EXPERIMENTAL CAMPAIGN ON THERMAL COMFORT IN NATURALLY VENTILATED UNIVERSITY CLASSROOMS

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SUMMARY

Maintaining a satisfactory thermal environment is of primary importance because affects well-being, health and productivity, and becomes more relevant when the goal is to maximize learning such as in schools or universities. This paper presents an experimental campaign conducted in Milan during summer 2017 in 16 classrooms of Politecnico di Milano, including both naturally ventilated and air-conditioned environments. 985 students have been asked to report their thermal perception and the responses have been related to the measured thermal comfort parameters in order to assess the predictions of Fanger and Adaptive models, according to ASHRAE 55 and to EN 15251 standards. The results highlight how Fanger's model confirms to predict occupants' thermal sensations in air-conditioned classrooms with a reasonable accuracy. In naturally ventilated classrooms the Adaptive model proved to be suitable for predicting students' comfort zone according to ASHRAE 55 Standard, while the adaptive comfort temperatures recommended by EN 15251 resulted not acceptable or not applicable for a large number of students.

Keywords: Thermal comfort; Field study; Fanger model; Adaptive model; Natural ventilation;

1 INTRODUCTION

Thermal comfort is a condition of mind that expresses satisfaction with the thermal environment (ASHRAE 55, 2013) and is known to influence both productivity and health (Parsons, 2003). Schools and universities students spend most of their daytime inside classrooms, highlighting the importance of a satisfactory and healthy thermal environment in order to maximize performances in terms of close attention and learning.

Yao et al. (2010) performed a year-long field study in naturally ventilated university classrooms using measurements and surveys to investigate occupants' adaptive response and thermal environment perception. The adaptive thermal comfort zone derived from that field study showed a comfort range broader than that of the ASHRAE Standard 55-2004 in general, but narrower in the extreme cold and hot months.

Liuzzi et al. (2015) conducted an experimental study involving a total of 126 students in one air-conditioned and one naturally ventilated classroom during spring. Fanger's model and the Adaptive model results were compared to occupants' votes and their thermal sensations were investigated considering the possibility to adjust indoor microclimatic conditions. The PMV and PPD values were found to be similar to the votes reported in the questionnaires, and the optimal operative temperature determined by the Adaptive model was found to be consistent with students' thermal sensations. Furthermore, it was observed that when individual control decreased, the occupants were more dissatisfied.

This paper presents the results of an experimental campaign conducted at Politecnico di Milano with the aim of assessing the predictions of Fanger's model and the Adaptive model according to ASHRAE 55 (2013) and EN 15251 (2007) standards compared to students' thermal sensations in large naturally ventilated classrooms.

2 EXPERIMENTAL CAMPAIGN

Politecnico di Milano is based in Milan, the capital of Lombardy. It's a town located in the northern Italy with a warm temperate climate characterized by warm summers and mild winters.

The experimental campaign was conducted during June 2017 in 12 naturally ventilated and 4 air-conditioned classrooms. Almost every naturally ventilated classroom, except for ID number 2 and 4, had fans on the ceiling for increasing air velocity, whose activation and speed that can be regulated manually for the all room. In every naturally ventilated classroom windows and sometimes doors were fully opened, while n air-conditioned rooms where they were kept closed.

2.1 Comfort survey

A comfort survey was carried out in compliance with ASHRAE 55 standard (2013) to obtain students' thermal comfort perception. Four direct questions were added to the questionnaire to assess actual degree of satisfaction or dissatisfaction about the thermal environment, the air quality, the visual and acoustic conditions (Table 1).

Table 1. Indexes of dissatisfaction and their definition.

Index	Definition	Method
PPD	Predicted Percentage of Dissatisfied	Fanger's model
APD	Actual Percentage of Dissatisfied	$\lvert$ Vote $\rvert \geq 2$
TEPD	Thermal environment percentage of dissatisfied	Direct question
AQPD	Air quality percentage of dissatisfied	Direct question
VCPD	Visual conditions percentage of dissatisfied	Direct question
ACPD	Acoustic conditions percentage of dissatisfied	Direct question

2.2 Measurements

The following probes were used to measure classrooms environmental parameters:

- Globe thermometer (Pt100, 150 mm diameter, accuracy: ±0.21 °C at 30 °C)
- Omnidirectional hot-wire anemometer (Tungsten wire, 9.45 µm diameter, accuracy: ±0.05 m/s in 0 ÷ 0.5 m/s range)
- Psychrometer (Pt100, forced ventilation, temperature accuracy: ±0.21 °C at 30 °C, relative humidity accuracy: 1% in 40 ÷ 70 % range)

According to UNI EN ISO 7726 (2002), environmental parameters were measured at the height of 1.1 m above the floor level, in a timespan of 45 minutes. Because of the instrumental time response of the globe thermometer and of the psychrometer, the first 15 minutes of data recording weren't considered. Instruments and measurements were classified as Class II, according to the standard of instrumentation and procedures (de Dear, et al., 1997).

