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# Influence of seasonal variation on thermal comfort and ventilation rates in Gaza Strip climate

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**Abstract:** The indoor air quality (IAQ) and thermal comfort in classrooms highly affect the health and productivity of children. Concerns have been raised regarding whether seasonal variation may affect thermal comfort and ventilation rate. In a two-season study of ventilation and thermal comfort of 36 classrooms in 12 naturally ventilated schools in Gaza, Palestine, ventilation rates and thermal comfort were measured. Data on environmental perception were obtained from 724 students by using a validated questionnaire. The results showed significant seasonal variation in perceived indoor environment and thermal comfort in the monitored schools. Differences in neutral temperature between seasons were also observed. Moreover, 83.3% of the classrooms presented a mean ventilation rate lower than 7.5 L/s per person in winter. During fall, only 50% of the measured classrooms presented a flow rate higher than the recommended value. Furthermore, there was a considerable increase in the carbon dioxide level in winter relative to fall. As vulnerable students, this situation negatively affects their performance and health. Therefore, mechanical ventilation systems are needed to provide a dependable and continuous supply of outdoor air.

**Key words:** Thermal comfort, schoolchildren, naturally ventilated building

## 1. Introduction

Good indoor air quality (IAQ) and thermal comfort in school buildings have a substantial impact on the health and productivity of students. Recently, several studies showed that IAQ and ventilation in schools are problematic in several countries, and are thought to be the main cause of sick building syndrome (SBS), increased transmission of infectious diseases, and rise in complaints of students [1,2]. Furthermore, inadequate ventilation in schools was associated with a 10% to 20% increase in student absence [3–5], and affected the academic performance of students [6–8].

IAQ alone is not sufficient to provide a good learning environment. Thermal comfort is also vital to the internal conditions of schools and is essential to the health of those who must stay indoors over an extended period of time on a routine basis. However, in several naturally ventilated schools, thermal comfort and ventilation rate do not meet the comfort range established by ASHRAE [9,10].

Several studies revealed that the occupants of NV buildings accepted higher indoor temperatures in summer and lower temperatures in winter, and they also accepted wider temperature ranges [11,12]. However, most of these studies involved adult subjects, mainly in offices [13]. Therefore, there is no assurance that these

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results apply to children. Moreover, the seasonal fluctuation of ambient temperature and relative humidity and as a result the ventilation rate may have effects on symptoms typical of SBS, student environment perception, and their productivity.

According to the literature, no data were available pertaining to thermal response and comfort in Mediterranean schools located in Arabian countries [14]. Thus, the aim of the present study was to clarify seasonal variation in a perceived indoor environment, the thermal comfort status, and ventilation rates in naturally ventilated schools in a Mediterranean area (Gaza Strip). In addition, this study is considered the first effort to characterize the dimensions of the current situation in relation to thermal comfort and ventilation rates in selected schools in the study area.

## 2. Materials and methods

### 2.1. Study area

This study was conducted in schools situated in the Gaza Strip of the Palestinian territories. The Gaza Strip is a semiarid coastal land of roughly 360 $km^2$ of arable land between longitudes 34°2" and 34°25" east and latitudes 31°16" and 31°45" north located at the eastern coast of the Mediterranean Sea as shown in Figure 1. The study area is part of the coastal zone in a transitional area between a temperate Mediterranean climate to the east and north and the arid climate of the Negev and Sinai deserts to the east and south. As a result, the Gaza Strip has a characteristic semiarid climate. The area is characterized by a Mediterranean climate with 4 months of hot dry summer and a short winter with rain from December to March. Fall (September–mid December) is characterized by an abrupt summer-type weather in the first three months, while the rest of this period is characterized by the unsettled weather of winter. The average summer and winter temperatures in the Gaza Strip are 25 °C and 7 °C, respectively. The daily relative humidity fluctuates between 65% in the daytime and 85% at night in the summer, and between 60% and 80%, respectively, in winter [15–17].

