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Evaluation of the Indoor Thermal Quality in high schools buildings: strengths and limits of different assessment methods

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Abstract

Recent studies have pointed out how much the indoor environmental quality in schools' classrooms is an important factor, which could prevent serious adverse effects not only on the students' comfort sensation, but also on their health and learning potential. However, although standards EN ISO 7726:2001, EN ISO 7730:2005 and EN 10551:2001 give recommendations about how to practically perform objective and subjective measurements, on the evaluation of the level of comfort perceived in buildings, there is the need to define a systematic and standardized way in order to implement the comfort assessment through a methodical and uniform approach. In this work the assessment of the Indoor Thermal Quality of two classrooms in one high school located in Treviso, a town in the North-East of Italy, is presented in order to highlight the strengths and the limits of two different evaluation approaches: field monitoring, and survey questionnaires. To reach the aim, two monitoring and surveys campaigns were carried out, one during the spring and one during the heating season. All the four comfort areas were investigated through the questionnaires: the thermal, the visual, the acoustic and the air quality perception.. Afterwards objective and subjective responses on thermal and visual perception have been compared.

Keywords - indoor thermal quality; school buildings; on site monitoring; satisfaction surveys

1. Introduction

Indoor environmental comfort in school buildings is an important issue, because it has a great consequence not only on students' thermal sensation, but especially on their health and attention. Since students spend around one third of their day inside school [1], it is important to assess and evaluate their comfort conditions inside classrooms and school facilities. In fact, it is demonstrated by several studies that a good indoor environmental quality

(IEQ) can lead to a reduction of illnesses and their seriousness, and therefore of the occupants' and workers' absenteeism. On this way, many recent studies have focused on the assessment of the indoor environmental comfort in classrooms but, despite European and worldwide Standards [2-4] give recommendations about how to perform measurements practically, the real current challenge is to define and validate a systematic and standardize method in order to reach a complete and efficient comfort evaluation.

Almeida et al. [1] assessed occupants' thermal comfort in some educational buildings in Portugal, in free-running conditions, using both means from field measurements and survey questionnaires. Objective measurements were used to implement a comfort evaluation through the PMV-PPD model, plus an adaptive model. That study pointed out the need to use a correction factor in the estimation of the metabolic rate for the comfort indices calculation for pupils: in order to understand it, it was useful to implement the different approaches in assessing pupils' thermal sensation, since using only PMV-PPD evaluation would have led to a wrong judgment. Moreover, a questionnaire was prepared in order to set the clothing thermal resistance. Starting from the same approach, Sarbu et al. [5] carried out a comfort evaluation implementing also a model simulation of a higher educational building in Timisoara. However, no detailed analyses were performed to reach a good estimation of the metabolic rate and the clothing thermal resistance, which were set according to EN ISO 7730 [3], basing on activity and seasonal evaluations. Comfort evaluation was performed only through PMV-PPD values and finally through a simulated prediction model.

Teli et al. [6] conducted a field study that included questionnaire surveys and simultaneous measurements of the environmental variables affecting thermal comfort. It was carried out in a naturally ventilated primary school in UK. The questionnaire surveys were administered outside the heating period in order to investigate the pupils' thermal comfort trends in relation to the environmental conditions during the free-running mode of the building. As in the above mentioned studies, many other studies [7-13] conducted comfort analyses using different approaches, based on the different situations' needs and objectives.

This work presents the results of a survey carried out in two classrooms of one High School in the North-East of Italy. The aim was to evaluate the overall comfort perception of students in the school during lessons. All the four comfort areas were investigated: the thermal, the visual, the acoustic and the air quality perception. Next to the questionnaires on field measures have been developed in order to give a comparison between subjective and objective responses on thermal and visual sensations. The results from the comparison of these methods were analyzed to highlight the strengths and the limits of each approach.

