TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 34, 2022

A new decade for social changes

ISSN 2668-7798

www.techniumscience.com

Technium Social Sciences Journal
Vol. 34, 180-192, August, 2022
ISSN: 2668-7798
www.techniumscience.com

Post-Occupancy Evaluation of Thermal Comfort Sensation of Pupils in School Establishments under Hot Arid Climate Conditions

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Abstract. School establishments have been considered the foundation of various civilizations, due to the importance of the educational process in producing future generations and shaping healthy societies. This paper aims to evaluate the thermal comfort sensation of pupils in school buildings under hostile climatic conditions in hot arid regions. The study employed the use of the post-occupancy approach with subjective assessments through questionnaires and physical measurements of the environmental physical parameters of thermal comfort: temperature, relative humidity, and air velocity as objective assessments. These measurements were in parallel with survey questionnaires that were undertaken during regular class sessions covering the hot and cold conditions of a school year, polling responses from 281 participants on their perception of the indoor climate. Finger's comfort indicators are calculated (PMV, predicted mean vote; and PPD, predicted percentage of dissatisfied people); and the actual people's clothing and metabolic rate are estimated in order to conclude the prevailing indoor thermal conditions. The investigations were carried out on three samples of school buildings in Biskra (Algeria) of different architectural styles. The study's results revealed that the levels of temperature were the most crucial parameter that influenced the thermal sensation with an average of 35C° with a PMV of 2.48, and 15C° in winter with a PMV of -2.56, indicating more than 90% dissatisfaction. Therefore, a well-thought bioclimatic school design is needed to ensure acceptable indoors, and promote healthy and safe learning spaces, by adopting sustainable design principles and low-energy-consuming techniques.

Keywords. Thermal Comfort sensation; School establishment; Questionnaire; Post-occupancy evaluation; Hot arid region

1. Introduction

In Algeria's post-independent society and as in many developing countries, a substantial need for new infrastructures emerged to cope with the large rise in demographics; school establishments were one of the most required infrastructures to heal the society after more than a century of colonization. Therefore, educational facilities were one of the most construction types that were built due to the importance of the educational process in rebuilding societies.

Schools in Algeria have been built since independence following a standard, rigid and typical design, according to similar architectural typologies and with the same and similar construction materials with a massive reproduction of these typologies throughout the national territory, regardless of the quality of neither the thermal environment nor the climatic contexts [1] , and with an absence of implementation of the thermal standards or limited building regulations, which has led to high levels of construction exploitation cost as the rest of African nations [2].

Schools are regarded as an important building type when considering the influence of indoor conditions on occupants' health, and performance. Children are less resistant to adverse environmental conditions than adults, thus the impact of the indoor environment on their performance may be greater than in other facilities used by adults. Indoor environmental conditions in schools are therefore of particular importance [3].

In modern societies, people spend most of their time indoors. The significance of creating suitable indoor conditions in school facilities is highlighted by the fact that pupils spend more time in schools than in any other facility, therefore providing a comfortable indoor environment in schools has always been a concern due to their large occupancy and frequent use [4]. The health and productivity of building occupants are significantly impacted by the indoor environment, and thermal conditions are regarded as the major impactful factor, researches has found that it influences the health of schools users and can cause pupils apathy and stress [5, 6], as well as other different diseases such as colds, asthma, and allergies [7], In this regard different studies conducted in school facilities, indoor school classrooms conditions have been linked to student productivity and performance. According to Zeiler [8] in schools, different thermal conditions have different effects on students' ability to understand instruction, where warm temperatures have been shown to reduce performance, while cold temperatures have been shown to decrease manual ductility and task completion speed, and high relative humidity has been shown to make pupils lazy and lethargic [9]. Therefore, climatic and geographical location has proven to have a great impact on student's attitudes towards school [10].

Considering all of the indoor environment elements, the thermal condition is considered the most curtail one spatially in climates with extreme conditions, such as the south of Algeria where a hot and arid climate prevails with hot and dry summers with air temperatures that reach a maximum of 50 C°, and cold dry winters.

