Indoor conditions in ultra-lightweight structures: a case study

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ABSTRACT
This paper reports a number of physical indexes for the assessment of the indoor environmental quality of new steel truss structures, used as classrooms at the Catania University Campus (southern Italy).

By means of a multi-channel recording apparatus and questionnaires filled in by the students, the following data were collected: indoor dry bulb temperature, relative humidity, air velocity, mean radiant temperature, workplane illuminance, PMV, PPD, MV, MMV. On the basis of these data, the comfort requirements are not achieved. In addition, the calculated PPD underestimates the discomfort recorded by the questionnaires.

In order to improve the environmental conditions, some technical solutions were proposed and applied in one of these classrooms. These interventions have significantly reduced the radiant thermal effects and the illuminance levels.

Final remarks are made about the congruity of this kind of structures with the local climate.

INDEX TERMS
Thermal comfort; PMV; Visual comfort; Questionnaires

INTRODUCTION
In 1996, it was decided to build in the University Campus of Catania three new steel truss structures used as classrooms of 222 seats each; these are covered by a PVC spread fabric of matt light colour.

The fruition of these structures resulted in many complaints because of discomfort conditions related to acoustic, thermal and visual environments.

As a consequence, the managers decided to make corrective intervention to improve the indoor quality.

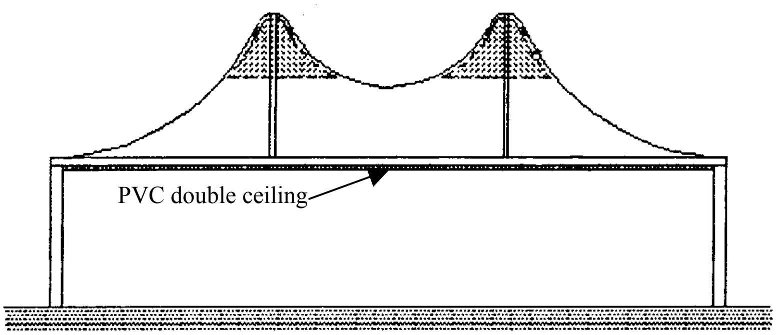

Figure 1 Vertical section of classroom B, after the adoption of a PVC double ceiling.

An extensive measurement campaign was carried out to detect the causes of discomfort and to propose effective technical solutions. The results of this investigation were reported in previously (Compagno and Marletta, 2000).

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A PVC spread fabric double ceiling appeared to be a cheap and easy solution to limit the high radiant heat exchanges and the excessive illuminance levels (Figure 1).

The following investigations were carried out: (1) measurement of physical indexes in order to evaluate the real luminous and thermal conditions; (2) proposal of technical solutions to improve the environmental comfort; (3) application of these solutions in one of these classrooms; (4) comparison with other classrooms and final assessments.

METHODS

The data were collected from March to May 2001 using a multi-channel apparatus with a sampling rate of 10 min and according to ISO Standards (ISO, 1994, 1996). The PMV and PPD indexes were determined assuming 0.5 clo and 1 met. The illuminance levels have been measured at 0.8 m from the floor.

To complete the measurement campaign a questionnaire, according to ISO requirements (ISO, 1995), was filled in by more than 300 students.

Tables 1–3 report the climatic local conditions, the main building features and the physical parameters examined.

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 buildings

	Classroom A	Classroom B
Year of construction	1997	1997
Persons per room	222	222
Floor surface	15 × 15 m	15 × 15 m
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 variables

Type		Description	Unit	Symbol	
				Indoor	Outdoor
Thermal	Measured	Dry bulb temperature	°C	T_{dba}	T_o
		Wet bulb temperature	°C	T_{wba}	T_{wbo}
		Globe temperature	°C	T_g	–
		Air velocity	m/s	V_a	V_o
	Calculated	Relative humidity	%	RU_a	RU_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 light weight of the structures, in both the examined classrooms (called A and B) the indoor air temperature is influenced to a large extent by the outdoor conditions (Figure 2).

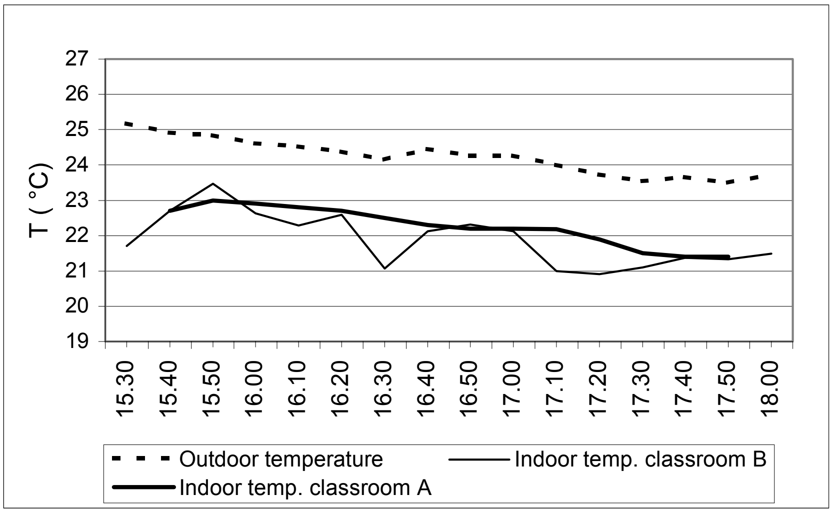


Figure 2 Comparison between the outdoor temperature and the indoor temperature of classroom A and classroom B.

