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Overall Assessment of Indoor Conditions in a School Building: an Italian Case Study

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ABSTRACT: Current standards for indoor comfort are based on studies of adults, but they also apply to children, even though children differ in terms of metabolic rates, clothing types, activity levels, and preferences in space arrangement. Children are also more sensitive to a range of environmental factors, they are usually unable to interact with their environment, and they accept indoor conditions passively. This study aims to extend research into indoor environmental quality (IEQ) for children by providing analysis, measurements and surveys carried out in an Italian primary school. Continuous monitoring was combined with a detailed spot monitoring campaign, during which pupils completed a questionnaire so that subjective and objective evaluations could be compared. Thermal comfort was also evaluated by comparing pupils' sensations based on the two most common approaches: the heat balance and adaptive comfort models. Tests revealed that there was no clear, uniform correspondence between subjective response and acoustic and thermal measurements. Children reacted actively to discomfort, suggesting that they should be allowed to interact with their environment. Building acoustics were also measured in order to evaluate the insulating properties of building elements. The following tests were conducted: façade sound insulation, sound insulation of the vertical and horizontal partitions between classrooms, and the impact levels between overlapped classrooms. Reverberation time and background noise were measured in unoccupied, furnished classrooms after school hours. Impulse response and Speech Transmission Index (STI) measurements were also performed in one classroom.

Key words: Indoor environment, Schools, Comfort, Survey

INTRODUCTION

It is well known that good indoor environmental quality is essential, in particular for work, study or convalescence (Frontczak and Wargocki, 2011; De Carli *et al.,* 2008). Many studies have evaluated the indoor conditions of commercial and educational buildings. Some, however, focused on one or two aspects only (Mendell and Heath, 2005; Bakó-Biró *et al.,* 2008 and 2012; Corgnati *et al.,* 2009; Humphreys, 1977; Trombetta Zannin and Reich Marcon, 2007), while others looked at the various aspects of overall comfort perception (De Giuli *et al.,* 2012; Astolfi A, Pellerey, 2008; Astolfi *et al.,* 2003; Mumovic, 2009; D'Ambrosio *et al.,* 2010). This present study falls into the latter category. Children are particularly sensitive to environmental factors (Mendell and Heath, 2005); for example, low ventilation rates in classrooms can impair pupils' attention and vigilance, lowering memory and concentration (Bakó-Biró *et al.,* 2008). One Italian study on high-school and university classrooms (Corgnati *et al.,* 2009) investigated the possible correlation between physical measurements and subjective response, focusing on thermal sensation only. Comfort sensation is the result of both psychological and physical status; therefore a number of aspects have to be considered when human satisfaction is being evaluated. Furthermore, one of the main problems in determining human satisfaction is establishing the weight of each indoor parameter in overall environmental evaluation (Humphreys, 1977), as environmental factors cannot be considered independently.

The two most common approaches used in existing comfort standards, i.e. heat balance (Fanger, 1970) and adaptive thermal comfort (de Dear and Brager, 1998), were applied and then compared to subjective evaluation (i.e. the questionnaire) to see whether they reflected the children's actual thermal sensation. This comparison was also carried out in a recent study that involved English school-children aged 7-11. The study revealed that both the Predicted Mean Vote (PMV) and the adaptive approach did not correspond to actual personal feelings, as pupil comfort temperatures were about 4°C and 2°C lower than the predictions for the PMV and the EN 15251

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Adaptive Comfort Model (ACM) respectively (Teli, Jentsch, James, 2012).

The main acoustic comfort and intelligibility parameters are reverberation time and classroom background noise (Sato and Bradley, 2008, Chang and Lai, 2007). However, sound insulation from external and internal sources (e.g. traffic and other classrooms) also plays an important role in decreasing background noise (Zannin *et al.,* 2006, Zannin *et al.,* 2009).

Some studies (Sato and Bradley, 2008) have shown the relevance of the Lambert effect in classrooms: the higher the background noise due to sources outside the classroom, the louder the internal noise due to children talking. The same applies to teacher voice-level.

This study is a development of a preliminary study carried out in seven primary schools near Venice (De Giuli *et al.,* 2012). It monitored the indoor microclimatic conditions in four south-facing classrooms of a primary school in Santa Giustina in Colle, a town in northeast Italy, during the last month of school (from May 10 to June 9 2011). The school is in the suburbs [Fig. 1 (a)] on a busy street. It was built in the 1970s, and it has traditional classrooms [Fig. 1 (b)] of about 43 m^2, which are too small for the number of students, as often occurs in Italian schools. The classrooms have windows at the side, fluorescent lights, manually controlled vertical brise-soleil, and a radiator heating system. In addition to the objective approach, 66 nine-to-eleven-year-old pupils were asked to complete a questionnaire about their level of satisfaction with their school's indoor conditions and with other aspects that might influence their perception and judgment of their surroundings (e.g. school appearance, classmates, furniture). Pupils' level of interaction with their environment was also investigated, and they were asked how they reacted to discomfort. They were also asked how often their classroom was aired, its lights were switched on and off, and its blinds raised or lowered to gauge their awareness of energy consumption and whether their teachers changed indoor conditions in accordance with outdoor ones.The differences between classrooms were also investigated, and pupils' gender was taken into consideration. When analyzing this type of data, literature usually employs standard parametric techniques (e.g. t-tests, ANOVA or regression analysis). For this study a Non-Parametric Combination (NPC) testing methodology was applied (Pesarin and Salmaso, 2010).