### 2.2. Sampling

Sampling was performed in 12 naturally ventilated school buildings with no provision for thermal conditioning (e.g., space heating for the winter). The selection of schools was based on the geographical distribution of the students, building prototype, and male or female students in the schools. Table 1 and Figure 1 present the details of each school. All schools in the Gaza Strip are naturally ventilated with three-story buildings and total height of 10 m. There are two common design models for schools buildings. The first is the L-shape model, which is naturally cross ventilated and single banked. The second is the parallel-shape model, which is cross ventilated and double banked and consists of two symmetric rows of classrooms meeting in corridors. Due to the large number of students, most of the schools work in double sessions. During fall the selected schools worked in the afternoon session. Thus, the sampling was held in fall from 1200 to 1700 during complete schools hours (5 h). Further, the selected schools worked in the morning session during winter. Thus, the sampling was held from 0700 to 1200.

The monitoring was carried out for three days in each school during fall and winter. An initial inspection of wind direction was made on the first day of monitoring to identify the windward side of the building. Therefore, three classrooms from the ground, 1st, and 2nd floors (same windward side of the building) were selected.

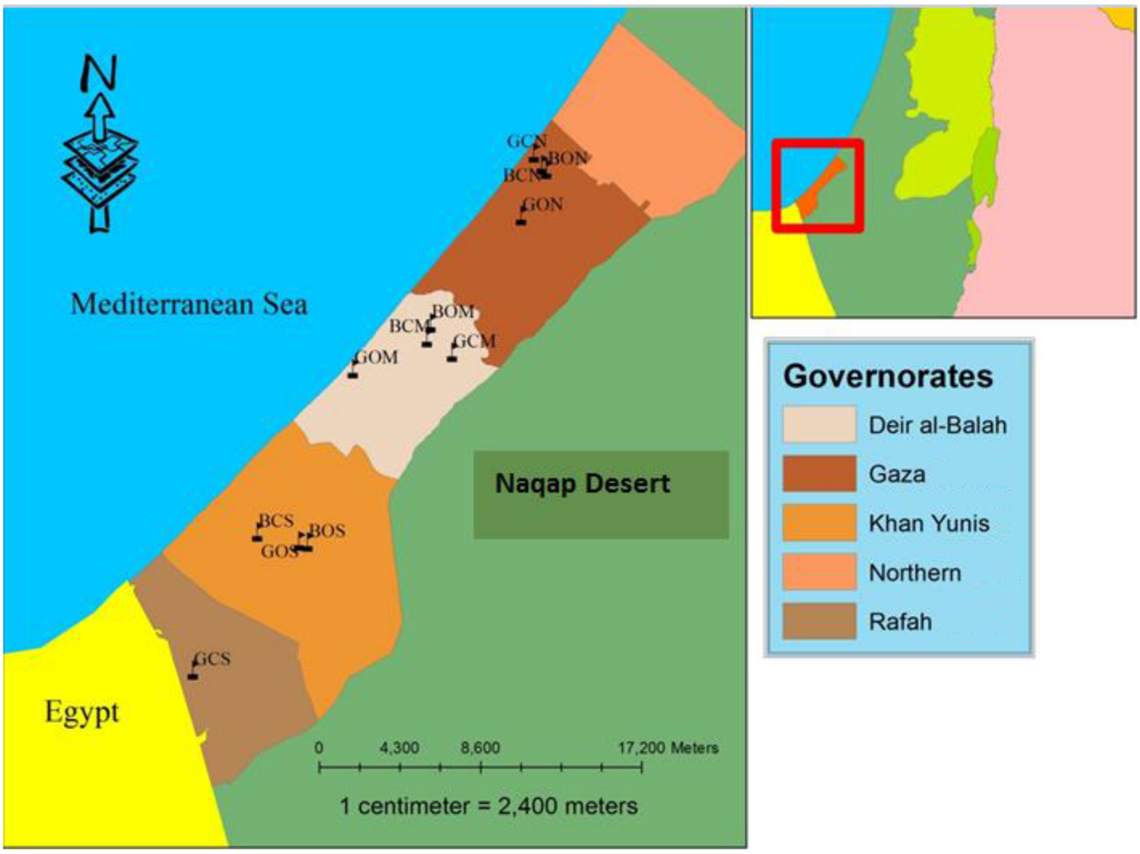


**Figure 1.** Map of the Gaza Strip and the monitoring locations.

**Table 1.** Characteristics of case study schools.

| School name | Code | Number of students | Building schematic | Windows area ($m^2$) | Ventilator area ($m^2$) |
|---|---|---|---|---|---|
| Nusirate Prep Boys A | MCB | 733 | Parallel | 9 | 2 |
| Nusirate Prep Boys D | MOB | 712 | L-shape | 15 | - |
| Elburaj Prep Girls B | MCG | 903 | Parallel | 9 | 2 |
| Dier Elbalah Prep Girls | MOG | 1024 | L-shape | 15 | - |
| Bany Suhiela Prep Boys | SOG | 1132 | L-shape | 15 | - |
| Bany Suhiela Prep Girls B | SOB | 1448 | L-shape | 15 | - |
| Ahmad Abed Elaziz Prep Boys B | SCB | 729 | Parallel | 9 | 2 |
| Rafah Prep Girls B | SCG | 578 | Parallel | 9 | 2 |
| Elzaytoon Prep Girls B | NOG | 883 | L-shape | 15 | - |
| New Gaza Prep Boys A | NCB | 1066 | Parallel | 9 | 2 |
| Beach Prep Girls B | NCG | 1183 | Parallel | 9 | 2 |
| Salah Eldien Prep Boys | NOB | 623 | L-shape | 15 | - |

The data were collected on window and door opening/closing by students during the periods monitored to connect envelope modifications to natural ventilation rates. To indicate the overall IAQ and to provide a means of inferring the ventilation rate based on the number of occupants, and the levels of $CO_2$ were monitored at 15 min intervals throughout the occupied day. Kanomax IAQ Monitor (Nondispersive Infrared) (Model 2211) (accuracy: 3% of reading or ±50 ppm, whichever is larger) was used for the indoor and outdoor measurements.