Thermal comfort is one of the most important parameters of indoor quality, it is defined through different Standards; in the ISO 7730 and ASHRAE 55 [11] is defined as *a state of mind that expresses contentment with the thermal environment, helps to create a thermal environment that is comforting to the well-being, and is conveyed by a pleasant sensation brought on by the fulfillment of physiological demands, and without any thermal stress placed on the thermoregulatory systems of the human body*. Six factors are influencing the thermal comfort of humans, four of which are environmental (physical parameters) and two personal factors. The environmental factors are the air temperature, the mean radiant temperature, the air velocity, and the air humidity. Personal factors are the metabolic rate and the insulation through clothing [12].

The assessment of thermal comfort is very important to determine the level of comfort inside a building and user satisfaction. Among the number of approaches and methods describing human thermal comfort, two basic and reliable parameters: the PMV and PPD indicators, where the Predicted mean vote (PMV) is the average comfort vote, using a seven-point thermal sensation scale from cold (−3) to hot (+3) as it is referred on the ASHRAE 55 Standard [11], which is based on experimental works. The PMV model predicts the average comfort vote of the occupants by predicting the percentage of unsatisfied persons (PPD) in the indoor environment [13].

The objective of this study is to assess the level of thermal comfort and pupils' thermal sensation in different school establishments located in Biskra, with a subjective and objective post-occupancy evaluation approach by collecting and analyzing quantitative and qualitative data.

2. Materials and Methods

This research uses a post-occupancy evaluation approach to assess the level of thermal comfort in three different school establishments and students' sensation of indoor thermal comfort. The post-occupational evaluation (POE) method offers an alternative to enrich the feedback of space users in every step of the design process; it helps in the identification and resolution of building problems, to meet the needs of users, and in general, improves the use of space according to the feedback.

The POE approach is based on different levels of investigation ranging from a quick and superficial examination to a deeper analytical investigation up to a diagnosis that correlates physical data with the perceptions of the occupants; generally, it consists of combining a few interviews with a visit to the building. A simple and short questionnaire can also be distributed [14, 15]. Therefore, this study was carried out through two procedures:

The first is an objective diagnosis of the building samples by site visits, observations, and thermal physical data monitoring using the *Testo 480* instrument.

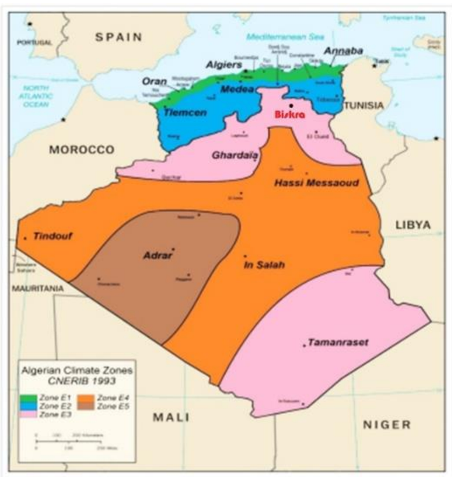
The second is a subjective evaluation with questionnaires and focus group techniques.

Both steps were carried out simultaneously. The quantitative and qualitative collected data were processed using a statistical analysis program and then analyzed.

The study was carried out during two periods with extreme conditions, over 3 days in the same week (a day for each school) in summer and winter conditions.

2.1. Case study

2.1.1. Location and climatic context. The chosen monitored facilities chosen for this study are located in Biskra a South-eastern Algerian city with a hot and arid climate in the E3 climate zone; very high temperatures, low precipitation, and high solar radiation rates zone. Figure 1 shows the location of the city and its climatic context.



Technium Social Sciences Journal
Vol. 34, 180-192, August, 2022
ISSN: 2668-7798
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Figure 1. Biskra city location climatic context [16].

The use of the psychometric chart has allowed determining the thermal comfort zone range for the studied city where:

The comfortable range for Air temperatures is between 23 C° and 26 C° in summer and between 20 C° and 24 C° in winter and the Humidity percentage rage from 40% to 60% in both summer and winter seasons.

2.1.2. Buildings characteristics. Three Middle school establishments with different construction periods were selected for this study. In each building sample, different classrooms were selected for the measurement campaigns and the questionnaire sessions. Table 1 summarizes the characteristics of the selected building samples.

Table 1. Characteristics of the selected building samples.