MATERIALS & METHODS

Monitoring consisted in recording air temperature, relative humidity (RH) and illuminance using HOBO U-12 data-loggers, with a time step of five minutes and a measurement range from -20°C to 70°C for temperature, from 5% to 95% for RH, and from 10 lux to 30000 lux for illuminance. Data logger accuracy is ±0.35°C for temperatures from 0°C to 50°C and ±2.5% (typical) to a maximum of ±3.5% for relative humidity from 10% to 90%. Illuminance is more accurate for relative light levels because it is designed for indoor measurement only. The data loggers were positioned horizontally over the teacher's desk (0.75 m above the floor) from May 10 to June 9 2011. Continuous monitoring was supported by more detailed spot measurements that included plane radiant temperature and mean air velocity, which made it possible to

(a) (b)

Fig. 1. Site location (a), classroom (b)

calculate the PMV and PPD indexes (Fanger, 1982; ISO EN 7730, 2005). Air temperature, radiant temperature, relative humidity and air velocity were measured at the prescribed height of 0.6 m (ISO EN 7726, 1998), using a Brüel & Kjær Indoor Climate Analyzer. Indoor air quality was measured with an AirBoxx IAQ monitor, which recorded CO_2 concentration. Finally, desk illuminance was recorded with a Minolta CL 200 lux meter.

In order to evaluate thermal comfort, the adaptive approach was also applied, since it has been shown that a PMV model can accurately predict comfortable temperatures for HVAC buildings, but not for free-running buildings (de Dear and Brager, 1998). ASHRAE Standard 55-2004 and EN 15251 are the most widely used adaptive assessment thermal charts and they are an alternative to the PMV method. The adaptive thermal comfort diagram, adopted in EN 15251 Annex A (building without mechanical cooling systems), was then used to evaluate whether indoor temperature was acceptable.

The three acceptable ranges for operative indoor temperature, which corresponded to the percentages of satisfied people predicted (90%, 80% and 65% for categories I, II and III respectively) were calculated on a weighted value of the mean running outdoor temperature (20.8°C). These values derive from the mean daily outdoor temperatures on the days preceding measurement. Values were obtained from hourly data recorded by the meteorological station of the local public environmental monitoring service (ARPAV). The operative temperature was calculated for each classroom and compared to the limit values in order to determine which range they belonged to. The three categories of temperature limits for a calculated mean running outdoor temperature of 20.8°C cover the following values: Category I: 23.7°C–27.7°C; Category II: 22.7°C–28.7°C; Category III: 21.7°C–29.7°C.

Reverberation time was measured with a four-channel Svantek 948 real-time analyzer and a noise impulse method was adopted; the impulse source was a balloon bursting. The analyzer recorded the decay of the sound level after the balloon burst and calculated the reverberation time T for each frequency of the spectrum range under investigation. The measurements were made with the rooms furnished and unoccupied (only the operator was present). All measurements were performed as specified in ISO 3382 with at least one source position and six impulse detections in each room. The reverberation time was measured in six classrooms, in 1/3 octave bands from 100 Hz to 5000 Hz.

In one room, further analyses were made with a sine sweep signal in order to obtain information about Definition (D50) and Early Decay Time (EDT) values. The measurement chain was made by a GRASS diffuse field microphone connected to a 01 dB OPUS sound conditioner and a computer with Dirac software.

The measuring procedure for the weighted standardized level difference $D_{nT,W}$, between rooms in a building is specified in ISO 140-4, and the single number procedure in ISO 717-1. The following instrumentation was used for this set of measurements: a four-channel Svantek 948 real-time analyzer with Brüel & Kjær 4188 microphones; a Brüel & Kjær Type 4296 omnidirectional dodecahedron sound source [Fig. 2 (a)]; a LAB.GRUPPEN LAB300 power amplifier; and a Brüel & Kjær 4231 microphone calibrator.

Airborne measurements were taken for three horizontal partitions between classrooms and for three walls separating adjacent classrooms.

Impact level was measured with a normalized Norsonic tapping machine [Fig. 2 (c)]. The sound pressure level in the room below was measured with a four-channel Svantek 948 real-time analyzer equipped with Brüel & Kjær 4188 microphones. Impact level was measured in accordance with ISO 140-7 and the single number rating was calculated in accordance with ISO 717-2.

An outdoor directional loudspeaker was used to establish the weighted standardized level difference of the façade, $D_{2m,nT,W}$ [Fig. 2 (b)]. The source signal was a pink noise generated with NTI Minirator audio generator. Measurements were taken in accordance with ISO 140-5 and the single number rating was calculated in accordance with ISO 717-1.

The outdoor noise level was measured two meters from the façade with a single channel Svantek 949 real-time analyzer. The indoor levels were measured with a four-channel Svantek 948 real-time analyzer with Brüel & Kjær 4188 microphones.

