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Assessment of the IEQ in two high schools by means of monitoring, surveys and dynamic simulation

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Abstract

This workpresents an assessment of schools' indoor environmental quality, based on investigations carried out in three Italian classrooms in Treviso, in the North-East of Italy. A first monitoring campaign was performed during the mid season (May-June), a second oneduring the heating period (January-February). At a first stage, the study was focused on two different approaches, an objective and a subjective one, in order to compare the objective responses with the occupants' subjective sensations. The first method consisted of physical observations and field measurements of thermal environmental parameters, used to calculate Fanger's comfort indices and to apply a comfort adaptive model.The subjective approach was managed by giving students and teachers a survey about their personal judgment concerning the level of comfort perceived. Finally, a simulation model has been built-up and calibrated using the indoor values of air temperature and air humidity trends collected by data loggers. A generic optimization programhas been used to calibrate the thermal model. The responses from measurements, surveys and simulations were integrated, analyzed and compared, obtaining a good agreement between the three approaches in assessing the classroom thermal comfort category.

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Keywords: indoor environmental quality; thermal comfort; schools; survey; adaptive model; simulation model

1. Introduction

Indoor environmental quality in school buildings is an important issue because classrooms' conditions affect not only health and comfort, but also students' performance, with long-term future repercussions on productivity and social costs. In fact it is proved that good quality of the indoor environment can improve

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students' attention and concentration.Otherwise school buildings require high amount of energy and this situation has led in recent years to the spread of manystudiesinorder to monitor energy consumptions and indoor environmental conditions. The need to achieve a good comfort level in educational buildings is due to the fact that pupils spend around 30% of their life in schools. Indoor environmental quality was investigated in some primary schools near Venice[1], by means of spot measurements and questionnaires given to students about their personal judgment and behaviour towards discomfort. Physical measurements and surveys' answers were compared to find a relationship between them. Another study [2]analyzed the relationship between thermal comfort measurements and surveys in naturally ventilated classrooms in England. The results from subjective sensation were also compared to predictions achieved with comfort standards methods, e.g. the heat balance, and the adaptive model, using estimated values for clothing insulation and metabolic rate. Generally looking at an overview of all the studies done about IEQ in school buildings, the same method was usedalso in otherstudies[3][4][5][6][7]. The objective of all these studies wasto compare indoor microclimatic parameterswith students' subjective judgment.The aim of this work is to propose a further contribution to the researches on schools' thermal comfort conditions, presenting the results of a method based on the integration and the comparison of three different approaches: an objective evaluation by means of measurements, the subjective responses of people and the predicted responses by means of dynamic simulation.

1.1. Object of the study

This work is based on investigations carried out in three classrooms of two schools located in the Municipality of Treviso, a city in the North-East of Italy at 15 m on the sea level, characterized by a temperate climate with cold winter and hot-humid summer and located in climatic zone E, with 2378 heating degree days. The two schools wereselected in a sample of thirteen secondary schools by analyzing their energy performance. The first school, ITIS Fermi, was built between 1961 and 1975, before Italian regulation n.373/1976, the firstItalian law about building energy performance. Instead ITG Palladio was built in 1989, that is before D.P.R. n.412/1993, which is the act for the implementation of the second Italian law on buildings energy efficiency, L.10/1991. Calculating the energy performance of all the sample by means of UNI EN 13790[8] method, the first school had a Primary Energy Index (EPi) greater than the maximum one, whereas the second one had an EPi lower than the maximum one. The three examined classrooms meet the geometric features shown in Table 1.

For the construction features we based on energy diagnosis supplied by the Municipality of Treviso. Both schools have a mixed constructive technology. ITIS Fermi has a bearing external structure in reinforced concrete with infill in concrete blocks and a brick facing, brick internal walls and cement brick floors. ITG Palladio has an external structure made of concrete insulated with polyurethane, brick internal walls and cement insulated floors. All the classrooms are naturally ventilated and have a heating system with radiators, three elements in Fermi's classrooms, two in Palladio's one.

2. Investigation methods

The comfort performance of the three classrooms has been calculated by means of instrumental monitoring, subjective surveys and dynamic simulation. To achieve this aim two monitoring periods have been chosen, with the final objective of comparing three methodologies for the indoor quality assessment: a) objective approach; b) subjective approach; c) dynamic model simulation.

