INDOOR AIR QUALITY IN CLASSROOMS: FIELD CAMPAIGN BY QUESTIONNAIRES AND MEASUREMENTS

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ABSTRACT

A research project aimed at investigating IAQ and thermal, acoustic and visual comfort was carried out in Italian high school and university classrooms. The investigations were performed through field campaigns during regular lesson periods consisting of subjective surveys and measurements.
This work focuses in analysing the results from the IAQ investigations at four high schools of *Provincia di Torino* during the heating period. Measurements were addressed to evaluate the air change rate through the tracer gas technique, the air permeability of the building envelope through the blower door technique and the indoor air quality through monitoring the CO_2 concentration. Results from measurements were compared with the requirements from Italian standards and regulations for school buildings. At the same time, questionnaires were filled by students in order to qualify the perceived air quality.

KEYWORDS

High schools, indoor air quality, field campaign, measurements, subjective surveys.

INTRODUCTION

Indoor air quality (IAQ) is one of the major issues to satisfy in school building and students are very sensible to this environmental aspect.
Within a wide research project about global environmental comfort in Italian university and high school buildings (Corgnati et al, 2003; Corgnati et al, 2004), a specific study was dedicated to indoor air quality in classrooms.
In particular, this work shows the results from a field campaign performed at four high schools of the *Provincia di Torino* (Astolfi et al, 2003).
The field campaign was performed during regular lesson periods (morning or in the first part of the afternoon) and it consisted of both subjective surveys and measurements. Students judged IAQ in terms of air pleasantness and odour perception (human odours, smoke, chemical odours). At the same time, the outdoor and indoor CO_2 concentrations were measured and the CO_2 increase (ΔCO_2) was used as an objective indicator of the air quality. The Fanger's relationship expressing the percentage of dissatisfied people (PD) as a function of the ΔCO_2 concentration (CR 1752, 1999) was calculated and compared with the subjective answers.
Moreover, both the number of air changes per hour (ACH) and the envelope air permeability were measured. ACH was evaluated using the tracer gas technique (decay method), while the envelope air permeability was estimated by the blower door pressurisation method.
Results from measurements were compared with the requirements concerning ventilation and IAQ from Italian standards and regulations.

CLASSROOMS DESCRIPTION

The analysed classrooms were selected in order to give a representative sample of typical high school Italian classrooms. All the classrooms are medium-sized and parallelepiped shaped.
The four examined high schools are located three in Turin suburban city settings (“C. Levi”, “B. Vittone” and “A. Gramsci”) and one in Turin downtown (“Regina Margherita”). They are naturally ventilated and equipped with water- heating systems (radiators): this is the most typical configuration for Italian classrooms. The main characteristics of the analysed classrooms are summarised in table 1.
The study was performed during the heating period, which in Turin ranges from October 15th to April 15th. In particular, the investigations were carried out from the end of January to April. Turin is in the North West part of Italy at the foot of the Alpes. It has a continental climate, characterised by cold-dry winter and hot-humid summer. In particlar, during the heating period the mean outdoor temperature and mean irradiace on a horizontal surface are respectively 5.6°C and 90 W/m^2. The details about the climate conditions during the measuremets are given in the following chapter.

TABLE 1 - Main characteristics of analysed classrooms

School		Classroom	NS	NST	V [m^3]	F [m^2]	H [m]	W/F	EXP	WA [m^2]
High-school	C. Levi (Le)	4B	22	21	224	68	3.3	0.08	O	5,30
		2C	18	17	181	55	3.3	0.10	E	5,44
		LAB	20	17	276	84	3.3	0.07	E	5,44
	Regina Margherita (RM)	3 BL	18	17	222	54	4.1	0.20	S	10,80
		4 DB	22	22	258	63	4.1	0.18	E	10,70
		5 AL	22	21	219	54	4.1	0.20	E	10,28
		LAB	15	12	230	56	4.1	0.31	E; N	17,47
	B. Vittone (Vit)	2 D	20	20	166	55	3.0	0.17	N	9,52
		3 C	24	23	166	55	3.0	0.17	S	9,52
		LAB	25	23	332	100	3.3	0.16	O	17,56
	A.Gramsci (Gra)	1 A	22	22	138	46	3.0	0.17	NNE	8,60
		3 B	28	27	138	46	3.0	0.17	SSO	8,60
		LAB	15	14	292	97	3.0	-	-	9,7

NS = number of seats
NST = number of students
V = volume [m^3]
F = floor area [m^2]
H = height [m]
W/F = glassed area / floor area
EXP = windows esposure
WS = windows area [m^2]