In classroom B, a PVC double ceiling was adopted; it is made by the same material as that of the roof, and the space above it is not ventilated. Due to this solution the radiative heat exchanges are significantly reduced: the difference between the mean radiant temperature (measured by a spherical shaped sensor) and the dry bulb indoor air temperature in classroom A is generally more than 4°C while in classroom B this value is lower so that this environment can be classified as 'thermally moderate' (Figure 3).

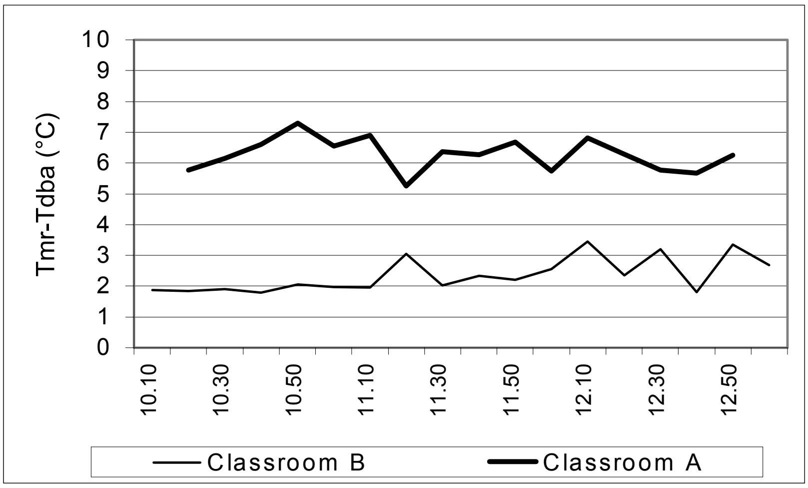
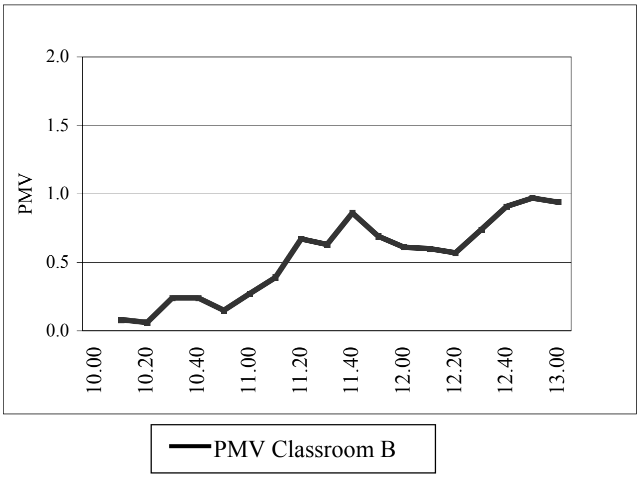


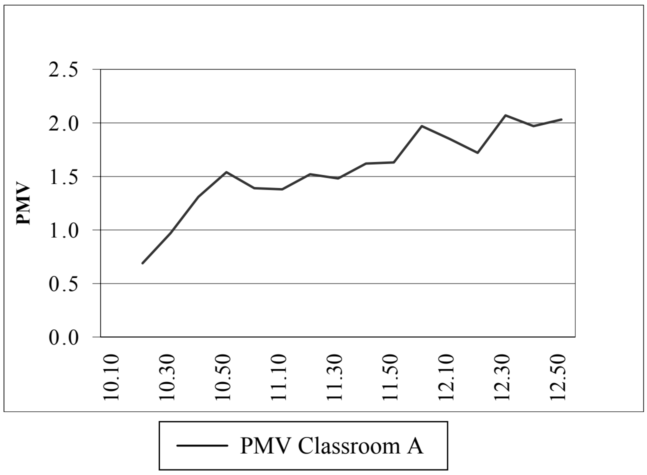
Figure 3 Difference between mean radiant temperature (T_{mr}) and dry bulb indoor air temperature (T_{dba}) of the two classrooms in a typical day.