The Kanomax IAQ monitor included a thermistor that measured ambient temperature (Temp) (accuracy: ±0.5 °C) and capacitive sensors measuring relative humidity (RH) (accuracy: ±3%). Zero and span were checked at regular intervals using zero air and a standard $CO_2$ concentration. Sampling was conducted both inside and outside of the selected classrooms during the studying activities. The sampler was placed inside the classroom opposite the blackboard at least 1 m from the wall and at least 1.5 m height from the floor [18]. For outdoor sampling, the sampler was placed at the front side of the building usually near the playground area. Due to lack of multiple samplers, indoor and outdoor measurements were taken alternately every 15 min.

### 2.3. Thermal comfort

According to the adaptive model of thermal comfort from ASHRAE Standard 55-2010, the range of indoor comfort temperature for a naturally conditioned space can be determined from the prevailing mean outdoor temperature (mean monthly outdoor temperature) and by using operative temperature [19]. To calculate the operative Eq. (1) is used.

$$\theta_c = 17.8°\text{C} + 0.31 \times t_{o,3days} \quad (1)$$

where $\theta c$ is the operative temperature and $t_{o,3days}$ is the outdoor ambient air temperature for the last 3 days.

Clothing insulation is the thermal insulation provided by clothing. Based on the ASHRAE Standard 55, and by observing the students in the class, the clothing and metabolic rate were estimated. Since it is compulsory for all students in this school to wear school uniform the lower clothing value was set at 0.5 Clo (which is for light fall ensemble), and the upper clothing value was set at 1 Clo (which is for typical indoor winter ensemble). In a naturally ventilated building located in an area with a Mediterranean climate the internal air speed was set 0.1 to 0.3 m/s, where 0.1 m/s is classified as not noticeable airflow and 0.3 m/s is classified as barely noticeable airflow [20].

### 2.4. Questionnaire

An adapted version of MM06 school questionnaire was used to investigate whether the classroom was comfortable for a substantial majority (at least 80%) of the students and to measure the occupant perception towards their indoor thermal comfort, air movements, and health symptoms that students complain about [21]. The questionnaire is a validated self-administered questionnaire designed for the epidemiological assessment of IAQ and SBS symptoms, and has been widely used in different studies [22,23]. The questionnaire was distributed during IAQ measurements in fall for 364 students, and repeated in the same classrooms for winter for a random sample of 360 students. The questionnaires were administered concurrently with the other measurements. From each of the 36 classrooms 10 students were selected randomly using the SPSS random number generator.

All 724 students (100%) participated in the baseline and follow-up questionnaire study in 12 schools. Regarding the characteristics of the participants, 50.9% were girls, 49% studied in L-shape schematic buildings, 33.2% were in ground level classrooms, and 33.9% were on the first level story. The average age was 14 years (range from 13 to 15).