VENTILATION

A field campaign for the measuring air change rate was performed in six classrooms of the examined school buildings using the tracer gas decay technique, employing SF_6 as tracer gas (ASTM, 1995).
The results were elaborated in order to obtain the local mean age of the air and the number of air change per hour. The analysis was performed with windows both opened and closed. All the classrooms are naturally ventilated (Brager et al, 2000). As a consequence, the air change rate depends on the climatic conditions of the site: the average conditions of the indoor and outdoor air during the measurements in the investigated classrooms are summarised in table 2. In figure 1 the results with closed windows, that is the typical winter configuration during lesson periods, are shown and compared to the values suggested by the Italian standard UNI 10339 (1995) (defining the ACH per person at 24 m^3/h for school buildings) and regulation D.M. 18/12/1975 (fixing the number of ACH at 5).
In figure 2, the changing of the air change rate with the number of opened windows is shown for

classrooms Le 4B. The windows have the same dimensions, 0,94 m of width and 0,94 m of height. As shown in figure 1 and 2, in the typical winter configuration with all the windows closed, the air change values prescribed by the Italian standard and regulation are not satisfied. The measured ACH maintain always below 1, except in Le 4B having 1,2 ACH. Such values are highly lower than the requirements.

TABLE 2 – Indoor and outdoor air: average conditions during measurements

Classroom	Indoor			Outdoor		
	T	RH	v	T	RH	v
	[°C]	[%]	[m/s]	[°C]	[%]	[m/s]
RM 4DP	25,1	35	0,07	9,1	71	0,85
RM 3BL	24,8	33	0,06	9,1	71	0,85
Vit 2D	24,5	46	0,04	20,4	62	2,16
Gra 3B	24,4	32	0,07	9,7	25	1,28
Gra 1A	26,4	21	0,05	9,7	25	1,28
Le 4B	27,0	32	0,03	7,6	81	1,41

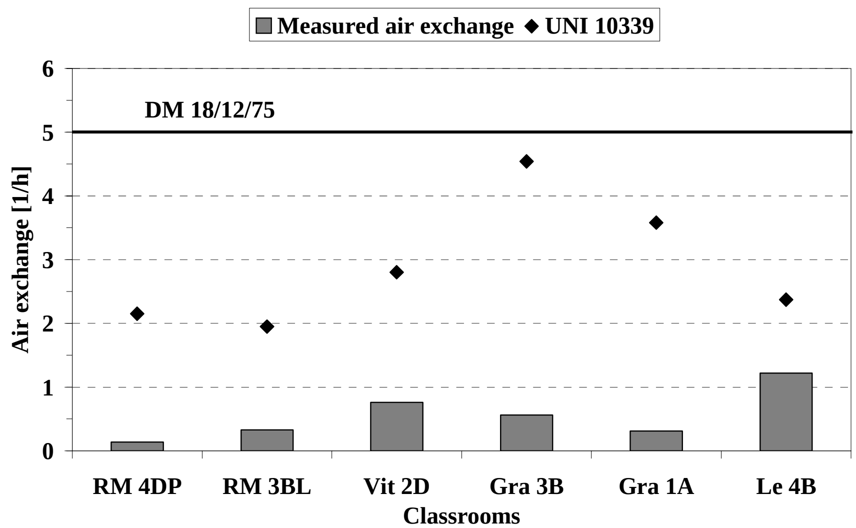

Figure 1 – Windows closed: measured air exchange and standard requirements

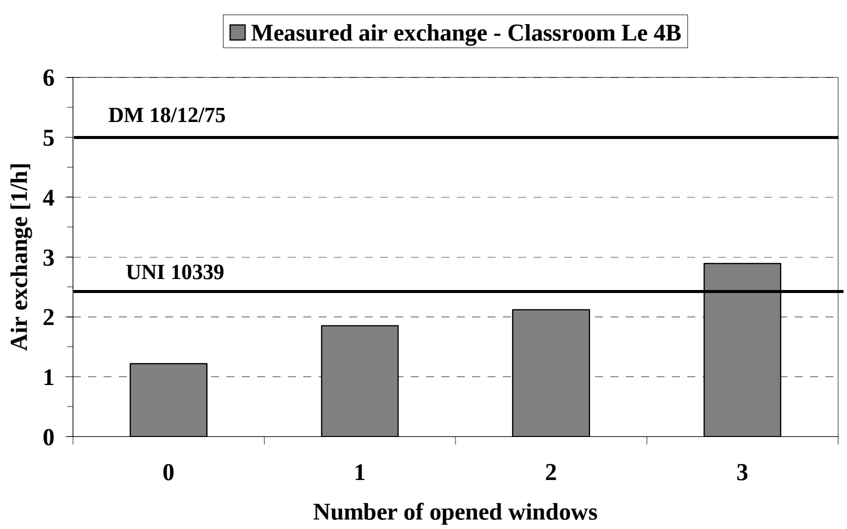

Figure 2- Le 4B with opened windows: measured air exchange and standard requirements

Results in figure 2, referring to classroom Le 4B, show that only with 3 opened windows the ACH prescribed by standard UNI is overcome. The 5 ACH required by D.M. 18/12/75 are never met.

