A STUDY ON THE THERMAL ENVIRONMENT IN GREEK PRIMARY SCHOOLS BASED ON QUESTIONNAIRES AND CONCURENT MEASUREMENTS

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ABSTRACT

The present study investigates the indoor thermal comfort perceived by students through a questionnaire survey conducted during spring 2013 in naturally ventilated primary schools in Athens. Thermal environment parameters such as air temperature, relative humidity, air velocity and mean radiant temperature were simultaneously measured. Then, Fanger's indices of Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD) were calculated by using clothing and metabolic rates. The main purpose of this work is the evaluation of the ability of the answers from students to be sufficient to assess the thermal environment of classrooms. The possible associations between subjective thermal sensation votes and objective measurements are examined by comparing students' answers based on the seven point thermal sensation scale and the results taken by the calculated indices of PMV and PPD.

KEYWORDS

Thermal comfort, Questionnaires, PMV, PPD, Schools

1 INTRODUCTION

Several recent studies have shown that inadequate thermal conditions in classrooms can affect students' performance and attendance (Mendell and Heath, 2005). There is also a number of studies carried on in offices where the adult thermal perception has been evaluated (de Dear and Brager 1998). Since there in an argue on children's ability to understand and express their feelings in a sensible way (Walker, 2001), thermal comfort field studies conducted in school classrooms are usually focused in the ages between thirteen and seventeen (Wong and Khoo, 2003). The study conducted by Humpreys (1977) is one of the few that did a survey on children of younger ages and found that they were capable of perceiving the thermal environment. However, there are limited studies on how children perceive, evaluate and accept the prevailing thermal conditions in school classrooms (Teli et al., 2013).

In the present paper the thermal comfort of the indoor environment of Greek Primary schools is investigated. The aims of this study are: (1) to investigate the thermal comfort votes (thermal sensation, acceptability and preference) of primary school students, (2) to assess the combination of votes of the thermal sensation versus the acceptability and preference and to examine whether significant gender differences appear in thermal comfort preferences, (3) to investigate if any kind (qualitative or quantitative) of correlation exist between the subjective answers from the questionnaires and the objective measurements, and if the correlation do exist to conclude on whether the answers from children of the certain age are representative for the evaluation of the thermal conditions of the classrooms.

2 SURVEY AND MONITORING METHODOLOGY

This field study was conducted in nine primary schools of the Attika basin in Greece during April and May 2013 (Figure 1 & Table 1). The survey was performed on a mid-season, (outside heating season) in order to assess the thermal comfort conditions into a free- running mode of the school buildings (Teli et al., 2013). The study includes students' questionnaire survey and simultaneous measurements of environmental variables affecting thermal comfort. All students participating in the survey were at the same age of eleven years old.

Figure 1: Map of Attika (left) and locations of schools (right)

Table 1: Schools characteristics and measurement periods

School name	School code name	Measurement period (Number of measurement days)	Year of construction	Classroom's floor area (m^2)	Classroom's volume (m^3)	Classroom's number of Students	Classrooms' orientation
Acharnae 14	1	1-5/4/13 (5 days)	2001	53	165	17	North
Thrakomakedones 1	14	8-12/4/13 (5 days)	1978	64	198	25	Northwest
Axharnae 4	4	14-18/4/13&24/4/13 (5 days)	1986	50	155	24	Southwest

Pallini 3	3	19&22/4/13 (2 days)	-	46	137	25	West
Acharnae 18	18	23/4/13 (1 day)	1991	47	138	18	South
Acharnae 12	12	13-17/5/13 (5 days)	1980	49	157	25	South
Thrakomakedones 2	2	20-24/5/13 (5 days)	2003	50	162	25	East
Acharnae 8	8	27-29/5/13 (3 days)	1999	52	159	19	West
Acharnae 11	11	31/5/13 (1day)	1994	55	172	15	South

2.1 Subjective Approach- Questionnaire Survey

The thermal perception of the students was assessed through subjective questionnaires. The questionnaire consisted of two sections: personal data and thermal comfort sensation. The personal data included questions regarding their age and gender. The part of thermal comfort sensation included three questions. In the first question, the participants were asked to evaluate their thermal sensation according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) rating 7-point scale (cold, cool, slightly cool, neutral, slightly warm, warm, hot) (ASHRAE 55, 2005). The ASHRAE rating scale was chosen instead of the Bedford scale (much too cool, too cool, comfortably cool, comfortable, comfortably warm, too warm, much too warm) as it was considered easier for the students to understand (Teli et al. 2013). The second and third questions were associated to the thermal preference (3-point McIntyre Thermal Preference Scale: warmer, no change, cooler) and acceptability (acceptable, unacceptable) of the thermal conditions (de Dear and Brager 1998).