2. Classrooms investigated

The classrooms investigated are located in a High School in the Municipality of Treviso, a city in the North-East of Italy at 45° 40’ N latitude and 12° 14’ E longitude, characterized by a temperate climate with cold winter and hot-humid summer and located in climatic zone E, with 2378 HDD.

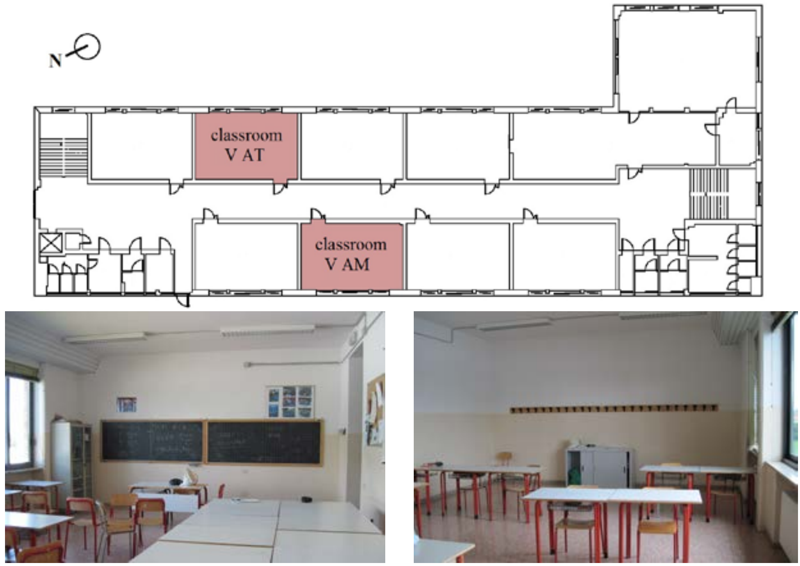

Fig. 1 Second floor of the school and location of the two investigated classrooms (up); pictures of the two investigated classroom, V AM on the left, V AT on the right

This school was built between 1961 and 1975, before the Italian regulation n. 373/1976, the first Italian law about building energy performance. The two classrooms, identical in their geometric features, are both situated at the second floor of the school and they have one windowed façade oriented towards East and towards West. Their area is 63 m^2 and the heated volume 187 m^3, with an opening surface of 11.4 m^2. The construction features were 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. All the classrooms have a heating system with three radiators placed under the windows in some recesses in the wall, and they are naturally ventilated. Ventilation, in fact, was managed by students and the operating mode was assessed through the survey questionnaires in both the field campaigns. Windows were opened from at least 2 to more than 5 times during the occupancy time in the mid season, whereas in the heating period windows were opened less frequently, between less than 2 and maximum 5 times a school day. Moreover, students stated that windows were opened during the teacher changes and during the breaks.

3. Survey questionnaires

Occupants' response was managed by administering to 90 students a survey questionnaire to investigate their personal comfort sensation. The questionnaire was specifically elaborated paying specific attention to the questions' comprehensibility for students.

In the elaboration of the questionnaire, the Guide of ASHRAE [14] was taken into consideration. Even though this Guide is thought up to assess the IEQ in commercial buildings, as expressed in its title, some of the prescriptions seemed to be suitable also for schools.

The questionnaire was divided into seven sections. The first two parts concern some general information: students' were asked about their physical features (height and weight), their position in the classroom, their level of satisfaction of school, their awareness about school's energy policies. This was necessary in order to make some behavioral observations and to relate subjective responses to personal characteristics. 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 and make further observations. The last four sections asked for the specific perception of the classroom environment. For each comfort area (thermal comfort, visual comfort, acoustic comfort, indoor air quality), the evaluation was conducted with different types of valuating scales:

- a perception scale, according to [4] [14] and Annex H of EN 15251 [15], rating from "hot" to "cold", corresponding to -3 to +3 and 0 being the neutral condition;
- a rating unipolar scale made of seven values, in ascending order from 1 to 7 according to [4][14] where the maximum vote expresses a total satisfaction;
- a scale of preference, according to Annex H of UNI EN 15251 [15]; e.g. for the air temperature the options were: higher, no change, lower;
- finally, a bipolar percentage scale of productivity [16]. This scale was used to ask the students to evaluate how much the indoor environmental factors influenced their productivity.

