ENVIRONMENTAL QUALITY ASSESSMENT OF CLASSROOMS

V. Corrado and A. Astolfi

Department of Energy, Faculty of Architecture, Politecnico di Torino
viale Mattioli, 39, 10125, Torino, Italy

ABSTRACT

In this work a methodology for indoor environmental quality assessment was applied, based on thermal, visual, and acoustic comfort indices and on their analysis and spatial representation.
Object of the study was one secondary school classroom of the Province of Torino (Italy), representative of several typologies of educational buildings, showing unsatisfactory environmental conditions.
The study was performed by means of HyperComfort, an informatic tool developed by the Authors, which enables to design and check comfort, and to represent indices graphically.
The work consisted of a preliminary phase, aimed at drawing specifications on comfort goals, a measuring phase for room physical chracterisation, and a simulation phase in order to determine comfort conditions and to compare different retrofit interventions.
About thermal comfort, the Predicted Percentage of Dissatisfied was determined. About visual comfort, the average daylight factor and the uniformity of illuminance were calculated, starting from measured values of light reflectance. About acoustic comfort, speech intelligibility was determined, using the Speech Transmission Index obtained from measured values of background noise and reverberation time.
The representation of comfort indices by means of isometric curves, weighting of thermal, visual and acoustic discomfort areas and the determination of synthetic indicators of environmental quality, allowed to compare different renovation solutions.

KEYWORDS

Thermal comfort, acoustic comfort, visual comfort, simulation, environmental retrofit.

INTRODUCTION

Indoor environmental quality of a building is its suitability to provide health and comfort performances for occupants. It includes thermal, visual and acoustic comfort and IAQ.
High levels of environmental quality can lead to positive effects in terms of satisfaction and productivity. Inadequate illuminance, presence of glare, excessive background noise, hot or cold environment, are only some of the problems occurring, which can influence students' behaviour and their school performances.
This work was performed within a large research project financed by the *Provincia di Torino* aimed at investigating environmental comfort in Italian high-school classrooms and assessing sustainability of retrofit interventions. The research project takes into account thermal, visual, acoustic and IAQ aspects, and includes field monitoring, subjective analyses and numerical simulation of some sample buildings.
Object of the study was a secondary school classroom of the Province of Torino (Italy), representative of several typologies of educational buildings, showing unsatisfactory

environmental conditions. The work consisted of a preliminary phase, aimed at drawing specifications on comfort goals, a measuring phase for room physical characterisation, and a simulation phase in order to determine comfort conditions and to compare different retrofit interventions.

ENVIRONMENTAL REQUIREMENTS FOR CLASSROOMS

The following indices were chosen to evaluate the environmental quality of a classroom:

- the Predicted Percentage of Dissatisfied (PPD) for global thermal discomfort;
- the reverberation time at 1 kHz (T_{1000}) for room acoustical quality;
- the equivalent continuous A-weighted sound pressure level ($L_{n,A}$) for noise annoyance;
- the Speech Transmission Index (STI) for speech intelligibility;
- the average daylight factor (DF_m) and the uniformity of illuminance (U_d), defined as the ratio of the minimum to the maximum illuminance all over the working plan, for daylight.

The reference values or the comfort ranges for each index are reported in Table 1, taken from international and Italian Standards and Regulations or from literature.

TABLE 1
Environmental requirements

	Applies to	Index	Range	Reference
Thermal	Thermal neutrality	PPD	≤ 10%	ISO 7730
Acoustic	Reverberation	T_{1000}	0.9 s[1]	D.M. 18/12/1975
	Room noise	$L_{n,A}$	≤ 35 dB(A)	Bistafa et al. 2000
	Speech intelligibility	STI	≥ 0.6	IEC 60268-16
Visual	Daylight	DF_m	≥ 0.03	D.M. 18/12/1975
		U_d	≥ 0.16	UNI 10840

CASE STUDY

The analyses were performed for a high school classroom located at the second floor of an old school building in the centre of Turin, Italy, adjacent to an urban street. It is placed on the long side of a rectangular court of 28 x 58 m, 17 m high.