### 2.5. Ventilation rate

The use of indoor concentration of carbon dioxide as a surrogate of the ventilation levels per occupant using $CO_2$ exhaled by occupants as a tracer gas offers a number of advantages, such as ease of measurements and a well-established methodology [18,24]. The generation of $CO_2$ and consumption of oxygen depend primarily on level of physical activity and occupant size [25]. Therefore, $CO_2$ concentrations have been used to calculate ventilation rate of classrooms using the following steady state Eq. (2):

$$Q_O = \frac{1.8 \times 10^6 \times G}{C_{in-C_o}}, \quad (2)$$

where $Q_o$ is the outdoor airflow rate into the space (L/s), $G$ is the estimated $CO_2$ generation rate in the space (L/s), $C_{in}$ is the measured indoor $CO_2$ concentration in the space (mg/m$^3$), and $C_{out}$ is the measured outdoor $CO_2$ concentration (mg/m$^3$). The $CO_2$ generation rate of an individual student ($G$) is calculated using Eq. (3):

$$G = V_{O2} \times RQ, \quad (3)$$

where $V_{O2}$ is the rate of oxygen consumption in L/s, and $RQ$ is the respiratory quotient, i.e. the relative volumetric rates of $CO_2$ produced to $O_2$ consumed. The value of $RQ$ depends on the diet, level of physical activity, and physical condition of the person [26]. Rate of oxygen consumption $V_{O2}$ can be calculated using the following Eq. (4):

$$v_{o2} = \frac{0.00278 \times AD \times M}{20.23 \times RQ + 0.77}, \quad (4)$$

where $M$ is the level of physical activity, or the metabolic rate per unit of surface area, in Mets; $RQ$ is the respiratory quotient; and $AD$ is the DuBois surface area in m$^2$, which can be calculated using the following Eq. (5):

$$AD = 0.203 \times H^{0.725} \times W^{0.425}, \quad (5)$$

where $H$ is the body height (m) and $W$ is the body mass (kg). The height and weight averages were obtained from students' health records and from Abudayya et al. [27]. The average DuBois surface area ($AD$) was calculated as 1.41 m$^2$ for male students by taking their average height of 1.53 m and average weight of 45.80 kg. In the same way, the average DuBois surface area ($AD$) was calculated as 1.44 m$^2$ for female students by taking their average height of 1.54 m and average weight of 48.40 kg. Using the previous equations (2 to 5) and Table 2 data, which give typical Met levels for various activities, and the $RQ$ value as 0.83, which was estimated by ASHRAE 62-1999, the ventilation rate was calculated.

**Table 2.** Typical Met level for various activities.

| Activity | Met |
|---|---|
| Seated, quiet | 1.0 |
| Reading and writing, seated | 1.0 |
| Walking at 0.9 m/s | 2.0 |
| Exercise | 3.0–4.0 |

## 3. Results and discussion

### 3.1. Overview

The levels of study parameters $CO_2$, temperature, relative humidity, and building ventilation rate in the selected sites were investigated using descriptive statistics in order to describe the basic features of the data sets. Table 3 shows the results of the environmental monitoring obtained at the 12 schools (36 classrooms) compared with the results obtained for outdoor monitoring and with ASHRAE standards.

**Table 3.** Detailed statistics of temperature, relative humidity, ventilation rate and $CO_2$.

| Parameters | Fall | | Winter | | ASHRAE |
|---|---|---|---|---|---|
| | Min–Max | Mean ± S. Dev | Min–Max | Mean ± S. Dev | Standards |
| $Temp_{indoor}$ (°C) | 11.8–30.6 | 25.1 ± 4.3 | 10.9–28.8 | 16.1 ± 4.0 | 23.0–26.0 |
| $Temp_{outdoor}$ (°C) | 10.6–31.6 | 25.4 ± 4.8 | 8.3–29.7 | 15.5 ± 4.5 | N/A* |
| VR (L/s per person) | 3.7–29.1 | 9.3 ± 4.6 | 1.5–28.8 | 7.2 ± 3.7 | 7.5 |
| $CO_{2indoor}$ (ppm) | 457.6–1881.9 | 787.1 ± 225.1 | 486.3–2370.9 | 1155.8 ± 321.7 | 1000.0 |
| $CO_{2outdoor}$ (ppm) | 390.0 - 485.0 | 398.54 ± 16.6 | 400.0 - 754.7 | 602.3 ± 64.8 | |
| RH $_{indoor}$ (%) | 41.9–96.3 | 61.9 ± 8.6 | 37.3–100.0 | 65.6 ± 11.7 | 40.0%–60.0% |
| RH $_{outdoor}$ (%) | 29.5–95.0 | 59.5 ± 7.8 | 28.4–94.0 | 63.7 ± 13.7 | N/A* |
| WS (m/s) | 0.1–7.0 | 3.5 ± 1.5 | 0.1–13.0 | 3.2 ± 2.5 | N/A* |