AIR PERMEABILITY OF THE BUILDING ENVELOPE

The air permeability of the building envelope was investigated in one classroom for each school building, using the “blower door” pressurisation technique (Charlesworth, 1988). Through such a technique, the relationship between indoor-outdoor pressure difference Δp and air flow rate V’ is obtained, so that the properties of the building envelope in terms of air permeability may be highlighted.
The measured experimental points (see Figure 3) were interpolated by an expression like

$$V' = C\ \Delta p^{\alpha}$$

where C is the global air permeability of the building envelope and α is the flow coefficient, set at 0,67 in the performed analyses. The presented data refers to the configuration with all the windows closed.
The obtained results confirmed the ones concerning the measurement of the air change rate in the classrooms. In fact, classrooms RM 3BL shows the lowest air permeability (and the minimum value of air change per hour) while classroom Le 4B shows the higher air permeability (and the maximum value of air change per hour).

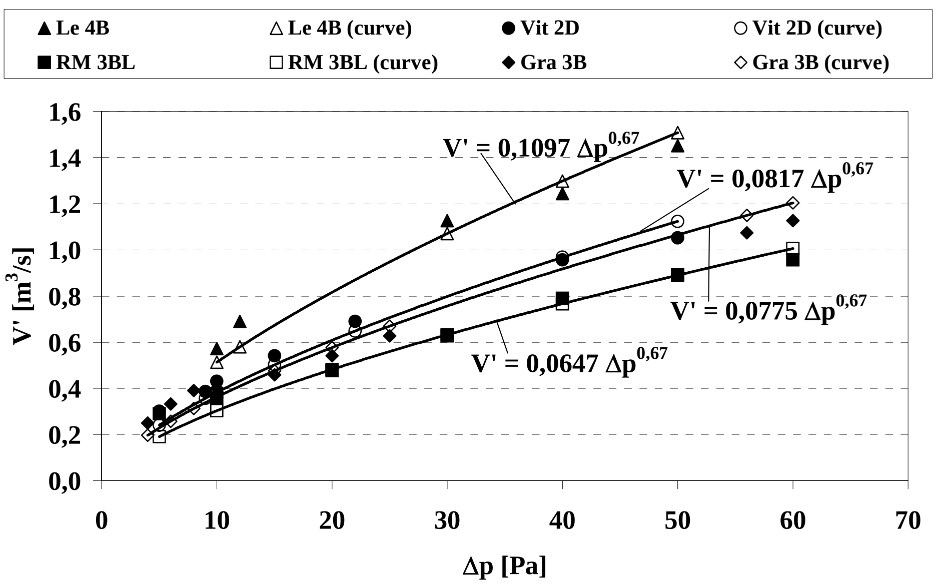

Figure 3 – Air flow rate vs. Pressure difference: results from the “blower door” pressurisation technique with closed windows

From results in figure 3, it can be calculated that a pressure difference of 1,6 Pa and 2,6 Pa are required respectively in classrooms Le 4B and RM 3BL to ensure the air change per hour according to Italian standard UNI 10339; such values increase respectively to 4,8 Pa and 10,3 Pa to ensure the air change per hour required by Italian regulation D.M. 18/12/1975. But in the analysed sites, for typical climatic conditions, the Δp values are lower than 1 Pa.

AIR QUALITY

People are the main contaminant source within a classroom. As a consequence, the CO_2 concentration level can be taken as a good indicator of the bio-effluent emission from occupants and, as a consequence, of the indoor air quality.

This is confirmed by the results of the questionnaires filled by the students about the air pleasantness (a vote ranging from 1 to 5 was assigned) and the odour perception (human odours, smoke, chemical odours). It was verified that the odour most frequently perceived in classrooms was the one from human bodies, even if other odours, like chemical and tobacco smoke odours, are considered more annoying (see figure 4).