The classroom is a parallelepiped (8.2 m long, 6.55 m wide, 4.1 m high, volume = 220 m^3) surrounded by other classrooms and by a corridor, except for the façade containing two large windows having area of 8.4 m^2 each (see Figs. 1 and 2).

Figure 1: Picture of the classroom.

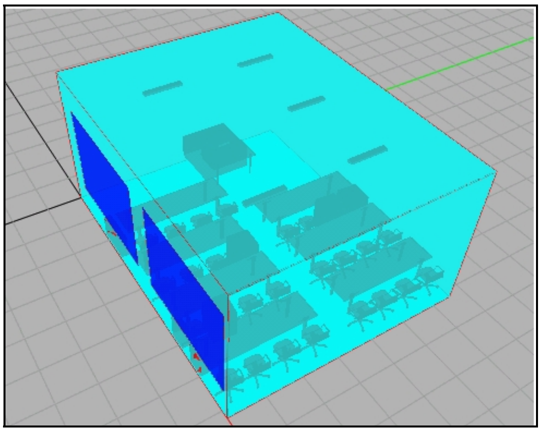

Figure 2: 3D model of the classroom.

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[1] Value for unoccupied classrooms. For occupied classroom Bistafa et al. indicate an optimal reverberation time of 0.5 s.

The building envelope is made of an uninsulated brick wall and single glass windows with wood frame. The internal surfaces are ceiled and grey painted from the floor to 1.6 m, white painted above, the ceiling is white ceiled, the floor is made of red tiles, the doors are wooden. The classroom contains 18 square desks and chairs, two blackboards, two radiators and six lighting appliances.

Environmental monitoring and physical characterization

In order to characterise the room, it was monitored during the occupation time in winter.
Concerning acoustical aspects, reverberation time (T) was measured by means of the interrupted noise method (ISO 1997). Results for both source and microphone positions were combined to give a spatial average value for the classroom as a whole. Analyses were performed in octave band from 125 to 8000 Hz. T_{1000} equals 1.1 s.
In the centre of the room an A-weighted overall noise level ($L_{n,A}$) of 52.4 dB(A) was measured. The noise came from adjacent rooms, from the corridor and from the internal court.
Concerning lighting aspects, values of light reflectance (ρ_v) for different coloured surfaces were measured using a spectrophotometer. The room weighted average reflectance is 0.48.
Concerning thermal aspects, thermal trasmittance of the façade (U_o) and windows (U_w) were assumed respectively equal to 1 W/m^{2}K and 5 W/m^{2}K.

Simulation for comfort assessment

The calculations were carried out by means of HyperComfort, a tool developed by the Authors (Filippi et al. 2000), in order to design, check and represent environmental comfort.
The indices were calculated on a square grid of about 1 m and represented as iso-comfort curves. The height of the grid was assumed as 0.6 m for PPD, the barycentre height of a seated person, 1.2 m for STI, the ears height, 0.80 m for DF, the height of the working plane.
For PPD calculation, a clothing thermal resistance of 1 clo and a metabolic rate of 1.2 met were assumed. Assuming reference winter conditions, indoor air temperature was set at 20 °C, relative humidity at 30% and air velocity at 0.1 m/s. Internal surface temperatures were set at 20 °C for internal partitions, 15 °C for façade, 0 °C for windows.
STI was obtained by means of a semi-reverberant sound field model (Bistafa et al. 2000). To this purpose, measured values of reverberation time and background noise versus frequency were assumed. The octave band speech levels at 1 m in front of the speaker's mouth were obtained according to IEC 60268-16 (1998), assuming a "normal" vocal effort (ISO 1996).
Concerning visual comfort, DF was based on Waldram method for the sky component calculation (Hopkinson et al. 1966). An overcast sky having a constant luminance distribution was considered. The light transmittance of glass (τ_v) was assumed as 0.8.
Figures 3, 5 and 7 show the spatial profiles of the calculated indices. PPD exceeds the required comfort limit all over the room. The reverberation time and the background noise level are too high. That affects the spatial profile of STI that is out of comfort limits in most of the floor area. On the opposite, DF_m is about 5.5 %, largely above its limit value of 3 %. while U_d equals 0.10, below its limit value of 0.16.