The questionnaires were handed out to students once every day at approximately the same time (10:15), 15 min after the pupils came into the classrooms right after a 20 min break. 667 questionnaires were collected in total from a sample of 193 students from whom only two did not want to participate to the survey. It should be mentioned that there were cases that the same students filled the same questionnaires more than one time, depending on the days of the survey's duration (Table 1, columns 2 &3). During the days when the students had gymnastics right before, the questionnaires were handed out one hour later in order to avoid the influence of the thermal sensation by the vigorous exercise instead of the classroom's thermal environment.

2.2 Objective Approach- Measurements

The measurements of the physical parameters affecting the thermal environment were carried out using the INNOVA 1221, thermal comfort data logger which is connected to a PC with the dedicated application software INNOVA 7701 software for the real time measurements (LumaSense Technologies). INNOVA 1221 is complied with ISO 7730/ CEN 27730 and ASHRAE 55. This instrument uses several transducers such as: air temperature, humidity, air velocity, wet bulb globe temperature (WBGT), operative temperature which are simultaneously collecting data. These data are used to calculate key parameters necessary to assess the thermal comfort environment such as predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) indexes, given the Metabolic rate (MET) and Clothing insulation value (CLO). For this case these values assumed to be equal to: MET=1.2 and CLO=0.8 that corresponds to sedentary activity and light daily wear clothing respectively according to ISO EN 7730. All the parameters were measured at height 1.1m above the floor according to the standard ISO 7726:1998 for seated people and the sampling interval was 5 min.

3 RESULTS AND DISCUSSION

3.1 Subjective Analysis by means of questionnaires

3.1.1 Thermal perception of students

The frequency distributions of the thermal sensation votes in each of the nine schools of measurement are shown in Figure 2. As it can be seen the greater amount of answers lies between neutral and the positive answers of warmth and resembles a half-normal distribution. In overall, the students characterized the thermal environment mostly as warm. In school 18 all students evaluated the thermal environment as neutral. More than 50% of the students in school 2 and less than half of the students in schools 3, 8 and 11 felt slightly warm during the survey. Approximately 20% of the students in school 1 and 10% of the ones in school 14 felt slightly cool. About 5% of the students in school 14 felt cold while the same percentage of students in schools 4, 3, 12 and 2 felt hot. A significant percentage exceeding 20% of students, in school 8 felt hot.