*Not Available

### 3.2. Seasonal variation in indoor temperature and thermal sensation

In naturally ventilated buildings, indoor temperatures fluctuate in response to the natural swings of the outdoor and indoor climate [28]. During fall the indoor air temperature ranged between 24.5 and 30.6 °C. Meanwhile, during winter the indoor air temperature ranged between 10.0 and 21.0 °C with an average of 14.7 °C.

Thus, as shown in Table 4, the adaptive comfort model was applied to the Gaza Strip based on monthly meteorological data from the Palestinian Meteorological Department (PMD). The indoor comfort operative temperature range was found to vary over the year and ranged from 19.40 to 28.3 °C using 80% acceptable limit with an average around 26.3 °C, 22.2 °C, and 23.2 °C in fall, winter, and spring, respectively.

**Table 4.** Calculated thermal comfort temperature.

| | School | SOB | MOB | NOB | MCG | NCG | MCB | NOG | MOG | SCG | NCB | SCB | SOG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fall | Outdoor Temp | 29.5 | 29.4 | 29.1 | 28.6 | 28.4 | 28.4 | 27.6 | 26.9 | 26 | 25.5 | 25.4 | 25 |
| | Indoor Temp | 28.6 | 28.7 | 29.2 | 27.1 | 28.2 | 27.5 | 27 | 26.5 | 26.1 | 25.4 | 25.8 | 24.8 |
| | TC (Average) | 25.32 | 25.32 | 25.32 | 25.32 | 25.32 | 25.32 | 24.33 | 24.33 | 24.33 | 24.33 | 24.33 | 24.33 |
| | TC (Min) | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| | TC (Max) | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 |
| | *Comfort status | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Winter | Outdoor Temp | 14.29 | 14.9 | 20.6 | 12.83 | 13.62 | 14.08 | 14.81 | 14.91 | 15.01 | 14.43 | 13.68 | 13.4 |
| | Indoor Temp | 14.3 | 15 | 22 | 13.7 | 14.4 | 14.7 | 14.6 | 14.6 | 15.3 | 14.9 | 14.4 | 16.2 |
| | TC (Average) | 23.24 | 23.24 | 24.28 | 22.66 | 22.66 | 22.66 | 23.24 | 23.24 | 23.24 | 23.24 | 22.66 | 22.66 |
| | TC (Min) | 19.4 | 19.4 | 20.5 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 |
| | TC (Max) | 26.4 | 26.4 | 27.5 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 | 26.4 |
| | *Comfort status | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

* 1 = too warm; 2 = comfortable; 3 = too cold

Differences in thermal comfort temperature between the two seasons were observed, suggesting that there are relaxed limits in the range of operative temperatures for determining comfort in a NVB space. This is with agreement with previous studies [29,30]. Moreover, by comparing measured indoor air temperature with 80% acceptability limits the result revealed that 75% of the monitored schools were within the thermal range during fall. Meanwhile, during winter 100% of the samples fell within the cold side.

The frequency distribution of thermal sensation votes is given in Figure 2. It is seen that 90.6% of the votes recorded ranged from –2 (too cold) to –1 (cold) with more than 60% of the students feeling cold (–1) in winter. Meanwhile, during the sampling period the indoor temperature for the students who felt cold ranged from 13.47 °C to 16.70 °C, with an average of 15.08 °C, and below the thermal comfort standard as presented previously. Further, 78.5% of the votes recorded ranged from +1 (warm) to +2 (hot) with 49% feeling hot in fall. The indoor temperature for the students who felt hot ranged from 24.60 °C and 30.21 °C, with an average of 27.40 °C in fall, close to the mean indoor air temperature of 27.06 °C.