2.3 Data collection

The procedure used to measure environmental parameters and to gather thermal comfort surveys involved a total timespan of 1 hour and 15 minutes. The first 15 minutes were used to correctly position the measurement stations near the subjects, in places where they were more concentrated. Then, for the following 45 minutes, the environmental parameters were measured. When measurements ended, the thermal comfort questionnaires were given to the occupants, explaining how to compile them for evaluating the thermal sensations experienced in the last hour.

3 RESULTS AND DISCUSSION

3.1 Fanger's model

Classrooms environmental parameters and the values of clothing insulation and metabolic rate from students' surveys were used to calculate the PMV and the PPD according to UNI EN ISO 7730 (2005). Considering air-conditioned classrooms (Table 2), the model reasonably predicts occupants' mean vote in almost every case, also considering that an uncertainty of 0.1 clo has an impact of about 0.2 on the PMV and of 4-6% on the PPD (when the PMV is around ±0.5). The actual percentages of dissatisfied are in line with model predictions, with slightly lower values, except for Classroom 10 where the students that expressed dissatisfaction for the thermal environment were considerably higher than predicted. This could be attributed to an ineffective ventilation as expressed by some occupants in the questionnaire's free notes.

Table 2. Fanger's model and surveys results for air-conditioned classrooms.

Classroom ID	$N_{students}$	PMV	PPD (%)	AMV	APD (%)
6	24	-0.50	10.15	-0.88	8.33
8	75	-0.86	20.45	-0.91	10.67
10	60	0.25	6.29	0.57	28.33
15	99	-0.68	14.77	-0.61	13.13

Considering naturally ventilated classrooms (Table 3), in four cases (Classrooms 1, 4, 5 and 14) the differences between actual and predicted votes were below 0.1, in six cases (Classrooms 2,3,7,9, 11 and 16) the actual mean thermal sensation vote was higher than predicted of about 0.4-0.8, and in only two cases (Classrooms 12 and 13) lower. The model correctly predicts the only two cases with a percentage of dissatisfied lower than 20% (Classrooms 1 and 12). In five situations, the dissatisfied were greater than expected by 20-40% (Classrooms 2, 3, 7, 9 and 11), and in only one case (Classroom 13) the dissatisfied were significantly lower than predicted of about 18%. Despite these quantitative differences, in all cases the model correctly predicts when the percentages of dissatisfied are greater than 20%.

Table 3. Fanger's model and surveys results for naturally ventilated classrooms.

Classroom ID	$N_{students}$	PMV	PPD (%)	AMV	APD (%)
1	117	0.76	17.18	0.72	18.80
2	38	1.25	37.59	1.92	76.32
3	37	1.45	48.04	1.84	70.27
4	52	1.30	40.25	1.38	51.92
5	60	0.90	22.17	0.92	32.79
7	41	1.35	42.88	1.73	63.41
9	41	1.63	57.77	2.44	87.80
11	39	1.33	41.87	1.69	66.67
12	73	0.81	18.81	0.53	16.44
13	26	1.67	60.17	1.12	42.31
14	99	1.02	26.99	1.11	35.29
16	90	1.91	72.75	2.49	87.91

3.2 The Adaptive model

The operative temperatures limits of the comfort zones were calculated according to ASHRAE 55 (2013) and EN 15251 (2007) standards and were compared to the operative temperatures measured in the naturally ventilated classrooms (Figure 1). The mean outdoor temperature was calculated considering an interval of seven days before the one in which measurements were taken, in order to permit the process of human adaptation to outdoor temperatures, giving more importance to the recent thermal experiences (Nicol, F. et al., 2012).