Simulation for retrofit intervention assessment

The simulation analysis for the reference case study shows unsatisfying thermal and acoustic conditions. Visual performances are good because of the large size of the window.
For improving thermal comfort, a double glass installation was considered (U_w=3 W/m^{2}K). The effects on thermal and visual performances were slight (Figs 4,8). Better results could be expected by reducing the window size, insulating the façade, or acting on the heating system.

In order to optimise acoustic comfort, a second retrofit hypothesis consisted of the insertion of a false ceiling having a noise reduction coefficient (NRC) of 0.61. For the occupied classroom T_{1000} results 0.5 s, equal to its optimal value. Nevertheless, background noise level is 49.4 dB(A), still above its limit. So the STI requirement is not met on a large floor area (Fig. 6). A possible additional intervention could be to increase sound insulation of the room envelope.

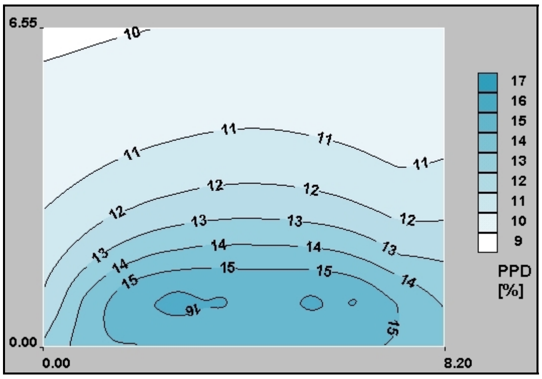


Figure 3: Spatial representation of PPD for the reference case study.

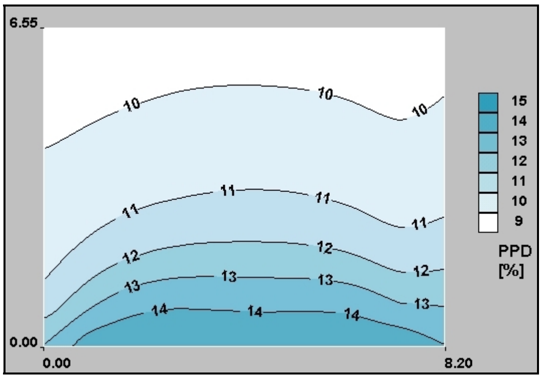


Figure 4: Spatial representation of PPD for the retrofit solution.

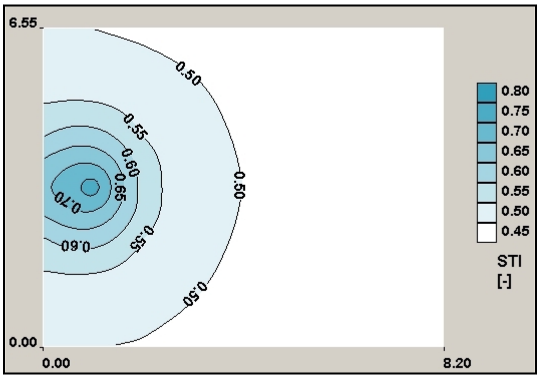


Figure 5: Spatial representation of STI for the reference case study.

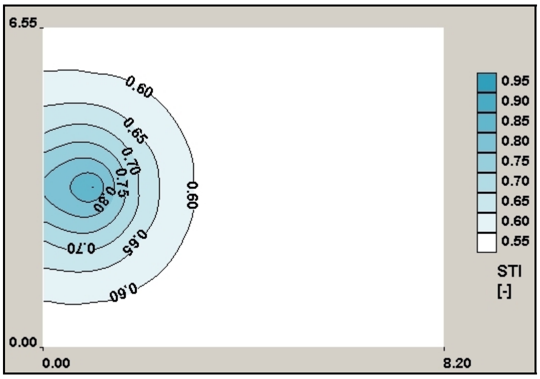


Figure 6: Spatial representation of STI for the retrofit solution.