	Establishment 1	**Establishment 2**	**Establishment 3**
			
period	Contemporary school 2016	Post-colonial school 1977	Colonial school 1945
Floor area	Total of 1290 m ² Classroom 60.075m ²	Total of 3320 m ² Classroom 52.84 m ²	Total of 925 m ² Classroom 45.68 m ²
N stories	3 Three-story building	1 One-story building	2 Two-story building
Orientations	North/South/East/West	North/South/East/West	North/South/East/West
Material	Red hollow bricks	Hollow cinder blocks bricks	Full cinder blocks
Windows	Wood frame simple glazing	Wood frame simple glazing	Wood frame simple glazing
HVAC systems	Naturally ventilated No Air-Condition	Naturally ventilated No Air-Condition	Naturally ventilated No Air-Condition

For this study, in each school establishment, the results of only three different chosen classrooms will be discussed.

2.2. Data Collection

2.2.1. Objective evaluation: Thermal measurements. Three indoor environmental physical variables required for the assessment of thermal comfort were collected (air temperature, relative humidity, and air velocity). The measurements were carried out in the different school buildings' chosen classrooms in different positions as shown in Table 2.

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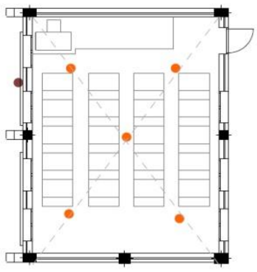
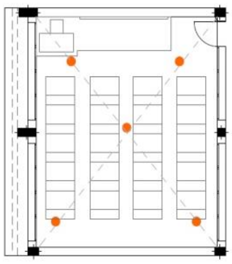
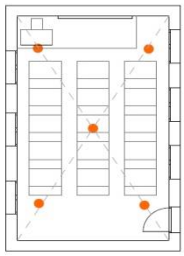
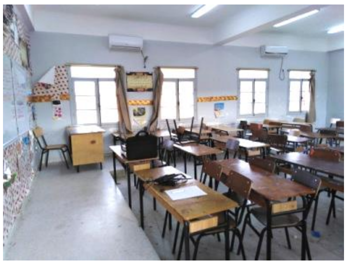
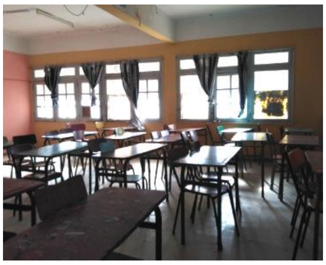
Table 2. Characteristics of the selected building samples.

	Building 1	Building 2	Building 3
Classroom Samples And measuring points			
			

The measurements were made:

- Using **Testo 480** which is an instrument with a hydrothermal probe with a precision of ±0.2°C to ±0.5 °C. Figure 2.

Figure 2. The used measuring instrument *Testo 480.*

- Under clear sky conditions.
- No air conditioning or any active HVAC system.
- Measurements were taken at the height of 1.1 meters (at the work surface level) according to ASHRAE-55-2010 standard [11]; also, at different points to determine the average value.
- During two extreme weather conditions; a summer hot day and a cold winter day in a school year.

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2.2.2. Subjective evaluation: Questionnaire. Simultaneously with the physical measurements, a questionnaire survey was used in the classrooms to evaluate the students' thermal sensations in the different classroom environments. The questionnaires were initiated prior to focus group sessions and interviews with the teachers to distinguish the right way to explain the questionnaire.

The questionnaires were distributed to school students during a school session on a summer day and winter day. The questionnaire was developed taking into account the fact that it will be distributed to students in three classes, in three different middle schools, to pupils aged between 12 and 15. A pre-questionnaire was made to a small sample size during the design phase of the questions in order to distinguish which questions were not clear or needed to be explained to improve before the final questionnaire. The questionnaire was designed according to the following rules:

- Short and direct questions.
- Questions with simple and precise expressions.
- Questions adapted to the vocabulary of children and young people with simple and non-formal language.
- Closed choice questions and avoidance of open-ended questions as possible.
- Questionnaires only in Arabic the pupils' native language.
- Animated questions with colors, schematic illustrations, and figures in a paper and pencil format as shown in figure 3.
- Insisting that all answers are correct and must be authentic and not influenced by their colleges' answers.
- The questionnaires were distributed during a class session at 09:00 am.
- The questionnaires are collected on the same day.