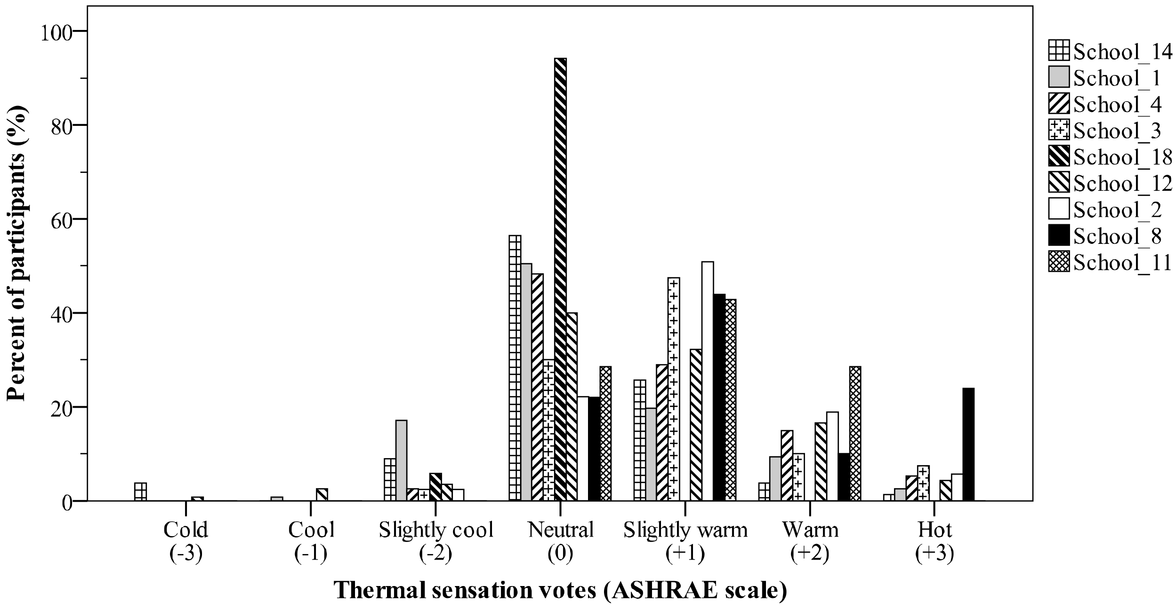

Figure 2: Distribution of the thermal sensation votes of students in all the schools

3.1.2 Thermal preference of students

Figure 3 presents the distribution of the thermal preference votes on the three-point thermal preference scale in each of the nine schools of measurements. More than 70% of the votes in schools 3, 2 and 8 preferred a cooler environment. Approximately half of the responds in schools 14, 1, 4, 18 and 11 didn't prefer any change in the thermal environment. The distribution in school 1 approaches a normal distribution. Less than 10% of the votes in schools 14, 4, 18, 12 and 8 preferred warmer thermal environment.

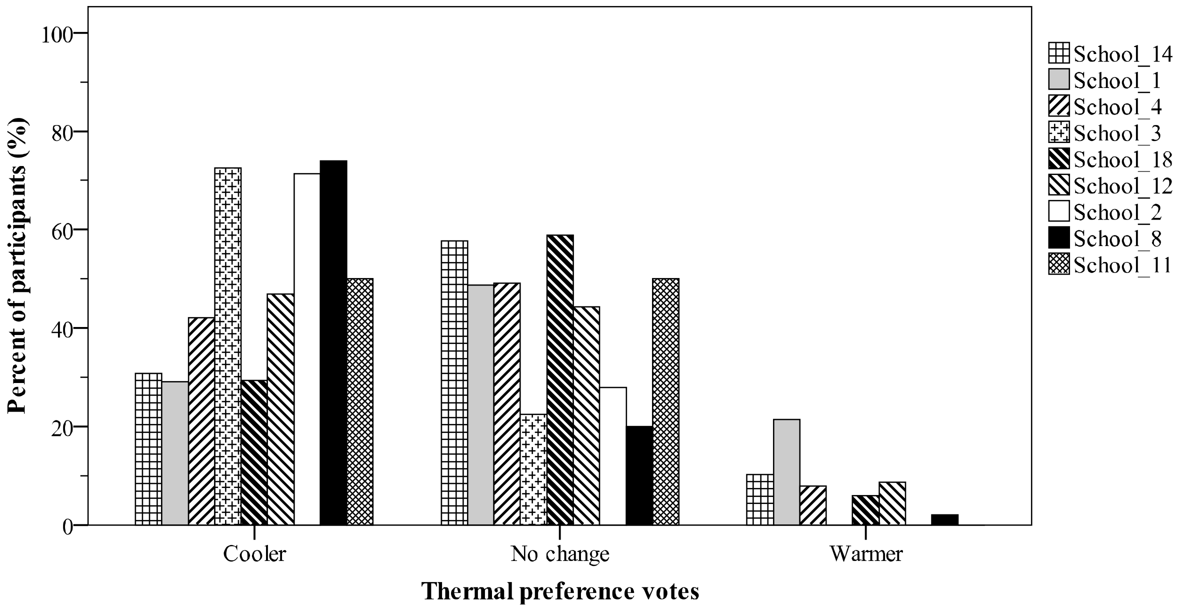

Figure 3: Distribution of the thermal preference votes of students in all schools

3.1.3 Thermal acceptability of students

Acceptable seemed to be the thermal environment for the majority of the students (Figure 4). In school 18, all students evaluated the thermal environment as acceptable. However, approximately 30% of the votes and only in schools 2 and 8 considered the thermal environment as unacceptable. In schools 14, 1, 4, 3, 12 and 11 the unacceptable votes were less than 20%.

