

# Thermal Comfort Evaluation and Building Heat Gain Assessment of Naturally Ventilated Public-School Classrooms in Rodriguez, Rizal: Basis for Thermal Comfort Intervention

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## Index Terms:

thermal comfort, naturally ventilated classrooms, building heat gain, DepEd buildings, Philippine tropical climate.

**Abstract.** This study aimed to examine the indoor thermal environmental conditions and their relationship to the thermal comfort of occupants in a naturally ventilated public-school building in Rodriguez, Rizal, Philippines during the dry season. Indoor environmental parameters such as air temperature, humidity, etc., and mean radiant temperature were monitored at various floors of the building at three-hour intervals during the day. Thermal sensation votes of approximately 30 students per classroom using ASHRAE 55 survey were also recorded. The findings revealed significant vertical and temporal variations in indoor environmental conditions within the building. Higher floor levels consistently recorded higher environmental parameter compared with lower floors which indicates the influence of solar heat gain through the building envelope. Thermal sensation responses of students also reflected increasing levels of thermal discomfort during midday and afternoon periods when indoor temperatures were highest. Statistical analyses using Pearson correlation demonstrated strong relationships between thermal comfort responses and measured environmental variables, particularly mean radiant temperature and operative temperature. Repeated measures of ANOVA confirmed significant differences in thermal conditions among floor levels and across different periods of the day. The results highlight the substantial role of building heat gain and ventilation limitations in influencing indoor thermal comfort in naturally ventilated DepEd classrooms located in tropical climates. It also emphasizes the significance of the use of passive and active design strategies such as cross-ventilation, reflective paint, exhaust fans, and solar-powered whirlybirds to reduce heat stress in classrooms. Recommendations have been made to monitor the peak heat periods and limit the occupancy of classrooms when the thermal conditions exceed the safe comfort thresholds.

## Introduction

Thermal comfort is an important aspect in the providing a safe and conducive learning environment, especially in public schools. Indoor conditions like air temperature, air movement, relative humidity, and radiant heat greatly affect students' concentration and cognitive function. Prolonged exposure to heat in classrooms can lead to decreased attention span, increased fatigue, and decreased engagement in learning activities (Haverinen-Shaughnessy et al., 2015). Providing comfortable thermal conditions is therefore vital for effective teaching and learning.

In tropical countries like the Philippines, thermal comfort in naturally ventilated classrooms is difficult to maintain, especially during the dry season when temperatures and humidity are high. Although passive design techniques like operable windows and natural ventilation are effective in energy conservation it can lead to increased indoor temperatures during peak heat hours. Kasiglahan Village Senior High School in Rodriguez, Rizal has students in a three-story academic building with naturally ventilated classrooms. Observations indicate that the classrooms are hot, especially during midday and afternoon hours because of heat gain from roofs, walls, and direct solar radiation. However, there is a lack of empirical information on the actual classroom conditions. KVSHS academic building was chosen to be the representative naturally ventilated building that gives us a closer insight about the actual empirical data experienced by the learners.



The study was conducted at Kasiglahan Village Senior High School, Rodriguez, Rizal. The selected academic building consists of three floors with naturally ventilated classrooms, where students are primarily accommodated. Two classrooms per floor were selected for monitoring, resulting in 6 total monitored classrooms. The selected classrooms represented typical naturally ventilated learning spaces with similar construction materials, orientation characteristics, and occupancy patterns.

Measurements were carried out at three different periods of the school day, specifically at 8:00 AM, 12:00 PM, and 3:00 PM, to capture variations in indoor thermal conditions associated with solar heat gain and outdoor temperature fluctuations. Data collection was performed twice a week throughout the duration of the monitoring period. This DepEd 3-storey building follows the original plan taken from DPWH website, other schools in Rodriguez were also from this building plan. The selected school effectively represents all other naturally ventilated classroom building around the area.

### *The Sample*

The participants for the study were the students in the selected classrooms of Kasiglahan Village Senior High School. The convenience sampling approach was adopted and all students in the selected classrooms at the time of data collection were considered. The participation in the ASHRAE 55 thermal comfort survey was voluntary, and the students' answers were kept confidential and anonymous. The sample produced adequate result to determine the relationship between the measured building heat gain factors and the students' thermal comfort. There were a total sample of 182 students.