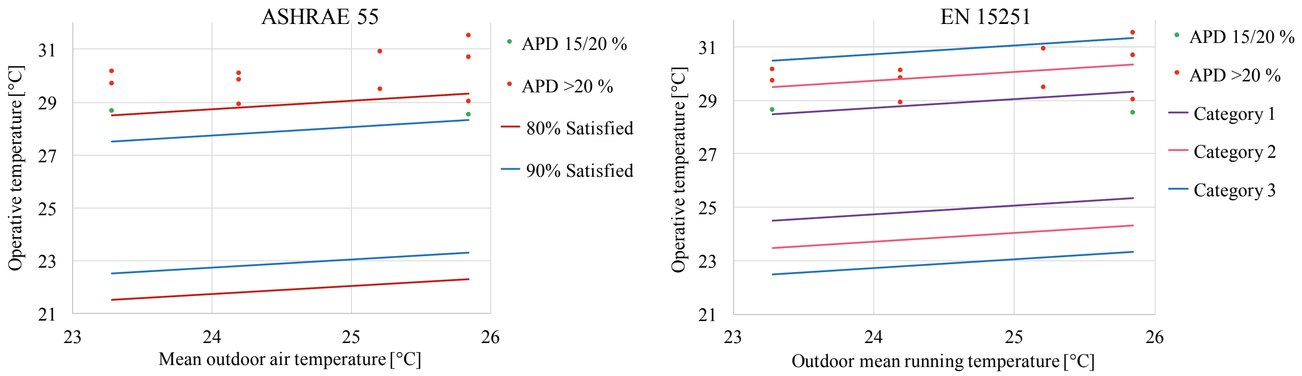

Figure 1. ASHRAE 55 (2013) and EN 15251 (2007) standards comfort zones and surveys results.

Employing ASHRAE 55 standard (2013), the Adaptive model correctly predicts the dissatisfaction observed in ten classrooms over twelve, with three points at the limits of the comfort zone. Considering the EN 15251 standard (2007), the results are compared with the indications given for the thermal comfort zones even if these are not defined in terms of the expected percentage of satisfaction. This makes more difficult the interpretation of surveys results and the test of buildings compliance with the standard as already observed by J. Fergus Nicol and Mike Wilson (2011). Nevertheless, survey results show that, even if most of the operative temperature conditions fall in the second and third category, the percentages of dissatisfied were very large, up to 67% for Category II and 88% for Category III, which actually reveal not acceptable conditions.

These pictures and the results presented in the previous paragraph lead to conclude that in the monitored naturally ventilated classrooms it wasn't observed any higher degree of occupants' adaptability, as it would have been expected. This could be due to a lack of effective individual control of the environmental parameters in the university classrooms analyzed in this study, which are landscape spaces.

3.3 Relations with other indexes of dissatisfaction

Conventionally "the dissatisfied people" are the ones who vote -3, -2, +2 or +3 (APD). However, as observed by Von Grabe and Winter (2008) the people voting outside the comfort range aren't always dissatisfied and vice versa. In order to assess this behaviour, the students were additionally asked to answer to a direct question about their thermal satisfaction, from whom the related percentage of dissatisfied (TEPD) was determined for each classroom (Figure 2).

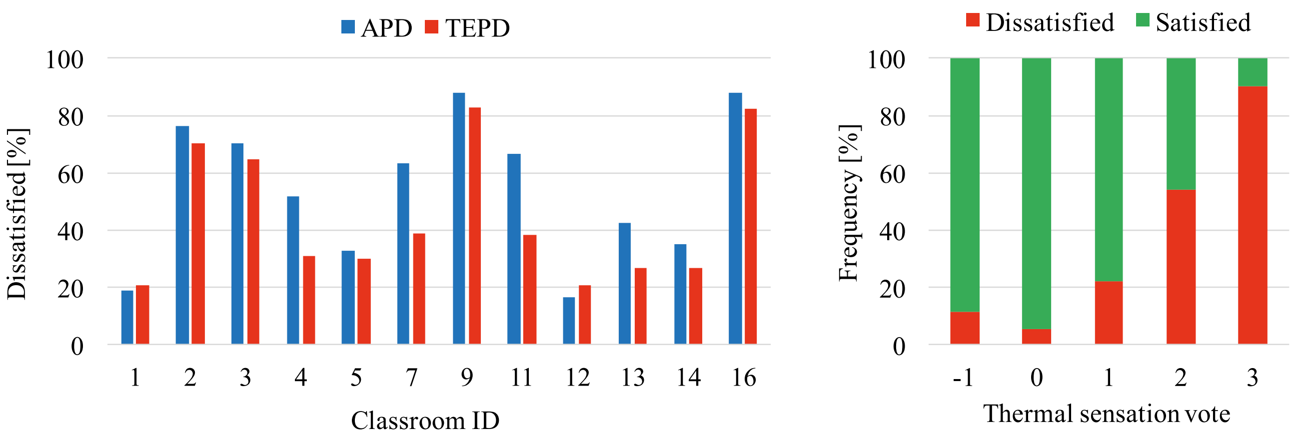

Figure 2. APD and TEPD comparison for naturally ventilated classrooms.

