INDOOR CONDITIONS IN ULTRA-LIGHTWEIGHT STUCTURES: A CASE STUDY

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ABSTRACT

Steel truss structures, covered with a PVC thin sheet of matt light colour, were used in recent time for the construction of three new classrooms in the University of Catania (southern Italy). Although the construction was fast and cheap, the classrooms proved to be uncomfortable in relation to thermal and luminous environment.
A first analysis revealed that the drawbacks were caused by the ultra-lightweight of the structure as a whole, resulting in thermal discomfort. Furthermore, the matt light colour gave raise to an excessively uniform luminous environment, with occurrences in discomfort glare.
To correct the architectural errors, a simple technical solution was adopted in one of these classrooms.
Before and after the intervention, the thermal and luminous parameters were recorded. In addition the thermal sensations experienced by the students were collected by a questionnaire. The comparison of the two set of data shows that the new design resulted in beneficial effects.
Final remarks are made about the relationship between ultra-lightweight structures and local climate.

KEYWORDS

Thermal comfort, visual comfort, lightweight structures, questionnaires.

INTRODUCTION

In 1997 three new classrooms were built in the University Campus of Catania (Southern Italy) to meet the increasing number of students. These classrooms were realised by means of a steel truss structure, covered by a PVC spread fabric of matt light colour. Low conductive panels were used for the vertical walls, and single-pane windows and doors were set up. The floor extension is 15 x 15 m^2 for each classroom, with 222 seats.
The fruition of these classrooms resulted in many complaints because of the discomfort conditions related to the acoustic, thermal and visual environment. As a consequence, the managers decided to bring corrective intervention in order to improve the indoor quality.
An extensive measurement campaign was carried out to detect the main causes of this discomfort and to propose effective technical solutions. The results of this campaign are reported in a previous paper (Compagno and Marletta, 2000).
A PVC spread fabric double ceiling appeared to be a cheap and easy solution to limit the high radiant heat transfer and the excessive illuminance levels (Figure 1). In order to investigate the real effectiveness of this solution, the following procedure was carried out:

1. Application of the PVC double ceiling in one of the classrooms (classroom B);
2. Measurement of the physical parameters to evaluate the real environmental conditions;
3. Comparison between classroom B and classroom A (where there is no PVC double ceiling), based on the results of the measurements.

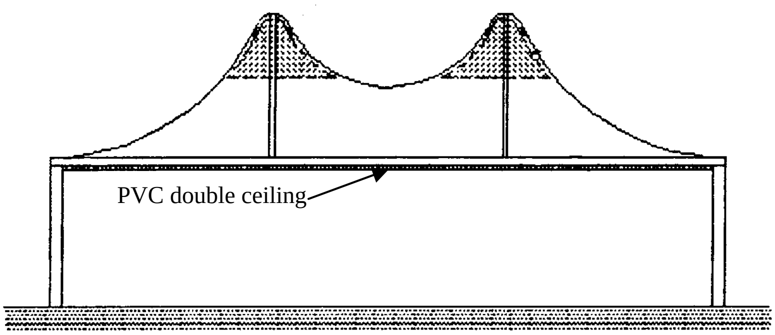

Figure 1: Vertical section of the classroom B, after the adoption of a PVC double ceiling.

METHODS

The data were collected from March to May 2001 by means of a multi-channel apparatus. The measurements were carried out according to the ISO Standards (ISO, 1994) (ISO, 1996); antemeridian and postmeridian measurement sessions were organized, and an apparatus sampling rate of 10 minutes was used. Tables 1 to 3 report the climatic local conditions, the main features of the classrooms and the examined physical parameters.

Then, the PMV and PPD indexes were determined assuming I_{CL} = 0.5 clo and M = 1 met as to the clothing's thermal resistance and the occupants' metabolic rate, respectively. The illuminance levels were measured at 0.8 m from the floor.