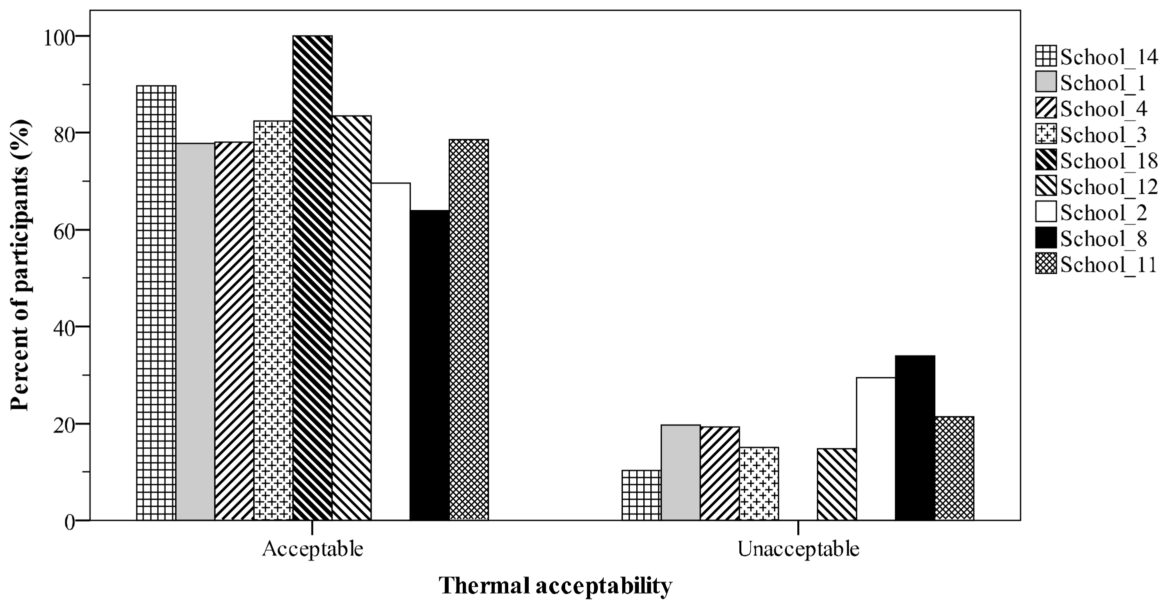

Figure 4: Distribution of the thermal acceptability votes of students in all schools

In the following three paragraphs the individual data sets from each of the schools have been considered as a united single sample so as to examine the combination of the thermal comfort evaluation questions.

3.1.4 Thermal sensation vs acceptability for the entire data set

In figure 5 the thermal sensation votes are presented versus the thermal acceptability for all the schools. Approximatelly 43% of the participants in the survey characterized the thermal environment as neutral from which a mimor 3% strangely considered it as unacceptable. The unacceptable votes lie mostly on the positive axis of the thermal sensation scale. It is worth mentioning that a small percentage of 3% feeling hot, and 8% feeling warm, seemed to accept the thermal environment.