### *Measurement Parameters*

Environmental data will include:

- Indoor air temperature (dry bulb and wet bulb)
- Relative humidity
- Air velocity
- Surface temperatures of roof, ceiling, and walls
- Mean radiant temperature, estimated from measured surface temperatures

### *Research Instruments*

Environmental data were gathered using calibrated field measurement instruments to ensure the accuracy and reliability of the recorded thermal parameters. Indoor air temperature and relative humidity were measured using a digital hygrometer (HABOTEST, HT607), which provided simultaneous readings essential for evaluating indoor thermal conditions. Air velocity was measured using an anemometer (HABOTEST, HT605) to assess ventilation conditions within the classrooms. Surface temperatures of the ceiling, walls, floor, and roof were obtained using an infrared thermometer (BSIDE IR Thermometer), allowing the evaluation of radiant heat transfer from building envelope components.

All instruments were calibrated prior to data collection in accordance with the manufacturers' specifications to minimize measurement uncertainty and ensure consistency of readings throughout the monitoring period. In addition, occupants' thermal perception was assessed using a structured questionnaire based on ASHRAE Standard 55.

<b>Instrument</b>	<b>Brand/Model</b>	<b>Parameter Measured</b>	<b>Accuracy</b>
Hygrometer	HABOTEST/HT607	Temperature, RH	±0.5°C, ±3% RH
Anemometer	HABOTEST/HT605	Air velocity	±0.1 m/s
IR Thermometer	BSIDE IR Thermometer	Surface temperature	±2°C

*Table 1. Environmental measuring tools brand and model.*

### *Data Collection Procedure*

Two classrooms were selected on each floor of the three-storey academic building to provide representative exposure to solar radiation and natural ventilation conditions. The choice of the classrooms was based on observations and reports of indoor environments that were perceived to have higher indoor temperatures. Before the actual data collection, all the data collection instruments were calibrated in accordance with the manufacturer's requirements to ensure accuracy and consistency in data collection.

Environmental measurements were carried out three times during the school day, specifically at 8:00 AM, 12:00 PM, and 3:00 PM, two to three times per week for a period of eight consecutive weeks to capture daily variations and peak thermal

conditions. During each schedule, the indoor air temperature, relative humidity, air velocity, and outdoor air, surface temperature of the ceiling, walls, and floor were collected using a digital hygrometer, anemometer, and IR thermometer, respectively. The students in the classrooms where data collection on the indoor environment had taken place were asked to fill in a questionnaire on their thermal comfort based on the ASHRAE Standard 55 framework to obtain data on their perception of indoor thermal comfort. All observations and instrument readings were systematically documented in a prepared data sheet and later organized in a spreadsheet.

*Conceptual Framework*



*Figure 2. Overview of the naturally ventilated building thermal assessment.*

*Computation of Thermal Comfort Parameters*

Thermal comfort parameters were computed using measured environmental data to evaluate indoor thermal conditions in the monitored classrooms. Mean radiant temperature was estimated from the measured surface temperatures of the ceiling, walls, and floor to represent the combined radiant effect of surrounding building elements on occupants. For practical field application in enclosed classroom spaces with relatively uniform geometry, mean radiant temperature was approximated using the average of the principal surface temperatures, expressed as:

$$T_{MRT} = \frac{T_{ceiling} + T_{walls} + T_{floor}}{3}$$

where  $T_{MRT}$  is the mean radiant temperature in degrees Celsius ( $^{\circ}C$ ), and  $T_{ceiling}$ ,  $T_{walls}$ , and  $T_{floor}$  are the corresponding measured surface temperatures.

Operative temperature, which accounts for the combined influence of air temperature and radiant heat exchange on human thermal sensation, was then calculated. Considering the low indoor air velocity conditions typical of naturally ventilated classrooms, operative temperature was determined using the simplified relationship:

$$T_{op} = \frac{T_{air} + T_{MRT}}{2}$$

where  $T_{op}$  is the operative temperature ( $^{\circ}C$ ) and  $T_{air}$  is the measured indoor air temperature ( $^{\circ}C$ ).