Intelligibility measurements were taken with a NTI TalkBox loudspeaker. The TalkBox provided a test signal that simulated a human speaker generating a sound pressure level of 60 dB(A) measured one meter in free field in accordance with IEC 60268-16. The STI parameter was measured with an NTI XL2 Analyzer. The loudspeaker was positioned on the teacher's desk to simulate the teacher speaking [Fig. 2 (d)], and the measurements were taken over students' chairs at around 1.2 m from the floor (approximate height of seated children's ears). Measurements were taken in an unoccupied, furnished classroom.

Measurements were linked to a bespoke questionnaire designed with psychologists and statisticians in order to obtain a child-friendly instrument.

(a) (b) (c) (d)

Fig.2. Acoustic measurements: a) airborne sound insulation; b) façade sound insulation; c) impact level; d) STI

The questionnaire investigated building-related aspects (e.g. space, furniture), indoor conditions, occupant-building interaction (how often windows were opened, lights were switched on/off and blinds were raised and lowered) and reaction towards any discomfort. Both teachers and children completed the questionnaire. Teachers were also asked additional questions (e.g. on Sick Building Syndrome (SBS) symptoms). The traditional seven-point rating scale used in UNI EN ISO 10551:2002 and in ASHRAE Standard 55 for thermal sensation was reduced to a five-point scale. For all of the questions concerning satisfaction and frequency of discomfort, a pair of four-point scales was preferred to the recommended five- or seven-point scales. There were two reasons for this: the first was to simplify the questionnaire and the second was to remove the central neutral answer so as to allow a clear distinction between positive and negative responses. The questionnaire answers were analyzed with Non-Parametric Combination (NPC) methodology (Pesarin and Salmaso, 2010; Basso et al. 2009); this multivariate system is an inferential technique based on both permutation tests and Non-Parametric Combination methodology. The four classrooms selected were then compared in order to find any significant differences in terms of p-value (a p-value below 0.05 means there is a significant difference).

RESULTS & DISCUSSION

Microclimatic parameters (air temperature, relative humidity, plane temperatures and air velocity) were processed in order to evaluate Fanger's thermal comfort indexes (PMV and PPD) in line with International Standard ISO 7730 and EN 15251. During the evaluation of these indexes, the metabolic rate was set at 1.2 met (sedentary activity), with clothing taken from the questionnaire (0.5 clo). As regards PMV and PPD values (Table 1), the specifications of EN 15251 placed all the classrooms into the most unsatisfactory category, Category IV ($PMV<-0.7$ or $PMV>0.7$); the only exception was Classroom 4B, which fell into Category III ($-0.7<PMV<0.7$). However when adaptive comfort criteria were applied, Classroom 4B was the most uncomfortable one, as it fell into Category III, while all the other classrooms came under Category II.

CO_2 concentration above outdoor did not exceed the basic requirement of 1500 ppm in any of the classrooms because the windows were open. In accordance with EN 15251, all of the classrooms fell into Category I (CO_2<350 ppm), the top one, except Classroom 4B, which fell into Category IV (CO_2>800 ppm), the bottom one.

All of the classrooms, except 5A, failed to meet the minimum illuminance requirements (300 lux). Lighting, however, was switched off in these classrooms, but it was on in 5A; consequently the lighting system should be sufficient to provide the required illuminance over all of the desks. The maximum illuminance values were very high: over 4000 lux in some cases due to daylight. Illuminance, however, was not uniform in each of the classrooms and this contributed to visual discomfort. The lowest values were recorded in Classroom 5B, where the maximum illuminance was around 1000 lux. Illuminance uniformity is necessary for visual comfort and uniformity in Classroom 5A is more than twice that in all the other three classrooms, due to both daylight and electric lighting.

Fig. 3 compares pupils' actual thermal comfort (percentage of pupils who answered "I feel too cold, cold, etc.") and indoor and outdoor conditions (operative temperature, air temperature and outdoor temperature).

The values for pupils' thermal comfort confirm its subjective nature when they are compared to the operative temperature. Although Classroom 4B had the highest percentage of pupils who felt thermal discomfort (around 60% answered "too hot") and the highest operative temperature (28.8°C) there is no clear,

Table 1. Microclimatic parameters, comfort indexes and indoor conditions during the day of monitoring

classroom	4A	4B	5A	5B
n.boys	13	8	5	4
n.girls	8	10	9	9
time	12:20 AM	11:50 AM	11:20 AM	10:40 AM
t_{air} (°C)	28.2	28.8	27.6	27.1
RH (%)	43	54	50	50
t_{op}(°C)	28.5	28.8	27.8	27.4
Θ_{rm} (°C)	20.8	20.8	20.8	20.8
PMV	-0.89	-0.52	-1.03	-1.54
PPD	22	11	27	53
v_{air}(m/s)	0.09	0.1	0.04	0.16
CO_2 (ppm)*	187	1001	145	140
CO	2.594	2.919	2.561	2.793
VOC (ppm)	0.018	0.025	0.023	0.031
E_{min} (lux)	227	182	393	92
E_{max} (lux)	4103	4539	1952	1057
E_{mean} (lux)	1274	1014	894	431
$E_{st\ dev}$ (lux)	1231	1095	580	362
door	open	close	open	open
windows	open	open	open	open
lighting	off	off	on	off

Key: t_{air}= air temperature; RH= relative humidity; t_{op}= operative temperature; Θ_{rm}= running mean temperature; v_{air}= air velocity; * CO_2 concentration above outdoor concentration; E_{min}= minimum illuminance; E_{max}= maximum illuminance; E_{mean}= mean illuminance level; $E_{st.dev}$= standard deviation of illuminance

uniform result for all of the classrooms. For example, the operative temperature was lower in Classroom 5A than in Classroom 4A, but more pupils complained in 5A than in 4A.