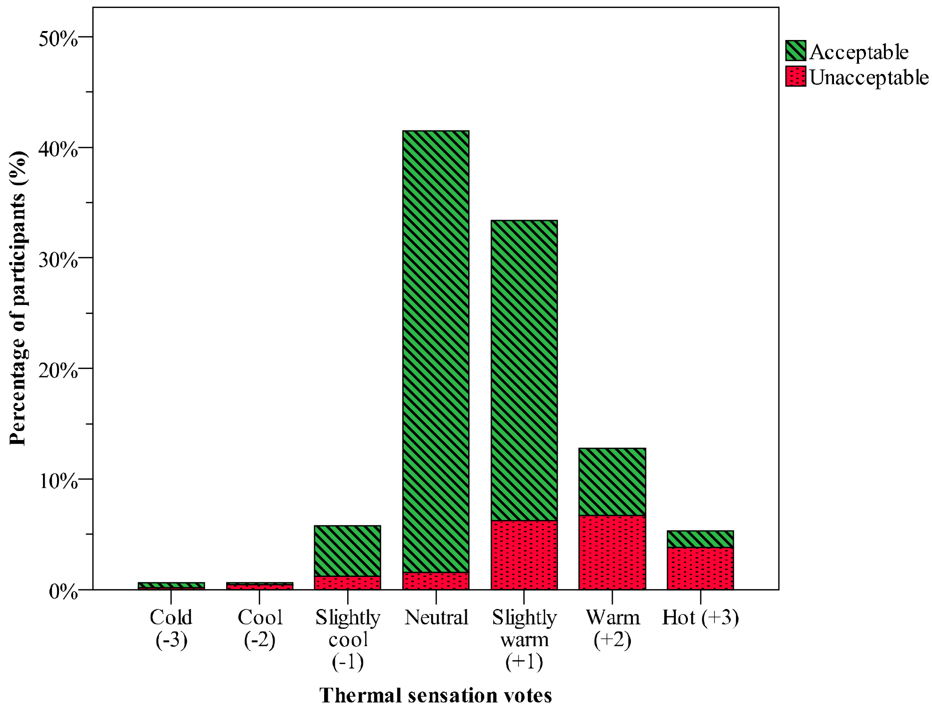

Figure 5: Thermal sensation votes versus thermal acceptability of all the schools

3.1.5 Thermal sensation vs gender for the entire data set

The thermal sensation is presented versus the gender in figure 6. Overall, the thermal sensation of girls and boys do not differ a lot. The greater differences however, between the two genders seemed to be for the votes of 'slightly warm' and 'hot'. Also greater proportion of girls than boys felt slightly cool. The greater amount of both girls and boys felt neutral however the percentage of boys was slightly higher.

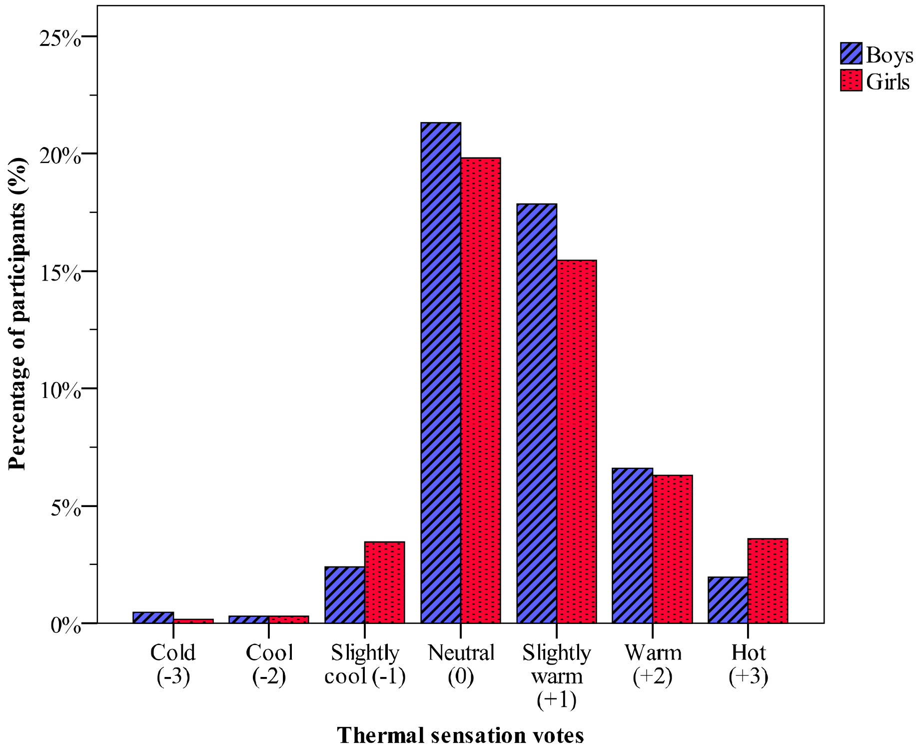

Figure 6: Thermal sensation votes versus gender of all the schools

3.1.6 Thermal preference vs acceptability for the entire data set

In Figure 7 the thermal preference is shown versus the acceptability. Approximately half of the responders preferred a cooler environment during the survey from which more than 15% evaluated the thermal environment as unacceptable. About 43% didn't want any change in the thermal conditions, from which 3% characterized them unacceptable. Less than 10% of the total students would prefer a warmer environment from which more than half accepted the thermal conditions.