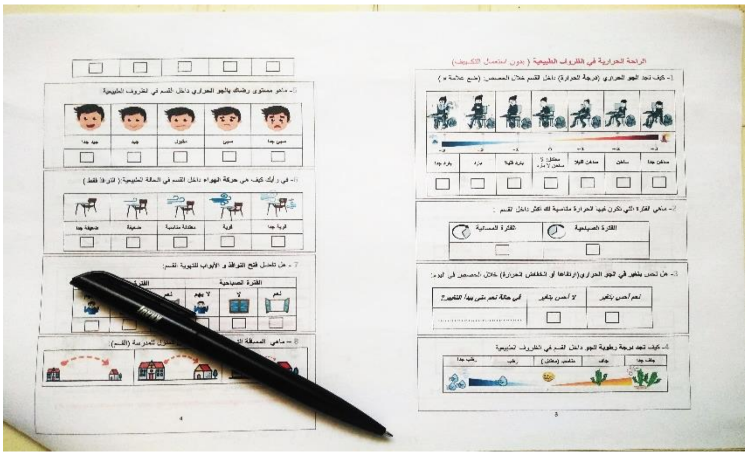

Figure 3. Example of the handed questionnaire for students.

A total of 314 questionnaires were distributed, only 281 were reliable questionnaires for further treatment with a percentage of 89 % (questionnaires that are incomplete, and inconsistent were eliminated), the questionnaires consisted of 4 sections;

The 1st section: gathered general information about the respondents: age, gender, position in the classroom.

The 2nd section: consisted of 6 basic set of questions which asked the students about their thermal sensation, comfort level, thermal preferences, acceptability level and their feeling toward the environmental variables (Temperatures, relative humidity airflow). Students were asked to answer the thermal sensation questions in accordance to the ASHRAE seven-point scales, and also with animated questions to make them easy to understand as recommended by the literature [17]. Figure 4 shows an example of the used questions.

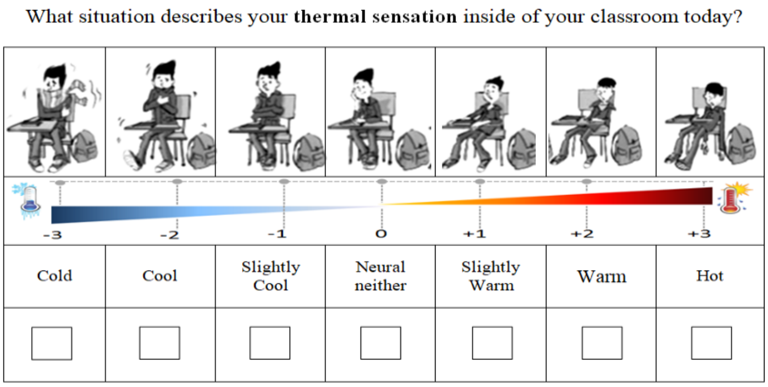

Figure 4. Example of the used questions with a graphical illustration.

The 3rd section: was attended to define the metabolic rate of the student when they come to class by asking them how they arrive at school, and a question about their clothing level, since they are the personal parameter of thermal comfort.

The 4th section: dealt with questions on satisfaction with the quality of the working environment, collecting qualitative data with open-ended questions on the elements that influence this quality, as well as suggestions for improving them.

3. Results and Discussion

3.1. The objective Evaluation results

Thermal comfort physical parameters were collected during the field measurements inside the selected classrooms in the three school buildings, table 3 presents the average recorded value of temperatures, relative humidity, and air velocity in the natural condition (no mechanical ventilation, air condition, or heating).

Table 3. The average recorded values in the natural condition.