To complete the measurement campaign a questionnaire, prepared by the Authors in accordance with ISO requirements (ISO, 1995), was distributed and filled in by more than 300 students, in order to compare the measured data to the real perceived sensations.

TABLE 1
Climatic conditions

Location	University Campus (Catania, Italy)
Latitude	37°30' N
Altitude	150 a.s.l.
Distance from the sea shore line	3 km
Climate type	Temperate subtropical
Max/min outdoor temperature (July)	31/22°C
Max/min outdoor temperature (Jan.)	14/8°C
Max solar irradiance	900 W/m^2 (on horizontal surface)

TABLE 2
Main features of the classrooms

	CLASSROOM A	CLASSROOM B
Year of construction	1997	1997
Persons per room	222	222
Floor surface	15x15m	15x15m
Frame	Steel truss	Steel truss
Wall material	Insulated boards	Insulated boards
Roof material	PVC spread fabric	PVC spread fabric
Adopted technical solutions	None	A PVC double ceiling

TABLE 3
List of measured parameters.

TYPE		DESCRIPTION	UNIT	SYMBOL	
				Indoor	Outdoor
Thermal	Measured	Dry bulb temperature	°C	T_{dbi}	T_o
		Wet bulb temperature	°C	T_{wbi}	T_{wbo}
		Globe temperature	°C	T_g	-
		Air velocity	m/s	V_i	V_o
	Calculated	Relative humidity	%	RH_i	RH_o
		Mean radiant temperature	°C	T_{mr}	-
		Predicted Mean Vote	-	PMV	-
		Predicted Perc.of Dissatisf.	%	PPD	-
	Inquired	Mean Vote	-	MV	-
		Percentage of Dissatisfied	%	PD	-
Optical	Measured	Illuminance	lux	E	-

RESULTS

Because of the lightweight of the structure, the indoor air temperature is strongly influenced by the outdoor conditions. Figure 2 shows that the difference between indoor and outdoor air temperature is very low in both the examined classrooms (A, B). This effect is most relevant in the classroom A, where the temperature gap lays around 2 °C, and the profiles of the indoor and the outdoor temperature are nearly homotetic, due to the extremely low thermal mass of the building. In the classroom B, thanks to the adoption of the PVC double ceiling, the indoor air temperature keeps lower than classroom A. The space between the roof and the PVC sheet is not ventilated, so significantly reducing convective heat transfer.

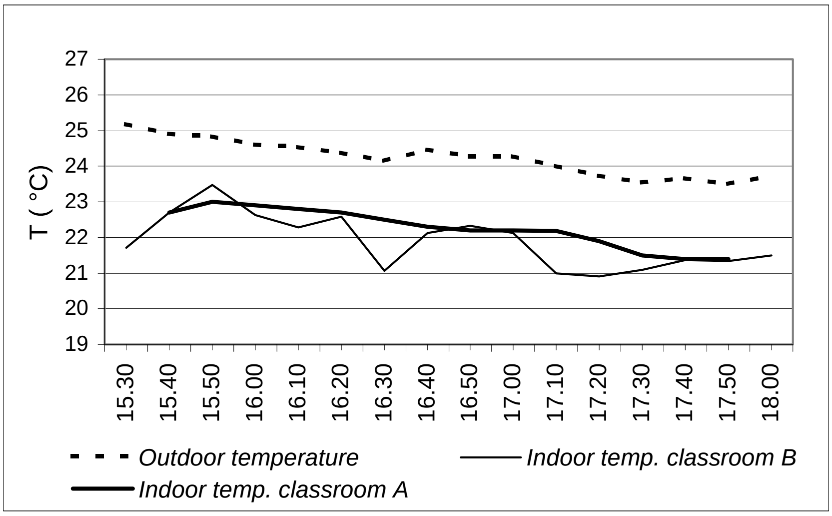

Figure 2: Comparison between the outdoor temperature and the indoor temperature of classroom A and classroom B.