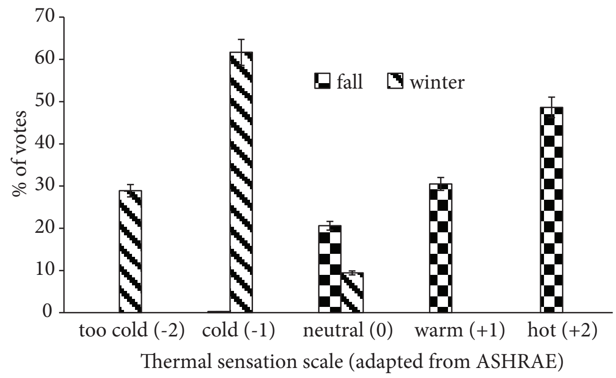


**Figure 2.** The frequency of the thermal sensation among the students.

The thermal comfort data showed that 75% of the schools in fall were within the acceptable thermal comfort range; however, the students were not satisfied by this proposed thermal comfort. Different studies conducted in various countries have indicated that significant discrepancies exist between the predicted values and actual responses in occupied buildings with no uniform direction on the comfort scale [14]. Moreover, the results of research conducted in Singapore .[31], Japan [9], Jordan [32], and Hawaii [33] revealed that thermal comfort in school buildings is alarming. Different studies of thermal comfort use linear regression to analyze the ASHRAE scale-based sensation votes against the temperature [34–36].

The simple linear regression fitted equation gives information on the slope (thermal sensitivity), the intercept (neutral temperature), and the level of statistical significance ($R^2$). [34]. Moreover, to eliminate the influence of individual differences in regression analysis the mean sensation votes (MSVs) in each 0.5 temperature increment were used instead of the individual actual votes [29]. The MTSV for each increment in temperature is presented in Figures 3a and 3b. The fitted equations can be expressed mathematically as shown in Eq. (6) and Eq. (7) for fall and winter.

$$MTSV\ (fall) = 0.186 \times t_i - 3.714(R^2 = 0.813) \tag{6}$$

$$MTSV\ (winter) = 0.095 \times t_i - 2.315(R^2 = 0.748) \tag{7}$$

where $t_i$ is the measured indoor temperature and MTSV is the mean thermal sensation vote. The $R^2$ value of the regression suggests a robust relationship between the MTSV and the indoor temperature. The neutrality is obtained by solving equations (5 and 6) for a mean sensation of zero. The predicted neutral air temperatures for fall and winter are presented in Table 5.

The predicted neutral temperature for winter is greater than that predicted in fall due to physiological acclimation and behavioral adjustment. Wang et al. [37] reported that subjects prefer colder environments in hot and humid areas, while occupants prefer warmer climates in cold areas, which indicates that human responses to thermal stress are influenced by psychological expectation. Further, Frontczak and Wargocki [11] reported that differences in neutral temperatures between seasons were observed in areas with warm winters and hot summers, while in areas with cold winters and warm summers almost no differences between seasons were seen. In addition, studies performed previously in offices and residential buildings [38,39] in the Middle

East indicated that resident-preferred conditions are usually somewhat cooler in summer, which is in accordance with our findings.