		Summer Measurements Average Mean values			**Winter Measurements** Average Mean values		
		classroom 1	**classroom 2**	**classroom 3**	**classroom 1**	**classroom 2**	**classroom 3**
Building 1	T(C°)	34.4	34.5	36.2	14.3	15.3	14
	RH (%)	39.9	40	41.3	54.2	53.9	56.9
	AV(m/s)	0.2	0.1	0.1	0.2	0.3	0.2
Building 2	T(C°)	31.8	32.9	35.3	15.9	16.2	15.8
	RH (%)	42.3	44.4	46.6	45.3	50.2	49.8
	AV(m/s)	0.2	0.2	1.2	0.15	0.3	0.25
Building 3	T(C°)	36.2	36	37	16.3	16.2	16.2
	RH (%)	47.6	51.1	49.3	51	52.3	50.8
	AV(m/s)	0.1	0.1	0.1	0.1	0.25	0.2

Comparing the indoor average recorded values with the thermal comfort zone limits shows that:

- *During the summer day:* the average temperatures were high fluctuating between *31.8C°*

and 37 C° in all buildings' classrooms which is far from the thermal comfort range and building 3 was the hottest, while humidity levels are between 40% and 49.3% which are within the thermal comfort range, and air velocity is almost stable with an average value of 0.15m/s.

- *During the winter day:* the average temperatures were fluctuating between *14C° and 16.3 C°* in all buildings' classrooms which is out of the thermal comfort range and building 1 recording the lowest values, while humidity levels are between 45% and 56.9% which are within the comfort range, and air velocity is almost stable with an average value of 0.2m/s.

The measurements indicate a state of thermal discomfort in all buildings' classrooms in both seasons mainly due to temperature levels.

3.2. The Subjective Evaluation results

On analyzing the data collected from the questionnaires it has been found that:

The general information part of the questionnaire indicated that: out of the 281 questioned people were 180 girls and 101 boys with an average age of 14. The participating teachers were 11 with a percentage of 4%.

For the personal parameter of thermal comfort;

The average clothing level was calculated through the answer of the seasonal clothing for the student inside the classroom the average values were consistent for all students with light clothing during summer at 0.4 Clo and in winter with 1.1 Clo. Clo is the unit of thermal insulation provided by clothing [18].

The metabolic rate was determined based on the type of classroom activities, where a metabolic rate for school activities was estimated as 1.2 met (reading, sitting, standing, light movements).

The thermal comfort sensation part:

Using the scale of ASHRAE, the results of subjective responses to **the thermal sensation of temperatures** are presented in the graphs in Figure 5.

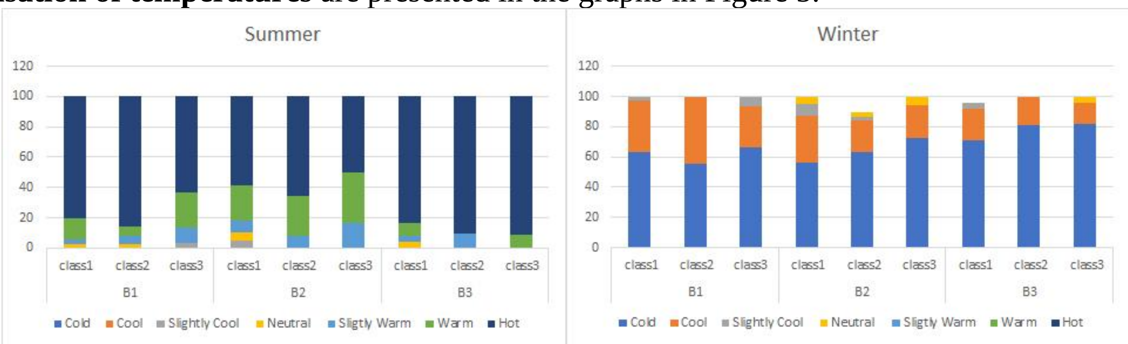

Figure 5. Thermal sensatioon of tempretures votes

During the summer day, the results show that the majority of the respondents in the different classrooms voted for a hot and warm sensation with percentages between 50% to 90.47% with a calculated PMV average of 2.48 and building 3 classroom 3 having the highest PMV of 2.9 which indicates a percentage of dissatisfaction of more than 95% of the responders.

During the winter day, most of the classroom users voted for a cold to cool sensation with an average PMV of -2.56 indicating that almost 90% were dissatisfied with the temperature levels. both the results of summer and winter evaluations indicate that most of the students and teachers were not in thermal acceptable conditions within their classrooms.

The results of subjective responses to the **sensation of humidity** are presented in the graphs in Figure 6.