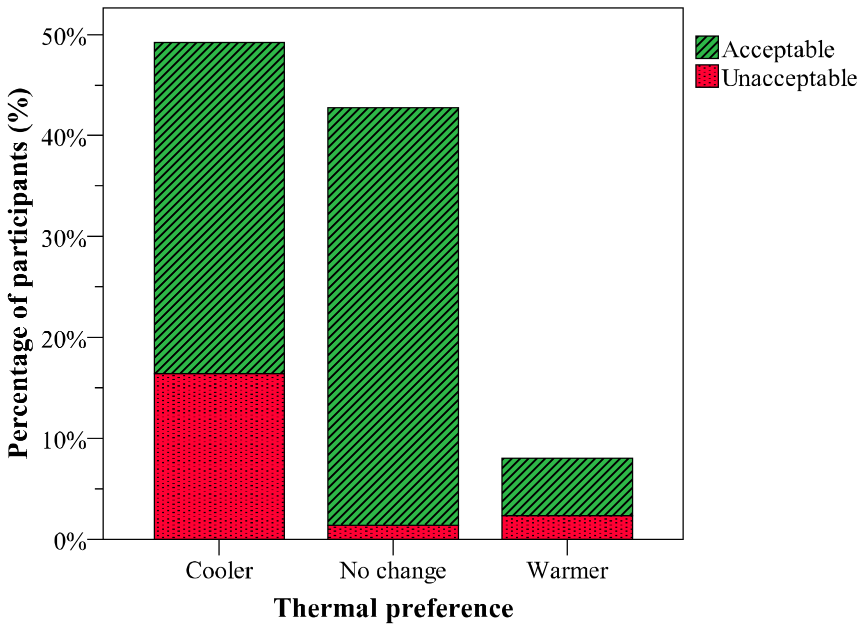

Figure 7: Thermal preference votes versus thermal acceptability of all the schools

3.2 Comparison of subjective answers from questionnaires to objective measurements-PPD

In the following section the correlation between the results from the objective measurements and the subjective answers from the questionnaires is presented. In order to make a reliable comparison between the two variables, the following methodology was followed. The calculated PPD value by the INNOVA 7701, was estimated only for the same 15 min period the students were filling in the questionnaires. Fanger's approach was followed in order to calculate the PPD from the subjective questionnaires, in which those who have voted ±2 or ±3 on the thermal sensation scale were considered as dis-satisfied (Fanger 1970). A single value of the subjective PPD was estimated from each day of measurement, which is compared to the corresponding 15 min averaged value obtained from the instrument, and is presented in Figure 8 in a temporal fluctuation diagram. There aren't any significant similarities between the subjective answers from the questionnaires and the objective measurements. There is a clear divergence in the trends in the two variables, meaning that the objective measurements are not representative of the actual percentage of dissatisfied considering Fanger's approach.

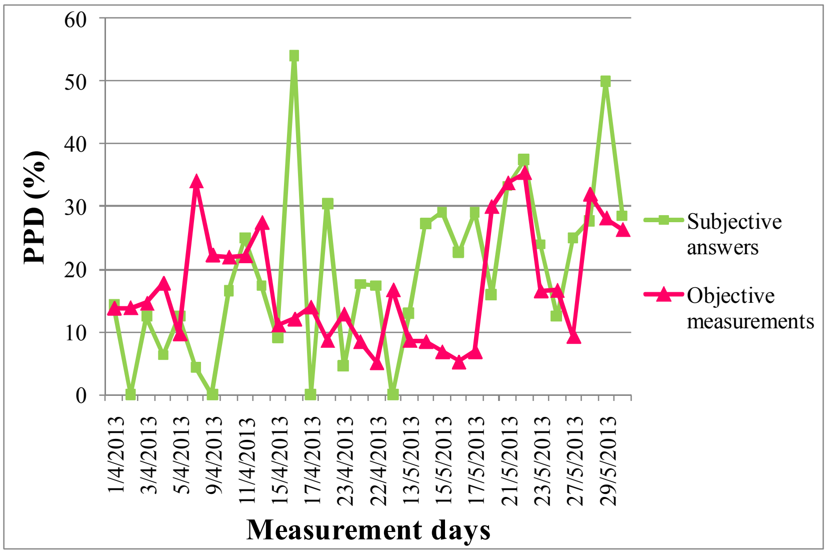

Figure 8: Temporal variation of the PPD indexes obtained from the measurements (Objective) and the questionnaires (Subjective)

3.3 Correlation between the subjective answers from questionnaires-TSV and the objective measurements-PMV

The measured Predicted Mean Vote (PMV) is presented versus the averaged Thermal Sensation vote (TSV) from the questionnaires in a scatter plot diagram in Figure 9. The TSV on the vertical axis arise from the daily mean value of the 7-point thermal sensation votes and it is presented versus the averaged 15 min of calculated PMV by the measuring instrument. As shown in Figure 9, a moderate correlation stands for these two variables ($r^2 \approx 0.5$), which encourages a further investigation of the correlations between the PMV, PPD and TSV indexes.