But the main effect of the PVC double ceiling is related to the reduction of the solar radiation transmitted through the ceiling. Figure 3 shows that the difference between the mean radiant temperature (T_{mr}) and the dry bulb indoor air temperature (T_{dbi}) in the classroom A is generally higher than 4°C, while in classroom B this value falls to about 2 °C, so that this environment can be classified as "thermally moderate". The mean radiant temperature has been calculated by means of Eqn. 1 (ASHRAE, 1992):

$$T_{mr} = T_g + k \cdot \sqrt{V_i} \cdot (T_g - T_{dbi}) \quad (1)$$

Here k = 2.2, T_g is the globe temperature, measured through a spherical shaped sensor, and V_i is the indoor air velocity (m/s), measured by an anemometer.

According to the measured data, PMV and PPD have been then calculated following the Fanger's theory (ISO, 1994). Figure 4 shows the PMV profile determined during a measurement session in May; the predicted sensation evidently gets worse in the hottest hours of the day. As a consequence, PPD index is negatively influenced, too. A similar trend has been obtained for classroom B, but PMV values keeps lower than PMV = 1, revealing better comfort conditions than the in classroom A.

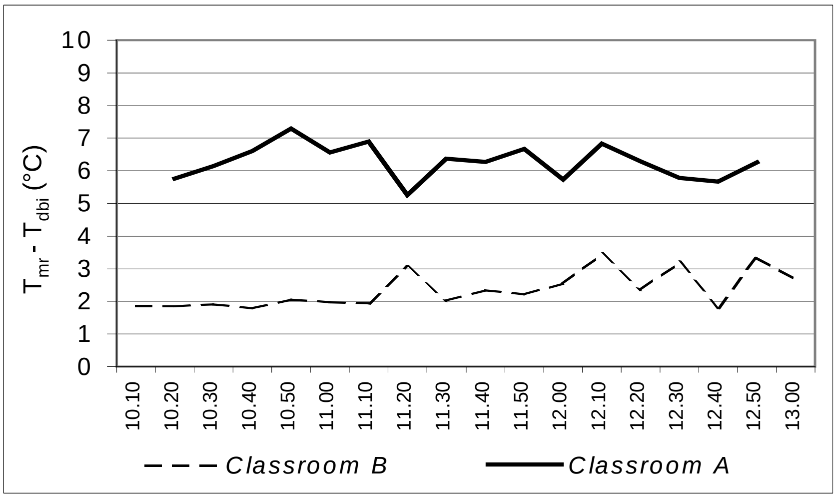

Figure 3: Difference between mean radiant temperature (T_{mr}) and dry bulb indoor air temperature (T_{dbi}) for the two classrooms in a typical day (May).