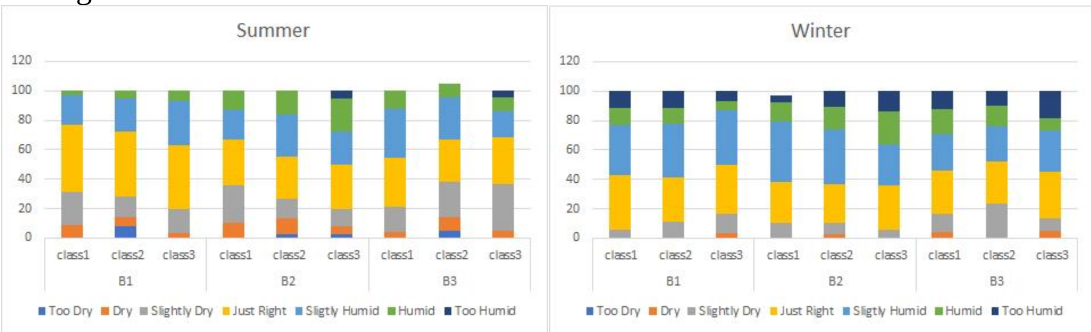

Figure 6.The sensation of humidity votes.

For both seasons it's observed that a high percentage of respondents' votes are within the central categories just right, slightly dry and humid (-1, 0, 1), indicating that the occupants were comfortable and more accepting of the relative humidity levels variation, regardless of has some sensation of high humidity in winter and some sensation of dryness in summer.

The results of subjective responses to the **sensation of Air velocity** are presented in the graphs in Figure 7.

Figure 7. The sensation of air velocity votes.

For both seasons a variety of responses is observed, however, the majority of the responders were comfortable with the indoor air movements, having most of them voted just right with an average of 40% and still with 35% which is in accordance with field measurement where the air velocity values were almost the same in all the buildings classrooms.

The results of subjective responses to the **thermal preference** are presented in figure 8.

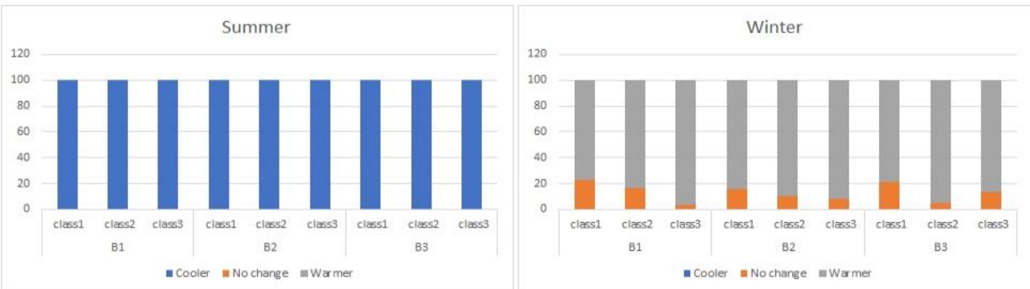

Figure 8. The thermal preference votes.

For the summer all buildings pupils' and teachers expressed that prefer a much cooler indoor thermal environment than the current one, while in the winter the majority expressed to prefer warmer environments however a small percentage between 5 to 20% voted for no change this is mainly due to that in winter and with the high clothing level some people can tolerate the cold conditions.

The results of subjective responses of **thermal Acceptability** are presented in the Figure 9.

From a comparison with the thermal preference votes, a similarity is noticeable indicating that the preference of thermal environment impact the responder's acceptability of the thermal environments, also in winter some responders expressed their acceptability to the thermal conditions.

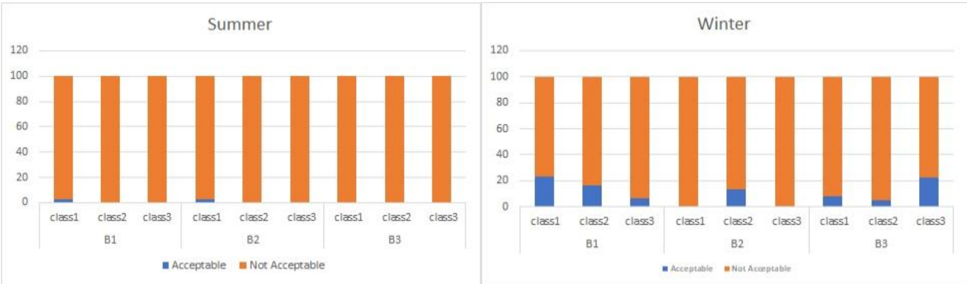

Figure 9. The thermal Acceptability votes.