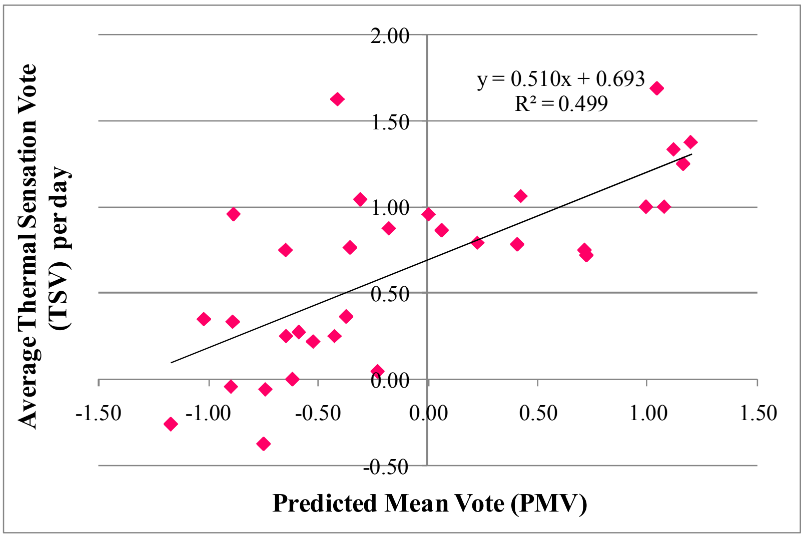

Figure 9: Scatter plot

Table 2 gives the Pearson's and Spearman's correlation coefficients between the objective and subjective TSV, PMV and PPD indexes. Significant Pearson correlation coefficients stand for the following cases; subjective TSV and objective PMV (r^2= 0.707), subjective TSV and subjective PPD (r^2= 0.826) and objective PMV and subjective PPD (r^2= 0.539). As for Spearman's rho correlation coefficients, they are significant for the same cases as Pearson's coefficients. In particular, significant correlations found for: subjective TSV and objective PMV (r^2= 0.726), subjective TSV and subjective PPD (r^2= 0.822) and objective PMV and subjective PPD (r^2= 0.611). It should be mentioned that all these cases were studied at the level of significance 0.01.

Table 2: Pearson and Spearman's correlation coefficients (N=32, same as the measurement days)

	Pearson correlation coefficient				**Spearman's rho correlation coefficient**			
	Subjective TSV	Objective PMV	Subjective PPD	Objective PPD	Subjective TSV	Objective PMV	Subjective PPD	Objective PPD
Subjective TSV	1	0.707**	0.826**	0.146	1	0.726**	0.822**	0.055
Objective PMV		1	0.539**	0.302		1	0.611**	0.015
Subjective PPD			1	0.130			1	-0.025
Objective PPD				1				1

**Correlation is significant at the level of significance: 0.01

4 CONCLUSIONS

The main conclusions arisen from this study are summarized further bellow: 1. the thermal sensation votes in the majority of the schools lied on the positive axis of the 7-point scale, indicating a rather warm environment, 2. About half of the students in most of the schools didn't prefer any change in the thermal conditions; however there were cases where the preference of a cooler environment exceeded 70% of the participants. 3. The thermal environment for most of the students seemed acceptable for the majority of the schools. 4. Most of the thermal unacceptable votes lied on the positive axis of 'warm' on the 7-point thermal sensation scale. 5. The thermal sensation of boys and girls was not significantly different. 6. Approximately half of the responders in all schools preferred a cooler environment from which more than half of them evaluated it as acceptable and about 40% of the responders didn't prefer any change in the thermal environment. 7. The temporal variation of the subjective and objective PPD indexes was compared and their trend lines seemed to differ by far. 8. The objective PMV was then compared to the subjective TSV of students and a moderate correlation was found between them. 9. Significant correlation coefficients were found between: the subjective TSV and objective PMV, the subjective TSV and PPD and for the objective PMV and subjective PPD. These correlations indicate that students at this age are capable to fully understand and evaluate the thermal environment of their classrooms.

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