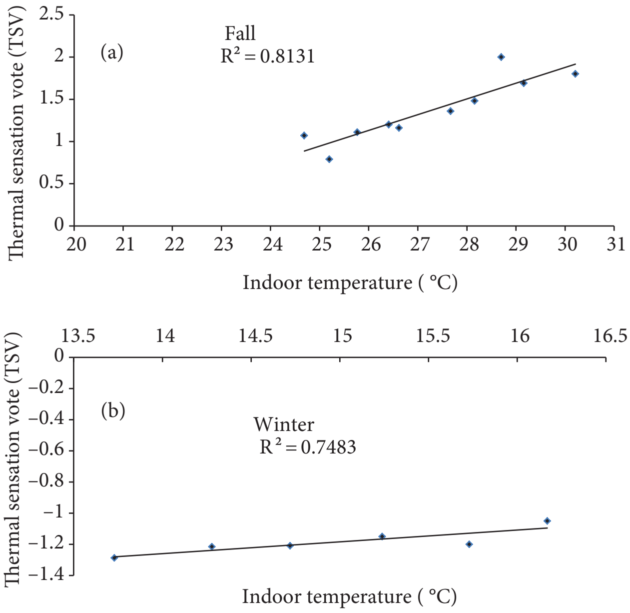


**Figure 3.** Regression of sensation votes against indoor air temperature (a) fall and (b) winter.

**Table 5.** Summary of calculated and predicted thermal comfort temperature.

| Season | Calculated $T_C$ using adaptive model | | | | | Predicted $T_c$ |
|---|---|---|---|---|---|---|
| | | 80% accepted | | 90% accepted | | |
| | Average $T_c$ | Min | Max | Min | Max | |
| Fall | 26.30 | 21.30 | 28.30 | 22.30 | 27.30 | 20.00 |
| Winter | 22.20 | 19.40 | 26.40 | 20.40 | 25.40 | 24.40 |

During winter the predicted neutral temperature was within the adaptive model. However, during fall the neutral temperature was 1.3 °C, lower than the minimum 80% acceptable limit. Current thermal comfort models are based on studies with adult subjects, mainly in offices. Therefore, there is no assurance that these models apply to children [13]. Therefore, the adaptive algorithms for naturally ventilated buildings need to be modified, taking into consideration seasonal differences to be suitable for children's environments. Various other field studies in naturally ventilated schools located in different climates and environments [13,34,36] reported the same conclusion.

### 3.3. Seasonal variation in relative humidity and humidity sensations

The weather in the Gaza Strip is very hot and humid during fall, and cold and humid during winter. Indoor RH in the two seasons is almost the same as the outside relative humidity, as shown in Table 3 and Figure 4a. During winter, relative humidity was higher than the ASHRAE standard 55-2004 [40] in most of the schools. The frequency distribution of humidity sensation votes is given in Figure 4b. More than 75% of the students felt too humid (–2) in fall, while 49% felt humid (–1) in winter. From the sample, 30% of the students voted neutral (0) in winter, and 70% voted for the two categories (–1, humid; –2, too humid) within the humidity range of 42.5% to 77.3%. This result means that most students were not satisfied with the humidity conditions either in winter or in fall. Therefore, indoor classroom environments in naturally ventilated buildings might not be able to provide suitable humidity comfort [9,10].