Moreover, the consistency of the answers were checked through open questions of verification. Students had thirty minutes to fill in their anonymous survey, while the measurements were going on under typical classroom's conditions.

4. On field measurements

Two on field measurements have been carried out during the Spring (on 26th May), in free running conditions, and during the heating period (on 24th February). The Thermal Comfort Data Logger INNOVA 1221 [17] was used to record data during the lectures while students were filling the questionnaires. Air temperature, operative temperature, air humidity, air velocity and globe temperature were measured for about one hour at one-minute intervals. Following the regulations given by EN ISO 7726 [2], the transducers were put on two tripods in the center of the classroom, at a height of 1,10 m, considering that this is the height of the head for sitting people, e.g. students and the height of abdomen level for standing people, e.g. the teacher.

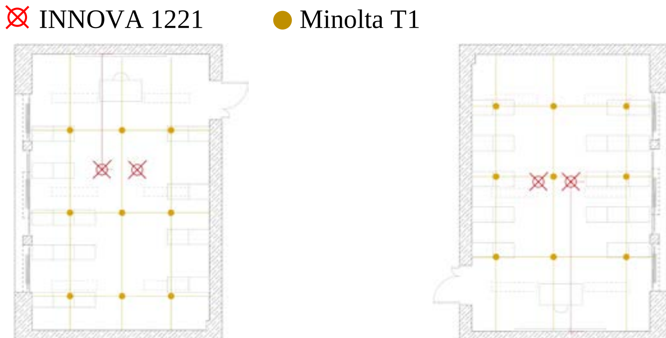

Fig. 2 Instrument position in classroom V AM (left) and V AT (right)

During the heating season environmental parameters have then been used to calculate Fanger's comfort indices, the Predicted Mean Vote, PMV, and the Predicted Percentage of dissatisfied, PPD, while during mid-season, when the system is off, the operative temperature has been used to assess the classroom comfort category according to the adaptive comfort model. During the lectures horizontal illuminance have been measured at student positions with a portable luxmetro, Minolta T-1 [18].

5. Subjective responses

In order to enable the comparison of the results of the different comfort areas, questions with the same 7-point valuating scale have been analyzed. The questions which were asked to the students were:

1. Can you see well when you are at your desk?
2. How much are you satisfied with the air temperature in your classroom?
3. How much are you satisfied with the acoustics in your classroom?
4. How much are you satisfied with the air quality in your classroom?

In the tables 1 to 4 the percentages of students' answers for each vote has been reported for all the comfort areas of each classroom, for spring and heating season. As we can see, the two classrooms have different scores. In Fig.3 the percentages of people satisfied for each comfort area is represented on the same plot. Votes from 5 to 7 have been considered as a satisfaction condition.

Despite V AM seems to have a better IEQ during the spring period, during the heating one V AT collects the best votes. It is possible to observe that the comfort areas with the major levels of criticality are the air quality and the acoustic comfort. Visual comfort appears to be the most esteemed sector, even if in the V AT students complained about discomfort caused by glares and dazzles due to the morning solar radiation (classroom east exposed). In terms of thermal comfort, percentage of satisfied people are approximately 40% for the spring period and around 20% – 40% in the heating season. V AM registered the worse scores in both the survey campaigns. Acoustic problems are caused by the absence of acoustic insulation and this leads to the presence of noise from the outside and from the adjacent classes. Regarding the air quality, students do not seem to be completely able to distinguish a lack in air quality from the thermal sensation. Most of the times, observing the students' answers, the two parameters appear correlated. Despite this, the poor air quality in the classrooms, noticed also during the inspections, is certainly caused by the absence of a mechanical ventilation system. For further observations, the distribution of the students' responses on thermal comfort inside the classrooms are mapped in Fig.4 and 5. Numbers express the average of the students' votes from 1 to 7. Colour brown states the teaching desk position, whereas light blue states the presence of windows.