Table 1. Classrooms' geometric features

Geometric data	ITIS Fermi V AM	ITIS Fermi V AT	ITG Palladio II C
Perimeter (*m*)	31.27	31.27	33.85
Heigh (*m*)	3.50	3.50	3.50
Net area (m^2)	54.60	54.60	60.05
Gross area (m^2)	62.63	62.63	71.39
Heatable volume (m^3)	186.82	186.82	210.00
Opening surface (m^2)	11.40	11.40	4.23
Windows (m^2)	8.50	8.50	7.00

2.1. Objective approach

The objective approach is based on field measurements campaigns carried out in two different periods of the year, the mid season, in free running conditions, and the heating period, during actual lectures. In order to do this, according to regulations given by UNI EN ISO 7726 [9], a Thermal Comfort Data Logger INNOVA 1221 was used to record data about thermal environmental parameters useful to the evaluation of moderate thermal environment, such as: air temperature, operative temperature, air humidity, air velocity, globe temperature. Metabolism and clothing thermal resistance were set according to UNI EN ISO 7730[10], taking into account the students' activity and the monitoring season. The transducers were put on two tripods in the centre of the classroom, at a height of 1,10 m, the height prescribed by norm UNI EN ISO 7726 for measurements at head level for sitting people and abdomen level for standing people.The measurements were carried out in both the two campaigns for the period of one hour, while students were filling in the surveys. These data were necessary in order to calculate Fanger's comfort indices PMV and PPD(respectively Predicted Mean Vote and Predicted Percentage of Dissatisfied) and to implement a comfort adaptive model to obtain the reference comfort ranges for the indoor operative temperature as a function of the outdoor climatic conditions.

2.2. Subjective approach

The subjective approach was conducted by giving students and teachers a survey questionnaireabouttheir personal judgment concerning the level of comfort perceived.We elaborated three survey versions, in order to pay particular attention to the questions' comprehensibilityfor each typology of users: students, teachers, school energy manager. The questionnaire has been divided into sections, each of which about a different comfort area: general information, thermal comfort, visual comfort, acoustic comfort, indoor air quality perception. Globally about 130 students were interviewed. They had thirty minutesto fill in their anonymous survey, while the measurements were going on under typical classroom's conditions.The evaluation was based on different types of valuating scales, according to UNI EN ISO 10551[11]: a perception scale, according to [4] and UNI EN 15251[12], rating from -3 to +3 corresponding to very cold and very hot and 0 being the neutral condition; a rating scale made of seven values, in ascending order from 1 to 7; a scale of preference, according to Annex H of UNI EN 15251; finally a bipolar percentage scale of productivity[13][14]. Moreover, the consistency of the answers were checked through open questions of verification. The survey was also used to make somebehavioral observations about occupants and their interaction with the environment. Among the general information, it was asked students to give some judgments about their level of school satisfaction and their level of information about school energy politics. Moreover, students were asked to indicate what they were wearing among a clothing check-list, in order to calculate, using UNI EN ISO 7730, their actual clothing level, then used in the evaluation of comfort indices.

2.3. Dynamic model simulation and model calibration

The simulation of indoor thermal comfort conditions and the model calibration were developed on one of the three classrooms, the *V AM* of ITIS Fermi during two periods of 15 days, at first in the mid season, then in the cold season. A microdatalogger type HOBO U-12was usedto measure air temperature and humidity trends, while other five identical instruments were used in the adjacent rooms in order to get information on the boundary conditions.All microdataloggers were attached to an internal wall of the different rooms at a height of 2.5 m, so that they were not affected by the solar radiation, external climatic conditions or by the presence of human bodies. External climatic trends were obtained by ARPAV meteorological station of Treviso.All the data recorded were necessary to implement the simulation model, made by Trnsys - Transient system simulation program[15].The main subroutines used to manage data were: Type56 for the building energy balance; Type9b forthe link with the climatic file, the occupants' presence file and the opening window schedule file;Type16c for solar radiation processing; Type33e for the psychometrics conditions; Type69b for the effective sky temperature.The main advantage of a dynamic simulation is the possibility of evaluating different scenarios for the application of technologies and strategies to improve energy performance by controlling at the same time the occupants comfort level.However, we first calibrated the simulation model, so as to act on all those building variables that were unknown or not well defined, in order to make the Building Energy Simulation (BES) the most responsive to reality.To calibrate the model a generic optimization program, GenOpt, was used, which works by setting a hybrid algorithm to manage variableschosen considering the temperatures trends and through iterative tests on the starting simulation[16]. To do this we made a differential sensitivity analysis, so as to analyze directly the results' sensitivity on varying the inputs. The variables, most related to the thermo physical building conditions, were: solar absorbance factor of the external wall, zone air capacitance, solar to air factor, infiltration rate and the windows' opening angle for ventilation. The calibration performance was evaluated calculating the Root Mean Square Deviation (RMSD) between the real air temperature and humidity and the simulated ones during the monitoring period.