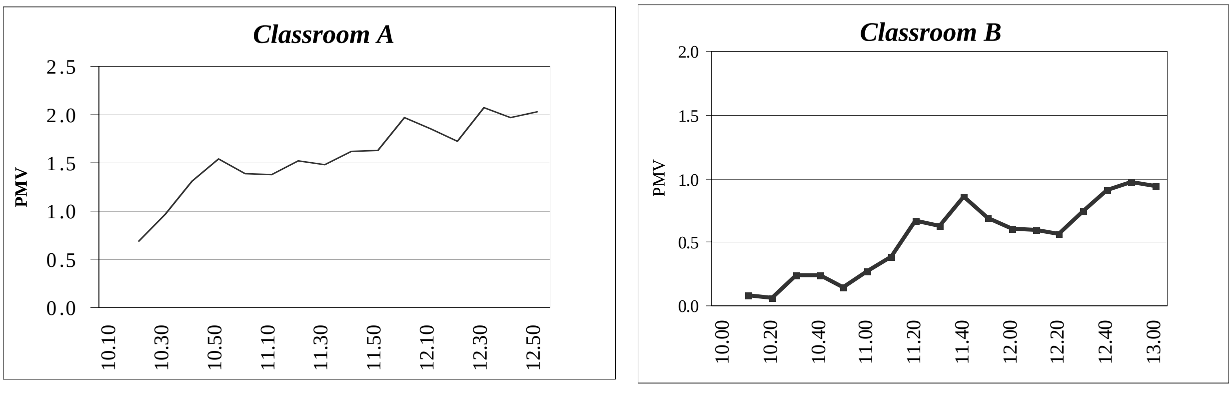

Figure 4: The PMV profile of the classroom B and the classroom A in a typical day of May.

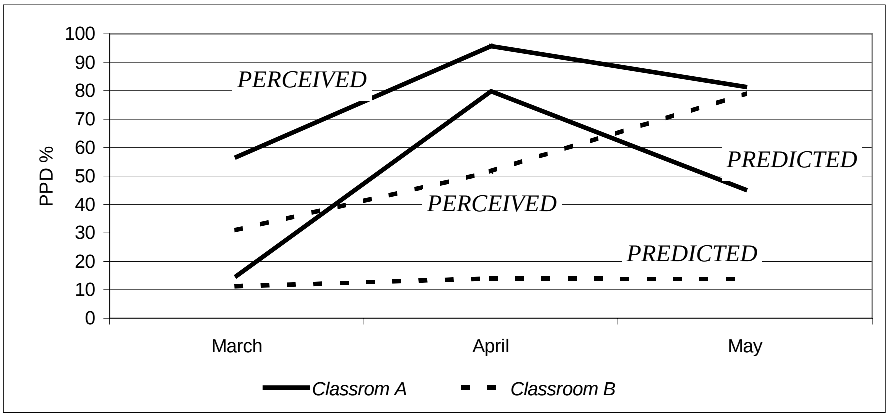

Figure 5: Comparison between the predicted and the perceived (real) percentage of dissatisfied into the two classrooms from March to May.

By means of the questionnaires filled in by more than 300 students, the perceived mean vote MV and the real percentage of dissatisfied PD have been determined. Figure 5 shows a comparison between perceived and predicted percentage of dissatisfied; it demonstrates that the predicted percentage of dissatisfied underestimates the perceived thermal sensation recorded by the questionnaires. This disagreement between predicted and perceived indexes could be due to the negative effect of a stressful mental activity on the perception of the thermal comfort: in fact the answers were given by the students at the end of the lectures.

This statement is confirmed by the results of a previous study (Compagno and Marletta, 2000), where calculated and perceived results were quite close for a similar ultra-lightweight structure used as a refectory; this means that a mentally relaxed condition and a short period of permanence by nature reduce the sensation of discomfort.

As regards the luminous environment, the high transmittance of the material used for the roof, in daylight time, produces illuminance levels too high for the visual task. In addition, the excessive uniformity of the luminance causes a difficult vision. In Figure 6 the mean illuminance levels measured during a day of May are shown for the two classrooms. In the classroom A the values are too high with respect to those recommended for classrooms (from 500 to 1000 lux) (UNI, 1994). The adoption of the PVC double ceiling in the classroom B has sensibly reduced the illuminance to more acceptable values, with beneficial effect on the visual comfort. This is evident by Figure 7, where the distribution of the illuminance on the working plane is shown.