The results of subjective responses to the **general sensation of comfort** are presented in the graphs in Figure 10.

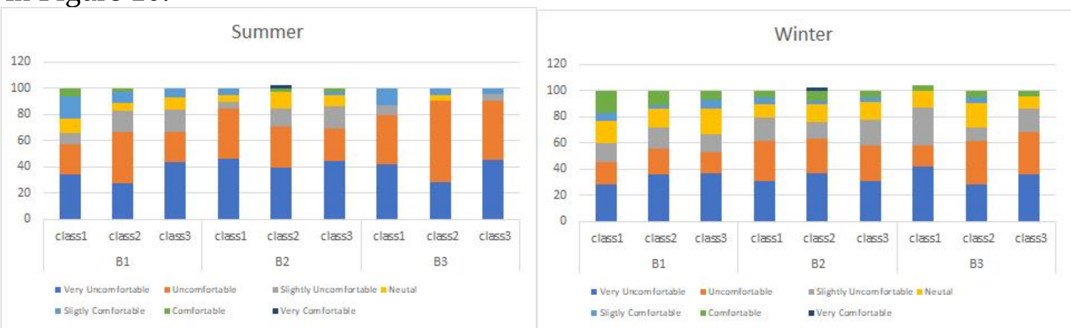

Figure 10. The overall sensation of comfort votes.

The obtained results showed that votes were ranging from very uncomfortable to neutral being in the negative range of the ASHRAE scale (-1, -2, -3), therefore, The majority were uncomfortable to very uncomfortable both in summer and winter in all buildings.

In the last part of the questionnaire were open-ended questions, when pupils were asked to give suggestions if they want any changes in their thermal environments; the majority of the responses were to use mechanical air conditioning and heating systems, some other minor responses were: taking or adding clothes, opening or closing windows, using larger less crowded classrooms.

In the part of the questionnaire and interviews that was directed to teachers, all of them indicated that during the months with the extreme conditions, the thermal environment impact the student academic achievement where student during those periods feel exhausted, less concentrating especially during summer afternoons when they reported that due to the high temperatures in even with the use of ventilation some student experience excessive sweat and even noise bleeding as shown in figure 11.

Figure 11. Health problems caused by high temperatures inside classrooms.

In general, the teachers were far from satisfied with the thermal indoor environment of their classrooms and expressed that without the use of ventilation or air conditioning deviced during the summer season, the space won't be functional to carry the educational process.

Conclusion

This paper has evaluated pupils' thermal comfort sensation in school establishments under hot climates using the post-occupancy approach, field measurements of the physical thermal comfort parameter took place in parallel with survey questionnaires inside three classrooms in three different school establishments, and the main findings of this study can be summarized as follows:

The measurements revealed a thermal discomfort condition due to high temperatures recorded in summer varying from 31.8C° and 37C°, and from 14C° to 16.3C° in winter, while humidity levels and air velocity levels were within the comfort range.

The questionnaire evaluation of the thermal comfort personal parameter revealed an average clothing level of 0.4 Clo during summer and 1.1 Clo in winter, while the metabolic rate was estimated as 1.2 met based on the type of classroom activities.

A high level of thermal discomfort with high PPD (percentage of dissatisfaction) between 50% to 95% in all buildings. The winter conditions were more tolerable by pupils than the summer.

The result of the thermal sensation toward thermal comfort physical parameters: temperature, humidity, and air velocity found that the levels of temperature are the most crucial parameter that influence the pupils' thermal sensation, whilst humidity and air movement having a minor to no impact.

The interviews with the teachers revealed that thermal condition impact significantly student academic performance and even health conditions.

In accordance with the measurement results the subjective evaluation using questionnaire shows a state of thermal discomfort expressed by the students and teachers both in summer and winter natural conditions; therefore, a well thoughtful school design is needed to insure acceptable indoors , promote health and aid learning, future school facilities must adopt sustainable design principles (shape, orientation, shading, high room heights, mount ceilings, …etc.) and with low-energy consuming techniques to rise a future generations that are healthy and aware of the current world environmental crisis and to be active participant in their communities and society.

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