3. Results analysis

3.1. Mid season results

During the mid season thermal comfort conditions have been at first evaluated through the operative temperature values recorded during the field measurements collected on 26^{th} and 29^{th}May. As shown in Table 2, all the classrooms fall within the I Category except for Fermi's *V AM* which, however, is very close to it. In order to compare field measurements with subjective responses the PMV and PPD have been calculated using the environmental data. Even if those indicesshould be used in room with mechanical systems, otherwise they allowed us to compare objective and subjective evaluation. The values in Table 3 were obtained setting thermal insulation as 0.5 clo, that is the most appropriate value for a summer clothing condition and it was also the mean value most spotted in the surveys. Metabolic rate was set at 1.2 met (69.84 W m^{-2}). In the same table the last column reports the PPDs derived from the analysis of the surveys: these percentages include all the occupants that had given a non-zero neutrality score. In all the three analyzed cases, we obtained a PMV slightly above the zero neutrality, especially for Fermi's *V AM*. This fact means a slightly warm temperature and all the classrooms fall within the II

Category, as pointed out also by PPDs values. Although there's a slight difference between the analytical indices, the adaptive model outcome and the subjective judgment, it can be seena similar trend in the rooms. In fact, it is confirmedthat all the classrooms, especially the *V AM,* tend to a slightly warm temperature. Observing in more detail the student's answers about thermal perception, using the 7 points Fanger's scale, the percentage of answers with a vote between +1 and +3 (from slightly warm to hot) were: 61.9% for Fermi's *V AM*; 38.1% for Fermi's *V AT*, 75% for Palladio's *II C*.

Table 2. Comparison between recorded operative temperature values and comfort ranges of I Category, according to UNI EN 15251. Cells filled in red color means a value outside del comfort range. In green values inside the range

	I CATEGORY			
	Outdoor running mean temperature °C	upper limit °C	lower limit °C	t_o °C
Fermi V AM	15.25	25.83	21.83	25.88
Fermi V AT	15.25	25.83	21.83	24.65
Palladio II C	14.66	25.64	21.64	25.49

Finally, for the classroom which had highlighted much more thermal comfort problems, a dynamic simulation model was implemented. After having modeled the classroom and calibrated some uncertain variables we obtained a RMSD between the simulated temperature and humidity and the measured ones of about 0.5. To evaluate thermal comfort once more was used an adaptive model observing,through the simulated operative temperature during the period from the 27^{th} May to the 4^{th} June, for each hour of classroom occupation,in which category of thermal comfort the classroom was included in. The results shown that only 23% of hours came under the I Category of UNI EN 15251, whereas the 77% fell in the II Category. This supports the results obtained from field measurements.

3.2. Heating period results

During the heating period the thermal comfort evaluation was performed only through comfort indices and subjective responses (Table 3). PMV and PPDm have been calculated considering a metabolic rate of 1.2 met, whereas thermal insulation reference wasfixed in 0.8 clo, according to the average value of clothing index derived from the students answers. As we can see in Table 3, all the three classrooms lay in the I Category of comfort, being PMV values between -0.2 and +0.2, and PPD lower than 6%.

Table 3. Measured PMV, measured PPD (PPDm) and subjective PPD (PPDs) in each classroom

	Mid Season			Heating Season		
Classroom	PMV	PPDm [%]	PPDs [%]	PMV	PPDm [%]	PPDs [%]
FermiV AM	0.50	10.20	66.70	0.03	5.02	61.10
FermiV AT	0.23	6.10	52.40	-0.05	5.05	44.80
PalladioII C	0.25	6.30	80.00	-0.12	5.30	76.20

Analyzing the students' answers the neutral condition was declared by 39% of students in *VAM,* by 55% in *V AT* and by 24% in *II C*. This means that the classroom *V AT* is the one with the better comfort conditions as already revealed by measurements. Moreover52% students of Palladio's *II C* reported a cold sensation, according to the trend of the calculated PMV value, which is negative and the farthest from neutrality of all the three classrooms.

4. Conclusions

In this work indoor environmental quality has been evaluated in secondary schools, where in the last years a lot of interventions have been adopted in order to improve their energy performance. The assessment focused on thermal comfort, and based on three integrated approaches. What emerged from measurements is a slight discomfort confirmed by the students answers, both in the mid season and in the heating period. Some remarkable results must be listed: subjective results were in agreement with the outcomes of the objective approach, except for some small differences. But it is important to say that, whereas students daily enjoy their classrooms and are aware of its problems, thermal comfort measurements are often taken for brief periods of time, taking into account only the ambient condition in that moment. For this reason a dynamic simulation should be a useful instrument to control the thermal comfort conditions over a long term period.

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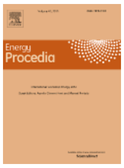

Biography

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