As regards long-term measurements, the air temperature and relative humidity are shown in Fig. 4 and Fig. 5 respectively, as are the outdoor values obtained by the ARPAV meteorological station. Indoor temperatures were similar in all the classrooms, with a maximum deviation standard of 0.9°C; Classroom 4A had the highest value (Fig. 4). No significant differences were found when pupils' thermal sensation was compared at scheduled points over the measurement period, not even when analysis was stratified by gender.

The requirements for classroom reverberation times are established by Italian law; the reverberation time is supposed to be less than 1.2 s, the average value over the octave frequency bands of 250, 500, 1000 and 2000 Hz with only two people in the room (Ministerial Circular no. 3150). A reference value for reverberation time is also given in ISO 11367, Annex C, where the optimum reverberation time in a room is related to the room's purpose (listening to speech or music performances); a reference value is also given for volume, according to the following relationship: T_{ott} = 0.32 log(V) + 0.03 [s] (unoccupied room used for speech). T_{ott} should be compared to the average reverberation time over the octave bands from 250 Hz to 4000 Hz. The reverberation time frequency values should not exceed 1.2 T_{ott}.

All of the classrooms had the same volume, i.e. 130 m^3, which leads to an optimum reverberation time of 0.7 s. This reference value is similar to the 0.6 s given by ANSI S12.60-2002. Reference values are significantly lower than the Italian legal limit of 1.2 s (average value from 250 Hz to 2000 Hz).

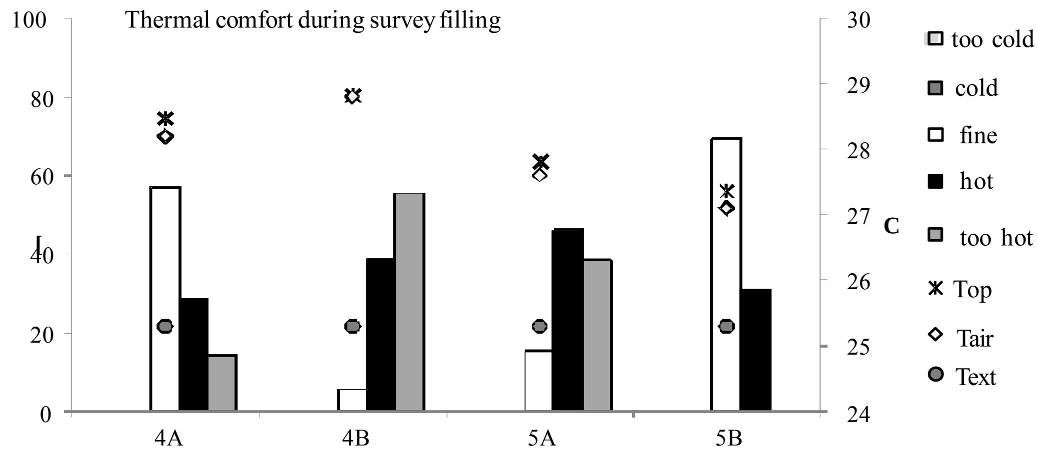


Fig. 3. Pupils' thermal sensation, related to measured operative and air indoor temperature and external temperature, during survey filling