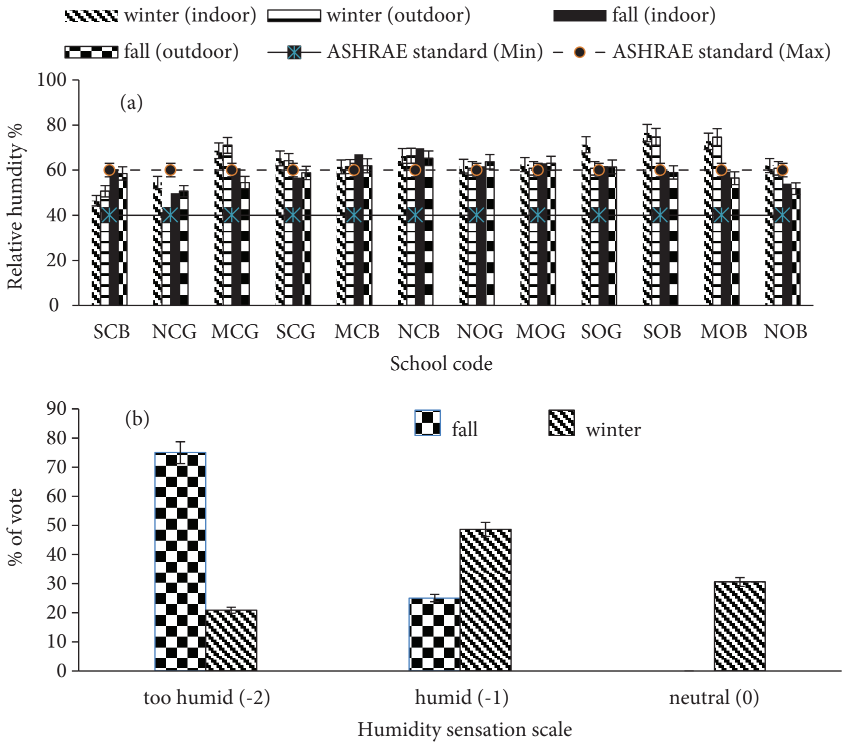


**Figure 4.** (a) Seasonal variation of relative humidity and (b) humidity sensation vote.

### 3.4. Seasonal variation in ventilation rate

Given the typical occupant density of 33 per 90 $m^2$ (2.7 $m^2$/student), the current ASHRAE standards recommend a minimum ventilation rate of 7.5 L/s per person (15 cfm/person) for classrooms [25]. The ventilation rate ranged from 1.5 L/s per person to 29.1 L/s per person with mean 8.27 ± 4.56 as shown in Table 3. Figure 5 shows that 83.3% of the schools in winter were below the ASHRAE 62-2004 standard. Furthermore, during fall, 50% of sampled schools were below the standard. This poor ventilation rate was related to two main reasons. Several classrooms had windows that were shut by students during the cold season to maintain thermal comfort or were obstructed by posters and furniture to prevent sun rays in fall. On the other hand, the ventilation rate in naturally ventilated building depends on two forces, wind driven force and buoyancy-driven force. While wind is the main mechanism of wind driven ventilation, buoyancy-driven ventilation occurs as a result of the directional buoyancy force that results from temperature differences between indoors and outdoors.

It is worth noting that when comparing the mean of Temp, RH, and ventilation rate by season, school schematic, geographical location, and floor level, a significant difference was noted ($P < 0.001$) between seasons as presented in Table 6.

Further, a significant difference was noted between the two school schematics in ventilation rate. This difference may be due to the difference in the window area, where the L-shape building schematic has more area of windows compared with the parallel shape [41].

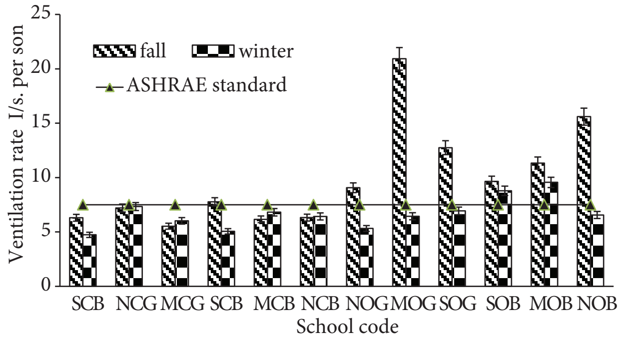


**Figure 5.** Seasonal variation in ventilation rate.

**Table 6.** Indoor environment data mean comparisons using t-test and one way ANOVA.

| | t-test | | One way ANOVA | |
|---|---|---|---|---|
| | Building schematic | Season | Location | Floor level |
| Temp | 0.331 | < 0.001* | 0.891 | 0.952 |
| RH | 0.101 | < 0.001* | 0.262 | 0.792 |
| Ventilation rate | < 0.001* | < 0.001* | 0.331 | 0.801 |
| $CO_2$ | < 0.001* | < 0.001* | 0.581 | 0.873 |

*P-value is significant at the 0.05 level

## 4. Conclusion

Records on temperature, relative humidity, ventilation rate, and perceived IAQ were monitored in 36 classrooms in 12 naturally ventilated schools that serve students in the Gaza Strip. During the study period, temporal and seasonal variations were observed for all mentioned parameters. The presented study shows significant differences between the observed students' thermal comfort and thermal comfort standards. The unsatisfied thermal sensation trends suggest that there may be temperature issues and risks that may pose health problems and affect student productivity. Furthermore, the adaptive comfort model did not accurately predict the seasonal thermal comfort conditions in the surveyed schools. Due to higher metabolic rate per kg body weight and schools activities children have a warmer thermal sensation than adults and prefer colder environments in the hot and humid season. The neutral temperature derived from the predicted MTSV during fall was about 1.3 °C lower than that predicted from the adapted thermal standard. Thus, this finding suggests that the ASHRAE 55-2010 adaptive comfort model is more appropriate for children's environments as studies on current thermal comfort models are with adult subjects and mainly conducted in offices.

Monitoring has shown that students tended to open or close windows to have a satisfactory indoor temperature and as a result the ventilation rates in most of the schools were below the ASHRAE standard. Based on the results presented here, it is necessary to set higher standards in school design and school regulations in order to ensure the delivery of suitable thermal comfort and ventilation rates for children.

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