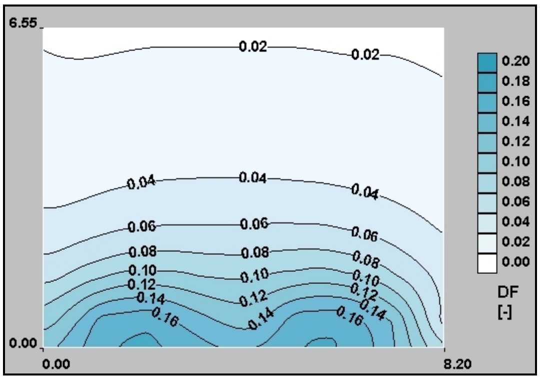


Figure 7: Spatial representation of DF for the reference case study.

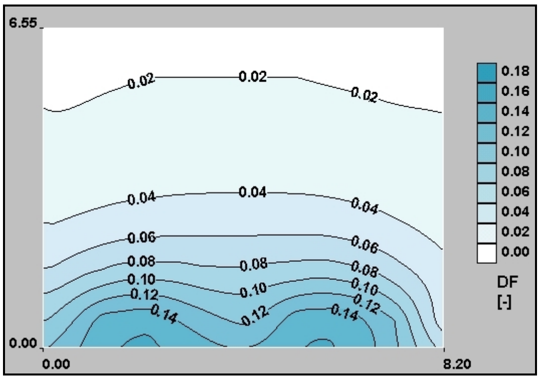


Figure 8: Spatial representation of DF for the retrofit solution.

EVALUATION OF ENVIRONMENTAL QUALITY

Description of the method

In order to compare different solutions, a method for the assessment of environmental quality was used, based on the spatial analysis of discomfort indices (Corrado and Astolfi 2001). The method assumes that any performance index used to check the meeting of environmental requirements can be correlated to a discomfort percentage (P_{dis}), considered either as a percentage of unsatisfied persons, or as a probability of unsuccessful task execution.

In order to make the evaluation scales about different requirements uniform, a discomfort factor (FD) is defined for each index, based on the maximum allowable discomfort percentage ($P_{dis,ref}$):

$$\begin{cases} FD = \dfrac{P_{dis}}{P_{dis,rif}} & \text{if} \quad P_{dis} \geq P_{dis,rif} \\ FD = 0 & \text{if} \quad P_{dis} < P_{dis,rif} \end{cases}$$

From a spatial analysis of FD, assuming an uniform distribution of occupants on the room floor area (A_f), it is possible to determine the percentage of discomfort area (PDA) and the mean value of discomfort factor (FD_m):

$$\begin{cases} PDA = \dfrac{A_{dis}}{A_f} \\ FD_m = \dfrac{\int_{A_f} FD \cdot dA}{A_{dis}} \end{cases}$$

For each requirement, the environmental quality of the room is expressed by means of a discomfort index (DI), defined as:

$$DI = PDA \cdot FD_m$$

Analysis of results

As far as thermal comfort is concerned, a maximum allowable PPD of 10% is assumed.

About acoustic comfort, according to ISO (2000), it is possible to correlate STI to speech intelligibility, assuming a $P_{dis,ref}$ of 30% that corresponds to a STI of 0.6 (Fig. 9).

About visual comfort, according to CIE (1986), illuminance can be correlated to visual performance, assuming a $P_{dis,ref}$ of 10% corresponding to a performance of 90% and to an illuminance of 500 lx for medium difficulty visual tasks executed by young persons (Fig. 10).