On the basis of the measured data, following the ISO standard (ISO, 1994), PMV and PPD have been calculated. As shown in Figure 4, the PMV profile becomes worse with the increase in the outdoor temperature, especially in May. As a consequence, the PPD index is also negatively influenced. Nevertheless, the calculated PMV and PPD in classroom B reveal better comfort conditions than the correspondent values in classroom A (Figures 4 and 5).

Further, by means of questionnaires filled in by more than 300 students, a perceived mean vote and a perceived percentage of dissatisfied were determined.

Figure 6 shows a comparison between perceived and predicted percentage of dissatisfied; it demonstrates that, generally, the predicted percentage of dissatisfied underestimates the perceived thermal sensations recorded by the questionnaires. The explanation of this disagreement between the calculated and the inquired results could be the negative effect of a stressed mental activity on the perception of the thermal discomfort: in fact, the answers were given by the students at the end of the lectures.





Figures 4 and 5 The PMV profile of classroom B and classroom A in a typical day of May.

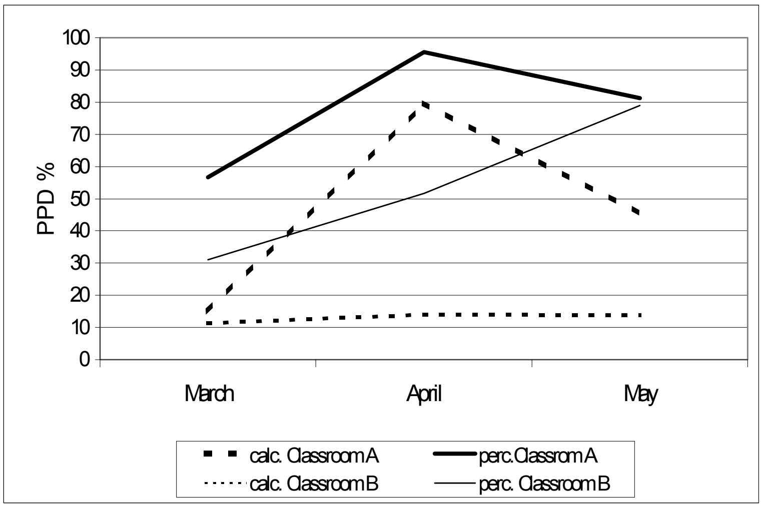


Figure 6 Comparison between the calculated and the inquired percentage of dissatisfied into the two classrooms from March to May.

As shown in a previous study (Compagno and Marletta, 2000), the calculated and perceived results had a fair agreement in the case of a similar ultra-lightweight structure used as a refectory; the mentally relaxed condition and the short period of permanence reduced the sensation of discomfort.

As to the luminous environment, the high transmittance of the material used for the roof, in daylight time, gives rise to illuminance levels too high for the visual task. In addition, the excessive uniformity of the luminance causes a difficult vision.

The adoption of the PVC double ceiling in classroom B has sensibly reduced the illuminance at more acceptable values with beneficial effect on the visual comfort.

The measured illuminance values of the two classrooms are shown, for a typical day, in Figure 7.

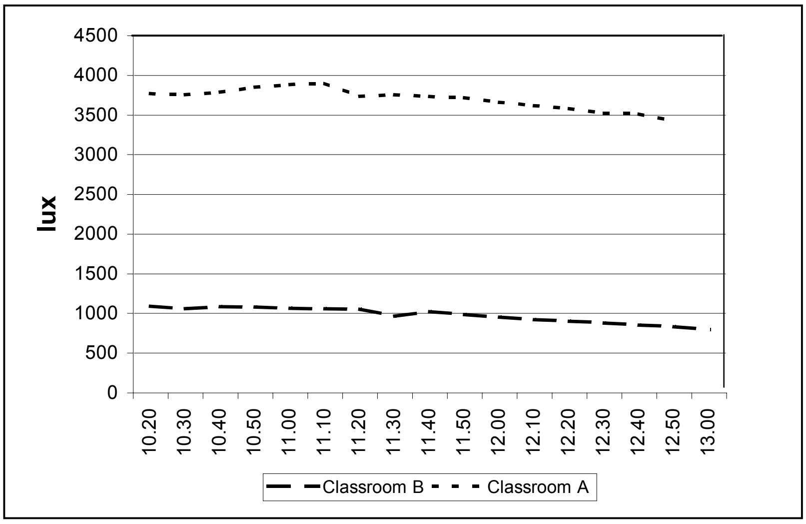


Figure 7 Illuminance in a typical day for the two classrooms.

CONCLUSIONS

The previous analysis has demonstrated that the ultra-lightweight structures are inadequate to guarantee satisfying environmental comfort in regions with temperate subtropical climate. For these structures, 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 inquired one through the questionnaires: under mental stressing activities, like a 2-h lecture, the perception of discomfort is higher than that predicted by Fanger's theory. So a generalization of a thermal comfort theory should include the mental condition as a significant variable.

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