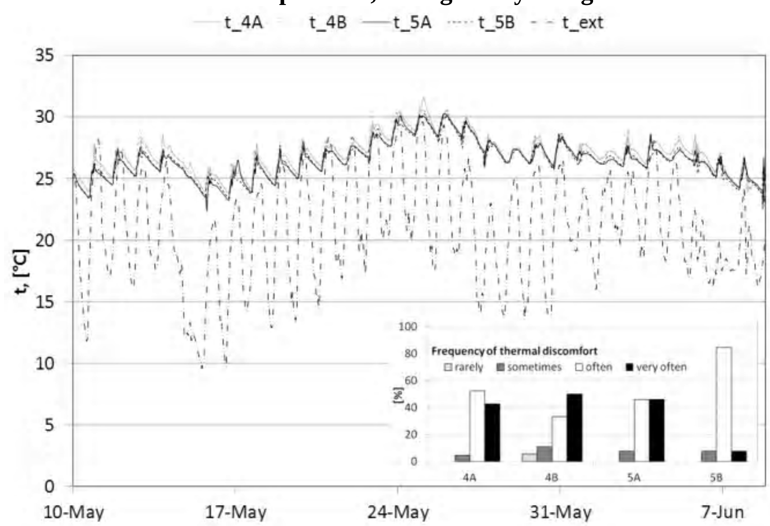


Fig.4. Frequency of pupils' thermal comfort related to air temperature profiles

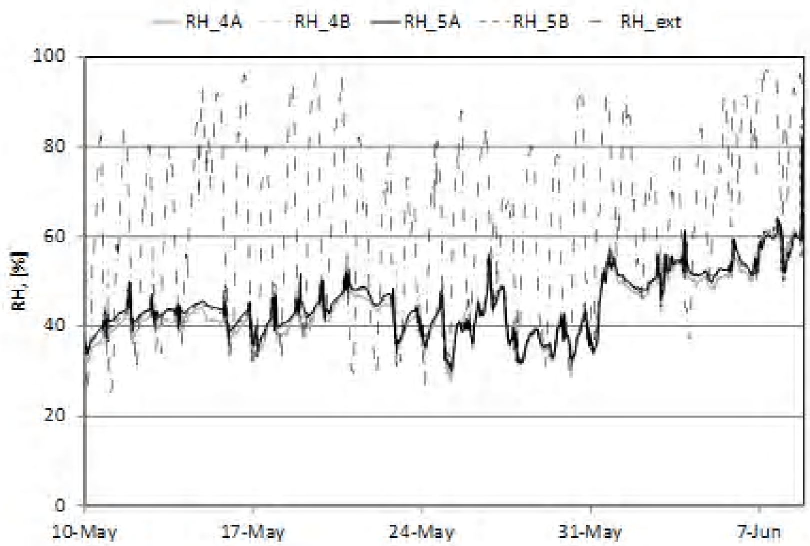


Fig.5. Relative humidity profiles of the four classrooms and outside values

Regarding the acoustic requirements for school buildings, Italian law (Prime Minister's Decree DPCM 5/12/97) envisages minimum sound insulation only for the façade and the building elements that separate classrooms from non-classrooms in the same building. The minimum value of the $D_{2m,nT,W}$ index for the façade is 48 dB. This value is extremely high and difficult to reach, even in recently built schools. There are no limits, however, for sound insulation between classrooms in the same building.

In July 2010, Italian Standard UNI 11367 set a range of reference values for school buildings that also took into account the internal partitions between classrooms; this standard gives two different classes of performance, with basic and superior reference values.

Table 2, Table 3 and Fig. 6 show that reverberation time exceeded the average limit of 1.2 s in every classroom.

Speech Transmission Index (STI) values measured in one classroom ranged from 0.48 to 0.58 (fair intelligibility), with an average of 0.52. This value only takes into account room size and reverberation time and not background noise, which is greater in an occupied room. The equivalent sound pressure of the NTI TalkBox (sound source used for STI measurements with the same directivity as the human voice) at the receiver positions varied from a maximum of 64.1 dB(A) to a minimum of 61.6 dB(A).

Building acoustics (D_{nTW}, L'_{nW} and $D_{2m,nT,W}$) are shown in Table 4 and compared to the reference values of Italian Standard UNI 11367, Annex A.

Table 2 . Room acoustic parameters measured in one classroom using sine sweep signal

***frequency* [Hz]**	63	125	250	500	1000	2000	4000	8000
***D*50 [dB]**	0.38	0.28	0.46	0.42	0.40	0.38	0.42	0.56
***T*20 [s]**	2.05	1.92	1.33	1.46	1.54	1.53	1.37	0.93
***EDT* [s]**	2.17	1.69	1.21	1.45	1.54	1.55	1.32	0.92

Table 3. Reverberation time measured with interrupted method. Frequency average values and reference values

	Measure n°1	Measure n°2	Measure n°3	Measure n°4	Measure n°5	Measure n°6	
Mean value 250-2000 Hz	1.8	1.7	1.7	1.6	1.3	1.4	*T* (M.C. n.3150) 1.2
Mean value 250-4000 Hz	1.7	1.7	1.7	1.5	1.3	1.4	T_{ott} (UNI 11367) 0.7

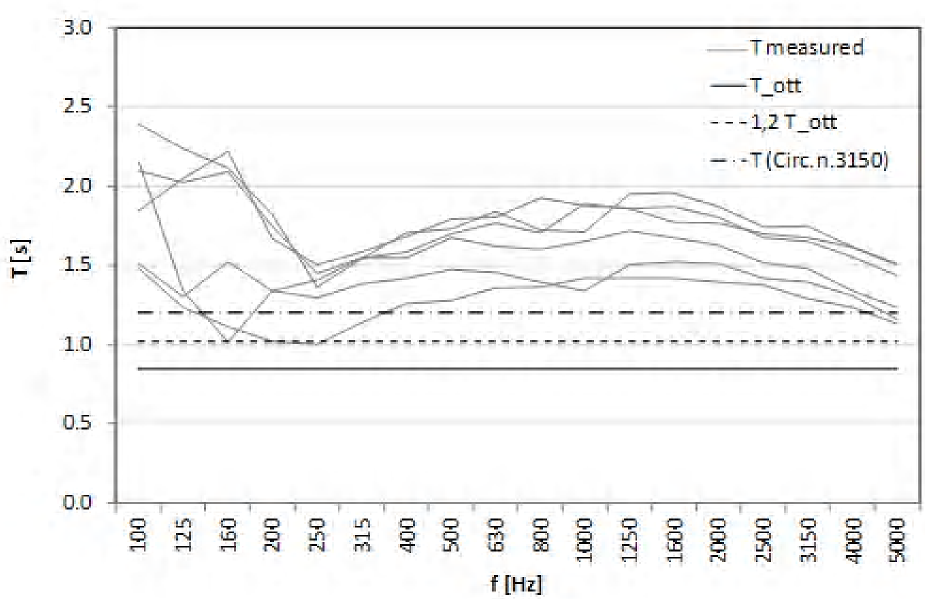


Fig.6. Frequency values of reverberation time measurements, Italian reverberation time limit (M.C. n.3150) and reference value (UNI 11367, Annex A)