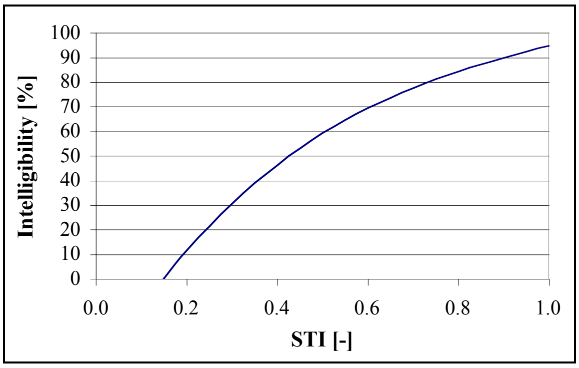


Figure 9: Correlation between speech intelligibility and STI.

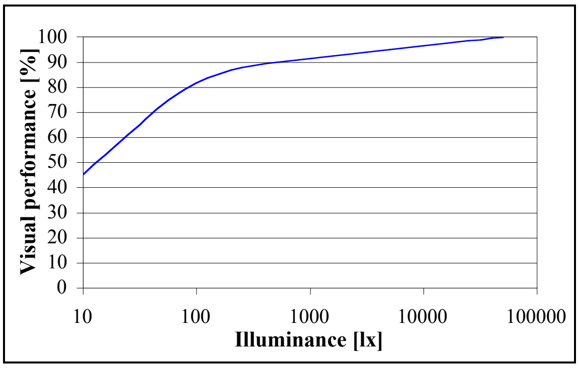


Figure 10: Correlation between visual performance and illuminance.

In order to calculate iso-illuminance curves, a standard outdoor illuminance of 16667 lx was assumed on horizontal plane, giving 500 lx on the visual task when the daylight factor is 3%.

The results of the spatial analysis for the reference case study and for the retrofit solution are reported in Figs. 11 and 12. As far as thermal and acoustic aspects are concerned, the values of PDA and DI show that, despite a large part of the room is out of comfort range, the percentage of discomfort is just slightly above maximum allowed values. Results also confirm that visual environment is the most favourable.

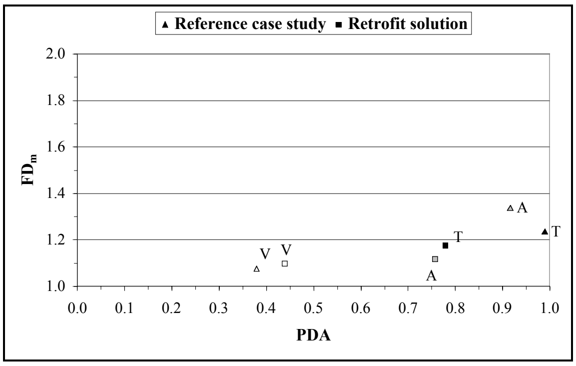
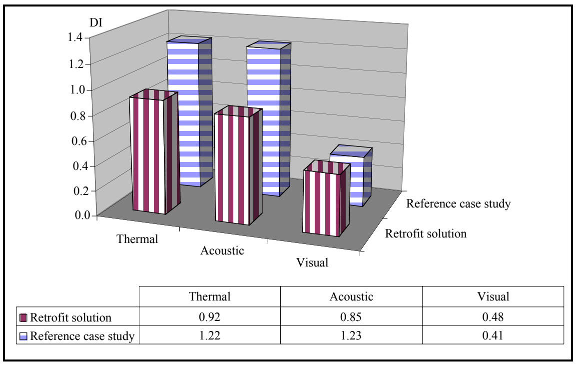


Figure 11: Discomfort Factor and Discomfort Area Percentage before and after retrofit.



	Thermal	Acoustic	Visual
🟥 Retrofit solution	0.92	0.85	0.48
🟦 Reference case study	1.22	1.23	0.41

Figure 12: Discomfort Index before and after retrofit.

CONCLUSIONS

This study points out the importance of carrying out spatial analyses for different aspects of environmental quality during the design stage, especially when assessing retrofit solutions.

A method is proposed for the evaluation of environmental quality, which proves to be very flexible, being adaptable to any kind of requirement and to any performance index, provided that it can be correlated to a discomfort percentage for which maximum reference value is defined.

The analysis of the case study showed an example of poor environmental quality in a typical classroom of an old Italian building, pointing out the ineffectiveness of slight retrofit interventions.

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