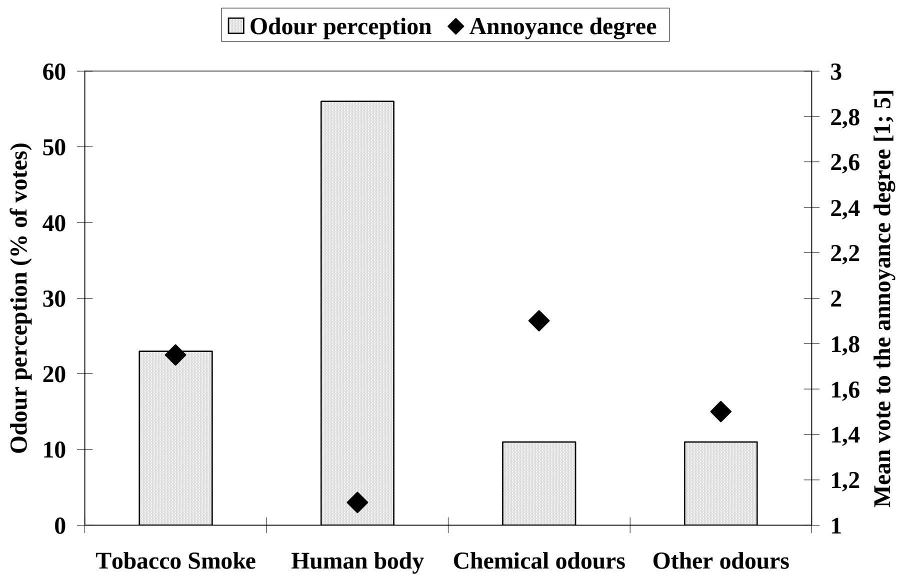

Figure 4 – Odour perception and annoyance from questionnaires (vote 1 = minimum annoyance)

As a consequence, the bio-effluent emission is traced by the CO_2 concentration level, which depends from the person activity level: for sedentary school work it is around 22 l/h per person. According to standard CEN 1998 [7], the maximum acceptable increase of the CO_2 concentration with respect to the outdoor background CO_2 concentration level is 660 ppm, corresponding to a percentage of dissatisfied people for the indoor air quality of 20%.

In table 3, the measured CO_2 concentration and the corresponding PD are presented together with the mean vote given to students to the perceived indoor air quality.

Results in table 3 show a ΔCO_2 concentration from 312 to 886 ppm. In the most of cases, the ΔCO_2 maintains below or around the prescribed limit (660 ppm), corresponding to a maximum percentage of dissatisfied people of 20%. Only in classroom RM 4BD and Vit 2D, the ΔCO_2 is appreciable higher than the limit. But, the vote given by students of such classrooms to the perceived air quality does not differ to the one given in the other classrooms: in fact, the subjective mean vote to IAQ maintains in a short range from 2.2 to 2.6 (mediocre air quality).

Table 3 – Measured CO_2 concentration, PD and mean subjective vote to IAQ

School		Classroom	ΔCO_2	PD (CR1752)	Mean vote to the air quality*
High-school	C. Levi (Le)	4B	679	20.3	2.7
		LAB	312	10.8	2.3
	Regina Margherita (RM)	3 BL	651	19.7	2.2
		4 DB	730	21.4	2.2
	B. Vittone (Vit)	2 D	886	24.6	2.2
	A.Gramsci (Gra)	1 A	414	13.7	2.0
		3 B	423	14.0	2.1
		LAB	483	15.6	2.6

** vote 1 = worst judgement to the air quality*

It has to notice that there is not a perfect inverse correlation between ΔCO_2 and measured ACH, as resulting by a steady state mass balance equation of CO_2 (ASHRAE, 2001). In fact, the measured ΔCO_2 are always lower than the one calculated from the application of the balance equation. This is because a steady state balance can not be applied due to the student habit of opening the window during the breaks at the end of each lesson (that is about 1 opening of a couple of minutes every one or two hours): as a consequence the contaminant concentration in classrooms is highly variable during the time. It is remarkable that students expressed in their questionnaires a very high degree of satisfaction in controlling “personally” the air change by opening/closing the windows.

CONCLUSIONS

The main results of the experimental campaign in naturally ventilated classrooms can be summarised as follow:

- with closed windows (typical winter condition), the measured ACH are significantly lower than the value required by Italian standards and regulations
- it is confirmed that bio-effluents are the first cause of unpleasant odours in classroom, so that the air quality can be effectively controlled using CO_2 as indicator
- the measured CO_2 concentrations in the most of cases maintains below the recommended values for good air quality (PD lower that 20%)
- the range of air quality evaluated according to CO_2 concentration is larger than the one indicated by the student judgements
- CO_2 concentrations increasing during lesson time (with closed windows) is controlled by the student habit of opening the widows every lesson breaks (one break every 1 or 2 hours)
- students express an high degree of satisfaction in controlling “personally” the air change by opening/closing the windows.

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