Table 4. Building acoustic measurement results and reference values given in UNI 11367 Standard, Annex A

	Measure n°1	Measure n°2	Measure n°3	Arithmetic mean value	Basic performance UNI 11367	Superior performance UNI 11367	Lower limit (DPCM 5/12/97)
$D_{2m,nT,W}$ [dB]	22 (28*)	32	33	29	38	43	48
$D_{nT,W}$ (walls) [dB]	43	44	45	44	45	50	/
$D_{nT,W}$ (floors) [dB]	48	48	48	48	50	55	/
L'_{nW} [dB]	76	73	78	75.7	63	53	/

* with external vertical brise-soleil completely closed

The average value of façade sound insulation was nearly 10 dB lower than the reference value envisaged by Italian Standard UNI11367 and nearly 20 dB below the limit envisaged by Italian law. This is due to the poor sound insulation of the school's single-glazed windows.

The equivalent mean A-weighted sound pressure level of background noise was evaluated starting from levels recorded during the measurement of building acoustics, and the value was 35 dB(A) in unoccupied rooms (after school hours) with the windows closed. Consequently, outdoor noise does not seem to cause high levels of disturbance inside the classrooms, despite the façade's poor sound insulation.

The weighted standardized level difference of walls and floors are, respectively, 1 dB and 2 dB lower than the basic reference values of Italian Standard UNI 11367. Impact sound insulation is particularly poor, as it was 12 dB below the basic reference value for the same standard.

The questionnaire was analyzed with a non-parametric statistical evaluation method that used a C-sample comparison for the four classrooms. Air quality (pvalue < 0.0001) was the only factor that stood out in the frequency of discomfort questions; however when a multivariate test was performed (i.e. one that takes into account all the questions on the same topic), the classrooms differed significantly (Table 5). Further statistical analysis was performed to account for gender. The only discomfort among the boys concerned daylight, while the girls were more worried by thermal comfort in the heating period and by air quality. Actual thermal sensation was found to differ significantly within both groups and even when gender was not considered.

Fig. 7 and Fig. 8 show the frequency of discomfort and the frequency of occupant-building interaction in terms of airing, switching lights on/off and raising/ lowering blinds. The percentage indicates the sum of the answers given to "often" and "very often" in order to assign each classroom an overall value, and thus rank them ("Top 2 Box" metric, Morgan and Rego, 2006). Descriptive analysis revealed that the main problem was thermal comfort during the non-heating season (over 80% dissatisfaction in all classrooms), but acoustic discomfort was also considered to be a major problem (around 40% dissatisfaction).

No significant differences were found between the classrooms for occupant-building interaction questions (Fig. 8). Electric lights were on for at least 40% of the entire school year, with peaks of 80% in Classroom 5A); lights, however, were switched off when they were not needed (e.g. during breaks and at the end of the school day), revealing that the occupants were energy conscious. Blinds were raised or lowered in accordance with weather conditions; they were lowered when solar radiation was excessive ("blind down") and raised when there was no more visual discomfort ("blind up"). Finally, opening the windows to air a classroom was frequent in all classrooms during breaks, during class and in the non-heating season.

Pupils were asked how they behaved when faced with discomfort, and their reactions were analyzed. The most frequent reactions to discomfort were: "I ask the teacher to open the windows", for poor air quality; "I wear my jacket", for draughts; and "I ask the teacher to repeat", for difficulty hearing the teacher. Where pupils differed most was their reaction to blackboard visibility, probably the most important classroom requirement. The pupils of Classrooms 4A and 5B moved their desk; the pupils of 4B ask the teacher to turn on the light; and the pupils of 5A asked a classmate in front of them to move. The percentage of pupils who reacted passively, answering "nothing", is shown in Fig. 9. The most passive reaction—a peak of 60% in Classroom 5A—was towards desk illuminance, probably because pupils are unable to improve the lighting.