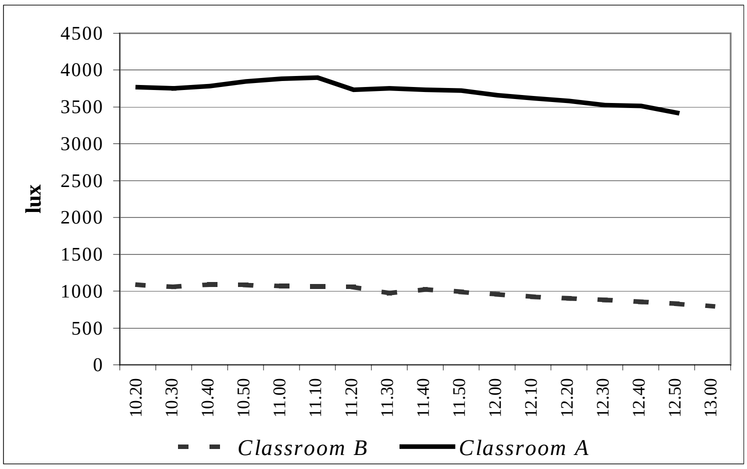

Figure 6: Mean illuminance levels during the measurement session in May.

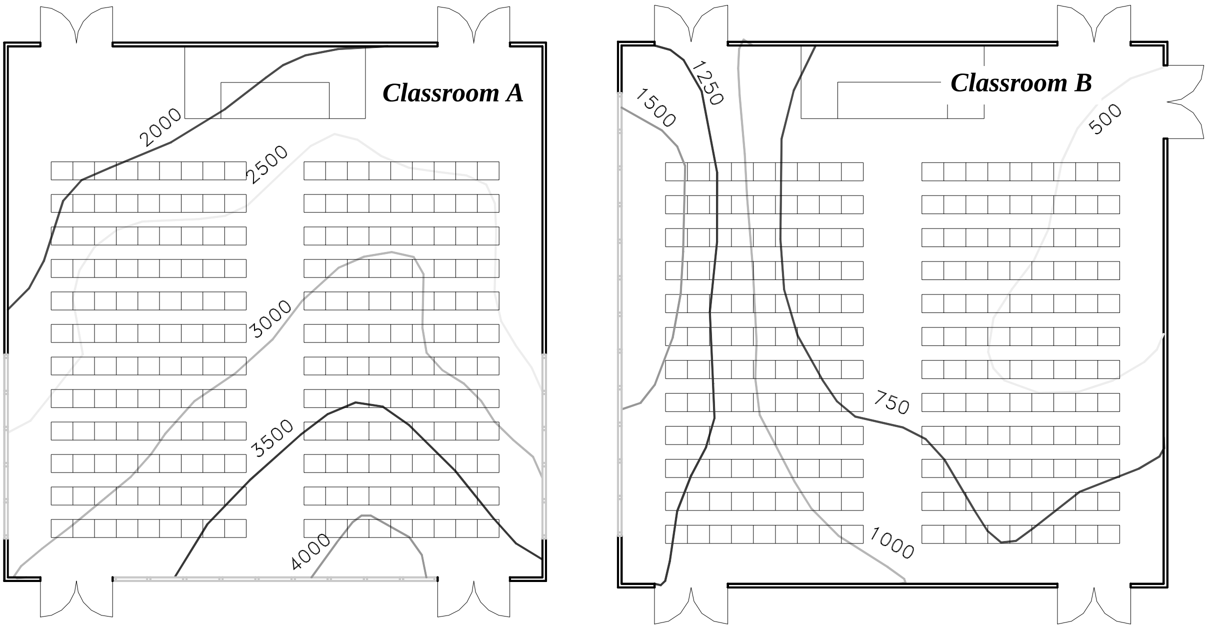

Figure 7: Distribution of the illuminance E on the working plane (lux).

CONCLUSIONS

The previous analysis has shown that the ultra lightweight structures are inadequate to produce a satisfying environmental comfort in regions with temperate subtropical climate. For these ones, the buildings should have a thermal inertia high enough to contrast the consistent temperature swing, especially in summer. Nevertheless, simple in-field interventions can increase the indoor environmental quality.

In addition, the predicted percentage of dissatisfied disagrees with the one determined through the questionnaires: under mental stressful activities, like a two-hour lecture, the perception of discomfort is higher than that predicted by Fanger's theory. So a generalisation of a thermal comfort theory should include the mental conditions as a significant variable.

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