Table 1. Percentages of responses for each vote

Spring period	**Classroom V AM**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	1. Visual comfort	0	0	0	19	9.5	66.7	4.8
	2. Thermal comfort	4.8	14.3	23.8	14.3	28.6	14.3	0
	3. Acoustic comfort	9.5	14.3	14.3	28.6	28.6	0	4.8
	4. Air quality	9.5	19	19	28.6	19	4.8	0
	Classroom V AT	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	1. Visual comfort	0	14.3	14.3	19.0	14.3	33.3	4.8
	2. Thermal comfort	14.3	4.8	23.8	19.0	23.8	14.3	0
	3. Acoustic comfort	0	23.8	33.3	19.0	23.8	0	0
	4. Air quality	0	28.6	57.1	0	9.5	4.8	0
Heating period	**Classroom V AM**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	1. Visual comfort	0	0	5.6	22.2	33.3	38.9	0
	2. Thermal comfort	5.6	11.1	11.1	33.3	16.7	16.7	5.6
	3. Acoustic comfort	11.1	55.6	5.6	16.7	5.6	5.6	0
	4. Air quality	16.7	16.7	33.3	33.3	0	0	0
	Classroom V AT	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	1. Visual comfort	0	6.9	3.4	27.6	27.6	31.0	3.4
	2. Thermal comfort	6.9	13.8	24.1	34.5	17.2	3.4	0
	3. Acoustic comfort	17.2	20.7	37.9	3.4	17.2	3.4	0
	4. Air quality	10.3	37.9	27.6	17.2	6.9	0	0

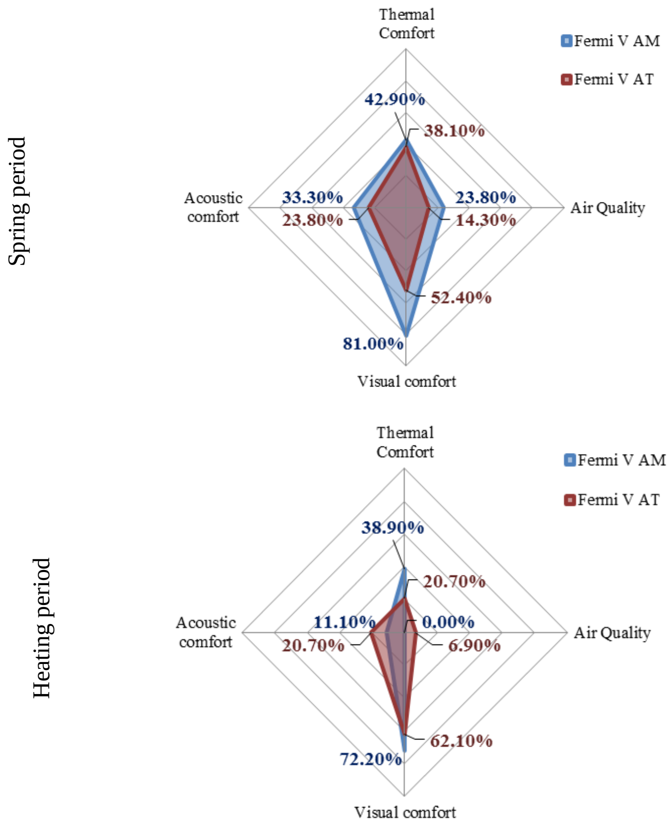

Fig. 3. Percentages of satisfied people: spring (up) and heating periods (down)

In Fig.4 and Fig. 5 it can be seen that during the Spring students sitting next to the windows declare better comfort satisfaction than the ones sitting far from windows while during the heating season the situation is the opposite in VAM with students sitting next to the windows less satisfied than the others. In VAT during the heating period the thermal perception is very uniform over the class, in fact the average votes lay between 2.5 and 4.5. The different sensation over the space could be attributed to the different mean radiant temperature inside the classroom area, but it cannot be objectively pointed out as this parameter was recorded only in the centre of the room.