Finally, Fig. 10 shows that there was a greater number of "passive users" among boys than among

Table 5. Significant differences among the classrooms, taking into account the gender

Item	all		boys		girls	
building-related aspects						
Classroom appearance	< 0.01	< 0.01	n.s.	n.s.	n.s.	n.s.
School mates	n.s.		n.s.		n.s.	
School building appearance	n.s.		n.s.		n.s.	
Classroom size	< 0.05		n.s.		n.s.	
Easiness to move	n.s.		n.s.		n.s.	
chair	< 0.01		n.s.		< 0.05	
desk arrangement	n.s.		n.s.		< 0.05	
actual thermal sensation	< 0.001		<0.001		< 0.05	
frequency of discomfort						
thermal comfort in heating period	n.s.	< 0.05	n.s.	n.s.	< 0.05	< 0.05
thermal comfort in free-runnig conditions	n.s.		n.s.		n.s.	
air quality	< 0.0001		n.s.		< 0.001	
air draughts	n.s.		n.s.		n.s.	
visual comfort: electric light	n.s.		n.s.		n.s.	
visual comfort: daylight	n.s.		<0.05		n.s.	
acoustic comfort	n.s.		n.s.		n.s.	
Reactions to discomfort						
poor air quality	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
air draughts	< 0.05		n.s.		< 0.05	
poor blackboard visibility	n.s.		n.s.		n.s.	
low desk illuminance	n.s.		n.s.		n.s.	
bad hearing the teacher	n.s.		n.s.		n.s.	

Key: n.s.: not significant

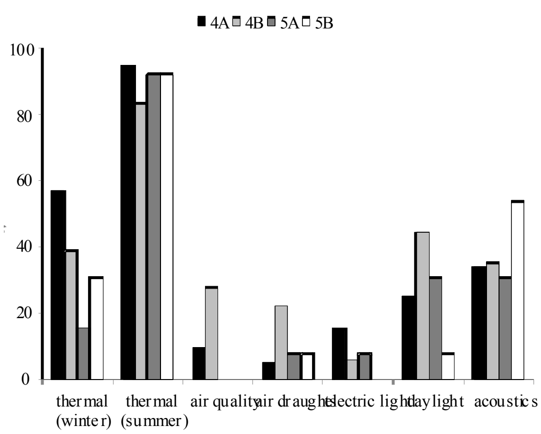


Fig . 7. Frequency of discomfort (a) and (b)

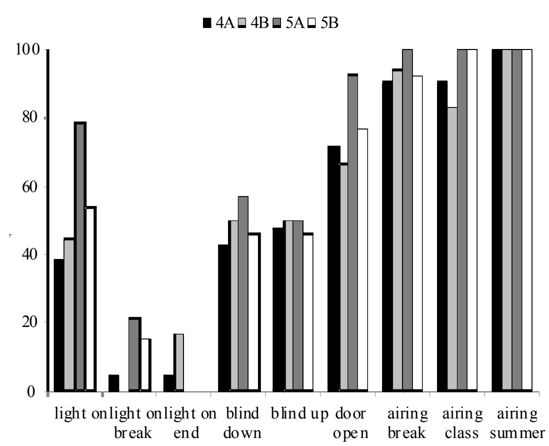


Fig. 8. Frequency of air changing, light and shading operation

girls. These figures mirror the results from studies on adults, but further analysis needs to be performed for children since expectations and requirements differ by gender in developmental age as well as in adulthood. Analysis of student answers to noise frequency questions ("How often do you hear disturbing noises during lesson hours?") revealed that only 18% of respondents were unaffected by noise; this result confirms the poor results for the façade's sound insulation and for the floors' impact sound insulation [Fig. 11 (a)]. Conversely airborne sound insulation values are very near to the recommended basic performances; however, we must take into account that sound insulation between adjacent classrooms is often impaired because teachers leave doors open during lessons (Fig. 8). These factors explain why the answers on noise origin point to corridors and adjacent classrooms as the biggest sources of disturbance [Fig. 11 (b)]. Other studies have also pointed to nearby classrooms as the main cause of disturbance in schools (Zannin and Marcon, 2007, Chiang and Lai, 2008).

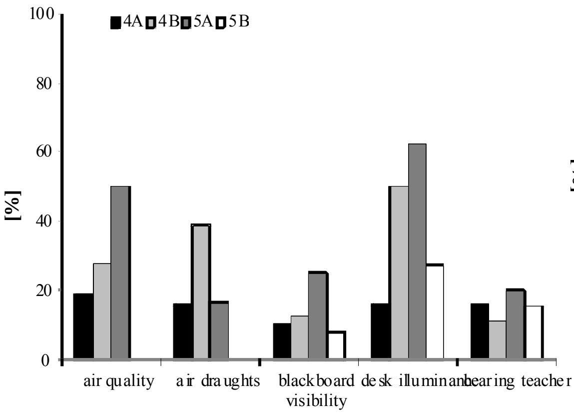


Fig. 9. Percentage of "passive pupils"

