in the space (low cost);

Replacing window panes with more insulating ones equipped with blinds inside the double glazing (medium cost) structure or connected to a building automation system (high cost);

Replacement of windows with others with improved energy and acoustic performance, in aluminium with thermal break and lift-and-slide opening system with the application of CO_2 detectors connected to automatic ventilation systems integrated in the window frame able to recover heat from the outgoing air (high cost);

Installation of home automation control and activation systems (high cost).

Lighting system: increase in the number of luminaires (Figure 13 g) or replacement of the existing luminaires with LEDs with automatic adaptive dimming systems and presence detectors (medium cost) or with centralized building automation lighting systems (high cost).

The results were included in the technical and performance virtual tour of the school as text boxes, images and videos linked to special interactive info-points of different colours and shapes (Figure 16). The virtual tour is available from the following link: http://www.itc.cnr.it/ba/vt/bari/liceo_fermi/

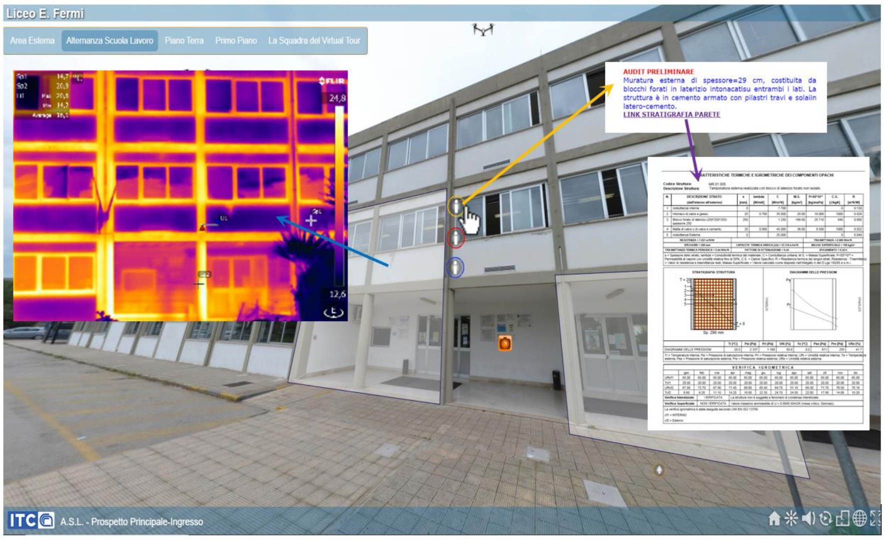


Figure 16. Virtual Tour, texts, images and external links

5. Conclusions

The visualization of the project activities through virtual tour turned out to be particularly important both as a means of spreading a very high amount of information, through multimedia accesses inserted in virtual environments, and as a method of easy learning and deepening of issues also complex for students. In fact, they are more accustomed to visualization and navigation through images than through texts and written sources.

In fact, making students and teachers aware of indoor environment quality issues, participating in their school building' audit, not only contributes to increase responsive behaviours for energy saving and comfort in the classrooms but also to be mindful of the need for adaptive behaviour when conditions change in order to restore comfort condition in the environment where they are located. This proactive attitude is very important in buildings that are naturally ventilated and receive a significant daylight to be optimized for the occupants' visual task.

Moreover, this technical virtual tour created by students at terrestrial and aerial level proved to be a useful tool to communicate the results and help facility managers create healthier indoor environment for occupants (students, teachers and school staff) and to spread best practise also to other schools.

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