6. Instrument responses

In addition to the subjective responses, instruments measurements of environmental and illuminance parameters were used in order to make a comparison of the results from the two different approaches. In particular, thermal comfort was assessed through the adaptive model of EN ISO 15251 [15] for the spring period, whereas PMV and PPD indices were calculated according to EN ISO 7730 [3] for both the campaigns. Since the main purpose of this work is the comparison between the objective and the subjective approach used to evaluate comfort, for space reasons details of the recorded indoor and outdoor temperature values are avoided. However, they were considered in the comfort evaluation and in the indices calculation procedures as prescribed by the above mentioned standards.

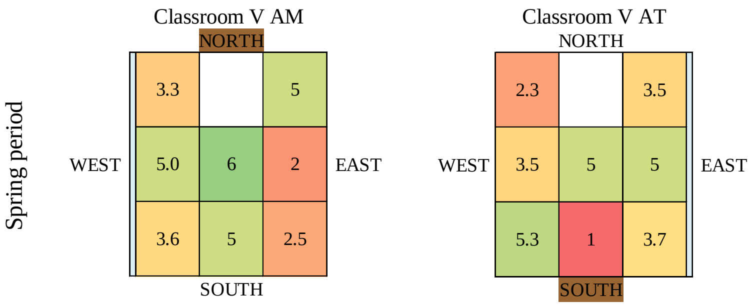

Fig. 4. Map of students votes on thermal comfort inside the classrooms during Spring

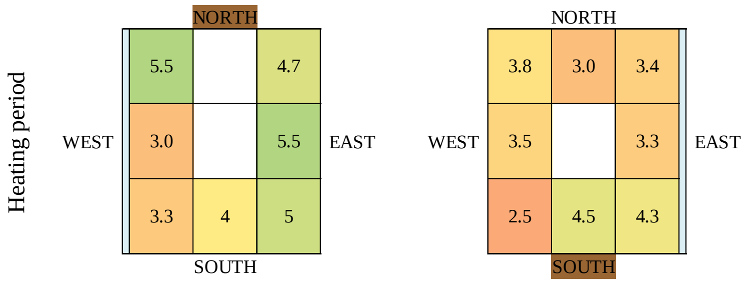

Fig. 5. Map of students votes on thermal comfort inside the classrooms during heating period

Since the upper limit of I Category is 25.83 °C, V AT falls in the I Category of thermal comfort with an operative temperature of 24.65 °C, whereas V AM is excluded by an extremely narrow margin, with an operative temperature of 25.88 °C. This result states that, from the objective data, both the classrooms have a good thermal comfort condition, which is confirmed by subjective responses only in the center of the rooms.

PMV and PPD have been calculated, setting a metabolic rate of 1.2 met, whereas thermal insulation reference was fixed in 0.5 clo for summer, and 0.8 clo for the heating period, according to the average value of clothing index derived from the students answers. As we can see in Table 2, while V AT lays in the I Category of comfort, being PMV values between -0.2 and

+0.2, and PPD lower than 6%, V AM lays in the II Category, with 10 % as predicted percentage of dissatisfied. These results are very far from what is the subjective response even though the relative condition of the two rooms is the same for objective and subjective results.

The daylight illuminance data were also recorded through the lux meter and they have been compared with the students' subjective responses in Fig. 6 UNI EN 12464-1 [19] recommends for school classrooms a maintained average illuminance level ($\bar{E}_m$) of 300 lx. These measurements were conducted during the spring and the heating periods with artificial lights off. Looking at Fig. 6 it is possible to see that despite the low levels of horizontal illuminance students feel a good perception of light quality both at position near the windows and at the ones far from them.