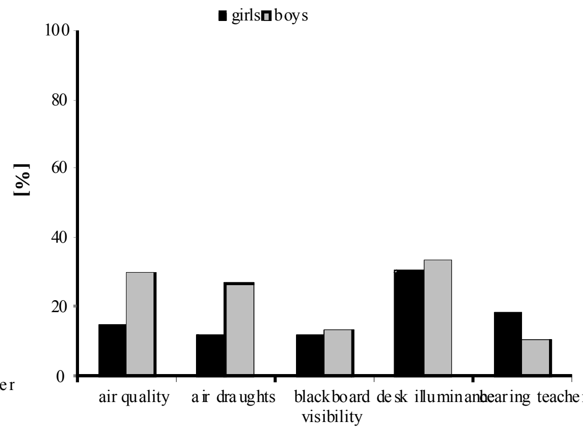
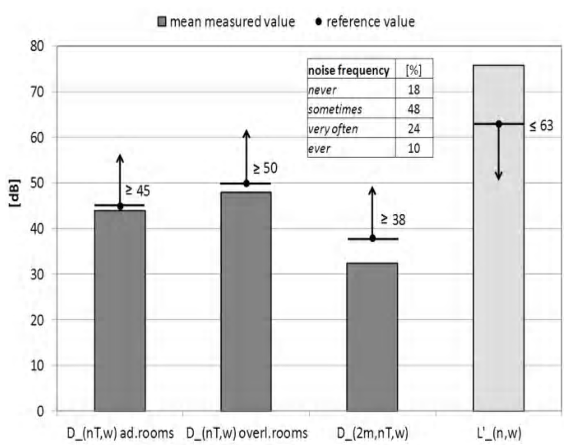
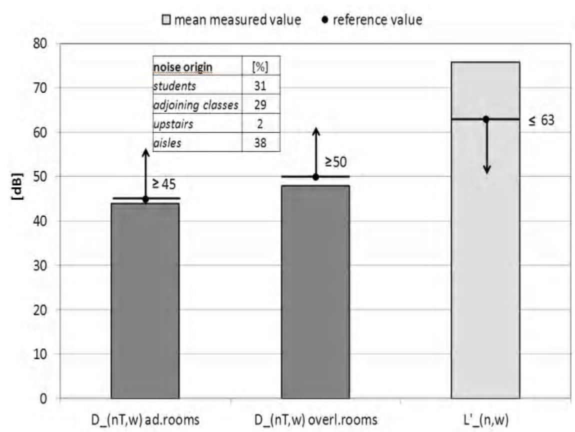


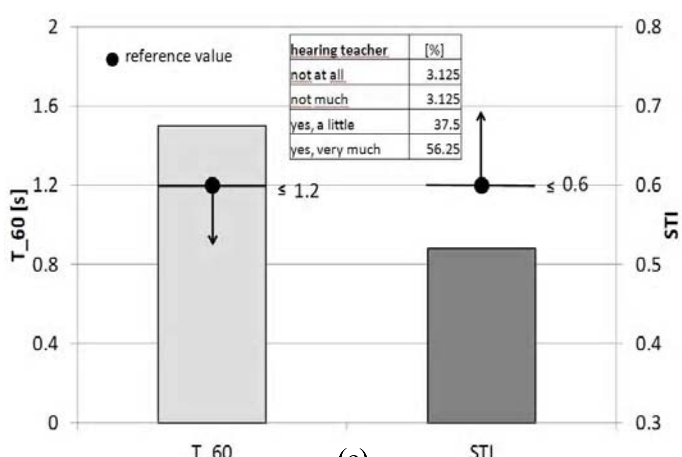
Fig.10. Percentage of"passive girls" and "passive boys"



(a)



(b)



(c)

Fig.11. Correlation between objective and subjective measurements (arrows direction indicate better values)

Few pupils complained that they could not hear the teacher despite the high reverberation time and the fair intelligibility level [Fig. 11 (c)]. When pupils were unable to hear the teacher, many asked the teacher to repeat what had been said, which suggests that they reacted actively to the problem.

CONCLUSION

This study investigates the indoor environmental conditions of an Italian primary school by means of spot and long-term measurements in free-running conditions and by means of a detailed questionnaire administrated to pupils. The questions dealing with pupils' reaction to discomfort helped us to understand whether children would change their indoor conditions if they could. This study revealed that they did not open or close windows, or change desk position of their own accord, but accepted their condition and the arrangement of their classroom. The study also showed that a high number of pupils reacted actively to discomfort; therefore being able to interact with their surroundings would enhance the wellbeing of both children and adults.

There was no clear uniform correspondence when the predictions made with the two most common approaches to current comfort standards (heat balance and the adaptive comfort model) were compared with pupils' actual thermal sensation.

The school being studied was built at the end of the 1970s and it has never undergone any major renovation work. The building has poor façade airborne sound insulation and floor impact sound insulation due to the way it was designed and constructed. The acoustic insulation between adjacent rooms is very close to the basic reference value envisaged by UNI 11367, but this insulation is reduced because the teachers tend to leave doors open during lessons, a factor that causes interference due to noise from surrounding classrooms.

Reverberation time is quite high in all classrooms, as there is lack of absorbent materials; we recommend a plasterboard ceiling be installed to reduce both reverberation time and impact noise levels.

The impression that pupils have of classrooom intelligibility is better than the reverberation time and STI measurements suggest. This is probably due to the fairly small classrooms, which results in there being shorter distances between teacher and students and in a prevalence of direct sound energy over reflected sound.

The methodology of this case study needs be improved if a strong correlation between the two approaches, one objective and one subjective, is to be found between all the IEQ factors, not only thermal comfort. A measuring campaign also needs to be undertaken in the heating period to gauge whether building behavior and children's perception change with the season. Air quality is an essential aspect for wellbeing and performance; therefore continuous monitoring for CO_2 concentration also needs to be carried out. Although this study is by no means complete, it is a first step towards evaluating occupant-building interaction and the need for repairs from both objective data (i.e. measurements) and occupants' expectations so that more people-centered schools can be built in the future.

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