In seven cases, the TEPD resulted to be similar to the APD, with differences below 6% (Classrooms 1, 2, 3, 5, 9, 12 and 16). In the other five cases, the TEPD was significantly lower than the APD, of about

15-25% (Classrooms 4, 7, 11, 13 and 14). However, in these situations the percentages of dissatisfied were still greater than 20%, expressing a high thermal dissatisfaction. Considering the answers to the direct questions, in the naturally ventilated classrooms, the 10% of the students that voted +3 and the 46% that voted +2 were satisfied. Conversely, the 22% that voted +1, the 6% that voted 0 and the 12% that voted -1 were dissatisfied.

In order to further investigate the possible influence of other sources of dissatisfaction, the percentages of dissatisfied from visual condition (VCPD), acoustic condition (ACPD) and air quality (AQPD) were reported from the students' answers to the direct questions (Figure 3).

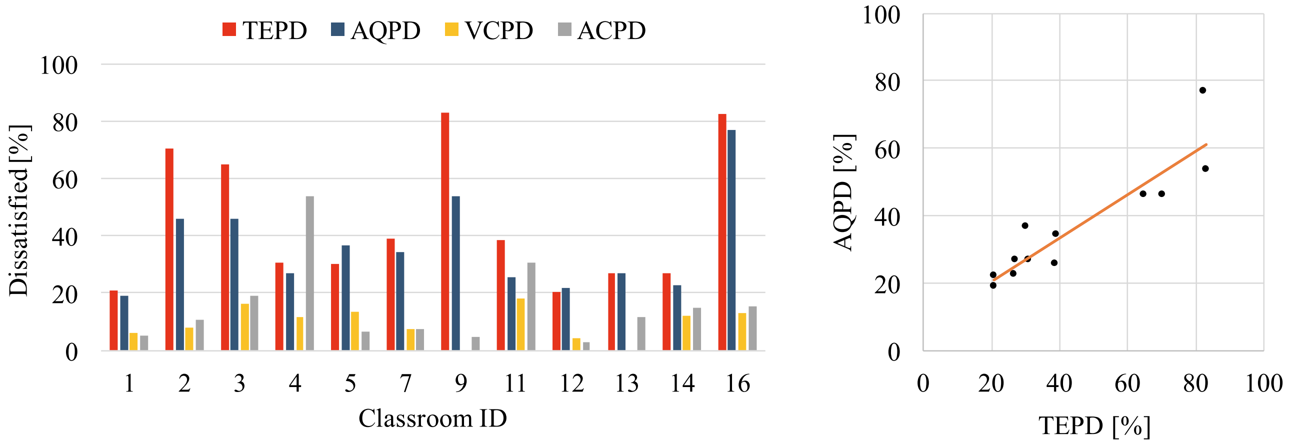

Figure 3. TEPD, AQPD, VCPD and ACPD for naturally ventilated classrooms.

The VCPD is lower than 20% in every classroom. The ACPD is lower than 20% in all the classrooms except for two cases in which it's equal to 54% and 31% (respectively in classrooms 4 and 11). This was due to the noise coming from the street near the two classrooms. Anyway, considering Figure 3, it isn't observed any influence of the ACPD on thermal environment dissatisfaction indexes (APD and TEPD). The AQPD is higher than 20% in every classroom. CO_2 measurements report most of the values in the range of 440-530 ppm, with two peak values at 670 ppm and 800 ppm (Respectively classrooms 16 and 5). The peak in classroom 16 is associated with the highest percentage of dissatisfied for the air quality, but there is no evidence of a general correlation between CO_2 levels and the AQPD. It has to be remarked that students' notes in the questionnaires reported the lack of an effective ventilation, which might have influenced the answers to the air quality question. Indeed, Figure 3 shows a linear correlation between the AQPD and the TEPD (with R^2= 83%) which might express the increase of air quality dissatisfaction associated to the request of higher air velocities to compensate higher temperatures.

4 CONCLUSIONS

This research work focused on the analysis of the dataset developed through an experimental campaign conducted during summer 2017 in 16 classrooms of Politecnico di Milano with a sample of 985 students. The comfort conditions were analysed using Fanger's model and the Adaptive model according to both ASHRAE 55 (2013) and EN 15251 (2007) standards, and were compared to occupants' thermal comfort perceptions.

The results confirm that in the air-conditioned classrooms, Fanger's model predicts occupants' thermal sensations with a reasonable accuracy. In the naturally ventilated classrooms, both Fanger's model and the Adaptive model based on ASHRAE 55 Standard (2013) proved to be suitable for predicting students' comfort zone. In addition, the survey revealed that the adaptive comfort temperatures recommended by EN 15251 standard (2007) were not acceptable for a large number of students, meaning that it might not be applicable in such landscape spaces, in which students don't have an actual individual control on their thermal environment.

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