Table 2. Measured PMV, measured PPD (PPDm) and subjective PPD (PPDs)

	Spring period			**Heating period**		
Classroom	PMV	PPDm [%]	PPDs [%]	PMV	PPDm [%]	PPDs [%]
V AM	0.50	10.20	66.70	0.03	5.02	61.10
V AT	0.23	6.10	52.40	-0.05	5.05	44.80

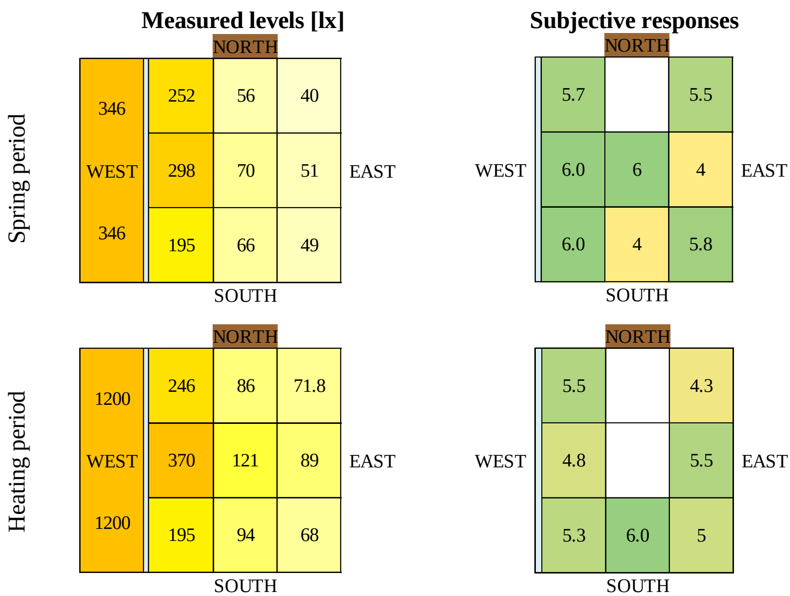

Fig. 6. Comparison between the measured illuminance space distribution (left) and the visual responses distribution inside classroom V AM

7. Conclusion

In the last years, the number of comfort surveys and building monitoring has increased due to the need of the assessment of energy efficiency consequences on occupants wellbeing. However, people satisfaction is not easy to investigate. One of the best investigation methods is surely the collection of people judgement by means of surveys. Direct surveys have some advantages, such as the possibility to collect a large number of questionnaires in a short period, so that responses can have a good statistical representativeness. However, there are some issues occurring in surveys that can be classified at three levels:

- Perception scales. When the aim is the overall indoor environmental quality judgement, including all the four comfort areas, there is the need of using the same scale. In this work a 1 to 7 point scale has been adopted but without giving some kind of definition for each point, so the votes of different people should risk to be different even though their sensation perceived is similar.
- People mood. People answers could depend on the moment during which the questionnaires are filled in, because of their own mood at that particular moment. In this work, some questions about students mood have been inserted. Moreover, people judgement could be related to an instant perception or could be based on a long-term experience of the indoor environment. In this work, different sections have been dedicated to instant and long-term judgment.
- Questionnaires distribution and elaboration. Some other limits of surveys concern the possibility of achieving an overall and long-term classification and certification of the indoor environment. EN 15251:2007 suggests to provide questionnaires at representative times during the year (i.e. spring, summer, fall, winter), but there is no assurance that the subjective perception on one single moment is able to reflect the perception along the whole season.

Next to surveys the instrumental monitoring is a reliable way to capture the building behavior under real use and during dynamic boudary conditions. Measurements are also useful to classify the building according to standard thermal, light, noise, pollution criteria. In contrast a comprehensive monitoring is very expensive and time consuming. That's why it should be preferable to implement measurements on single periods of time in representative rooms and at representative times during the year. What has been shown by this work is that sometimes objective measurements correspond to subjective responses especially in explaining the general trend of the perception. There is still a need of research on the subjective perception under controlled environmental condition in order to improve the knowledge on the correlation between objective environmental parameters and people satisfaction.

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