To evaluate thermal comfort acceptability under naturally ventilated conditions, the adaptive comfort model framework prescribed in ASHRAE Standard 55 was applied. The running mean outdoor temperature was first computed to represent prevailing climatic conditions using:

$$T_{rm} = 0.8T_{od-1} + 0.2T_{od-2}$$

where  $T_{rm}$  is the running mean outdoor temperature ( $^{\circ}\text{C}$ ), and  $T_{(od-1)}$  and  $T_{(od-2)}$  are the average outdoor temperatures recorded during the previous days. Based on this value, the neutral indoor comfort temperature was estimated as:

$$T_{neutral} = 0.31T_{rm} + 17.8$$

The acceptable indoor comfort range for naturally ventilated spaces was then determined using:

$$T_{lower} = T_{neutral} - 2.5$$

$$T_{upper} = T_{neutral} + 2.5$$

These computed limits were used to assess whether the measured operative temperatures fell within acceptable adaptive comfort conditions. The calculated thermal comfort parameters were subsequently compared with students' thermal sensation responses to establish relationships between physical measurements and perceived comfort in the classroom environment.

The following assumptions were applied in the computation of thermal comfort parameters:

1. Human Occupancy: Each classroom was assumed to have a typical student occupancy of 30 students and one teacher during measurement periods, with metabolic rates of 1.2 met for students (seated, light activity) and 1.4 met for teachers (standing, light activity). Clothing insulation was assumed to be 0.5 clo for students and 0.6 clo for teachers, representing standard school attire.
2. Air Velocity: Indoor air velocity was assumed to be low ( $<0.2$  m/s) to justify the simplified averaging method for operative temperature calculation.
3. Uniform Surface Temperatures: Ceiling, walls, and floor surfaces were assumed to be uniform within each classroom, allowing the use of simple averaging to estimate mean radiant temperature.
4. Steady-State Conditions: Measurements were assumed to reflect quasi-steady-state conditions during each monitoring period, acknowledging that transient fluctuations may occur between time intervals.
5. Occupant Adaptation: Students and teachers were assumed to exhibit typical behavioral adaptation strategies consistent with naturally ventilated classrooms, in line with the adaptive comfort model.

The computed thermal comfort parameters were subsequently compared with students' thermal sensation responses to establish relationships between physical measurements and perceived comfort in the classroom environment, enabling a comprehensive evaluation of heat gain and indoor thermal conditions.

### *Building Heat Gain Analysis*

The heat gain from the building envelope was assessed to quantify the contribution of individual classroom surface which are roof, ceiling, walls, and floor to indoor thermal conditions. Surface temperature measurements obtained from the infrared thermometer, together with classroom dimensions and material properties, were used to estimate the rate of heat transfer from each component. The total heat gain through a surface was calculated using the conduction formula for steady-state heat transfer:

$$Q = U \cdot A \cdot (T_s - T_{air})$$

where  $Q$  is the heat gain in watts ( $W$ ),  $U$  is the overall heat transfer coefficient of the surface ( $W/m^2 \cdot ^{\circ}\text{C}$ ) based on material thermal properties,  $A$  is the surface area ( $m^2$ ),  $T_s$  is the measured surface temperature ( $^{\circ}\text{C}$ ), and  $T_{air}$  is the indoor air temperature ( $^{\circ}\text{C}$ ).

For each classroom, the contributions of the ceiling, walls, and floor to the overall heat gain were computed separately, allowing the determination of which components exerted the greatest influence on mean radiant temperature and operative temperature. Roof contribution was already considered on the part of the ceiling. The analysis assumed quasi-steady-state conditions during each measurement period and negligible heat gain from internal sources beyond human occupancy.

The computed heat gain values were then correlated with measured operative temperatures and mean radiant temperatures to examine the effect of individual building envelope components on indoor thermal conditions. Graphical and tabular presentations, including floor-level comparisons and time-of-day trends, were used to illustrate the relative impact of roof, ceiling, wall, and floor surfaces on classroom thermal performance. This approach provided a quantitative assessment of building design factors influencing thermal comfort and supported evidence-based recommendations for reducing heat gain in naturally ventilated classrooms.

#### *Statistical Treatment*

The collected data were analyzed using appropriate descriptive and inferential statistical techniques to evaluate indoor thermal conditions and the influence of building heat gain on thermal comfort. Descriptive statistics, i.e., mean, standard deviation, minimum, and maximum, were used to analyze the gathered data concerning the environmental conditions such as indoor air temperature, relative humidity, air velocity, and surface temperature of the ceiling, walls, and floor, as well as the thermal sensation of the students using the thermal comfort survey results as per ASHRAE Standard 55. Pearson correlation analysis was performed to determine the strength and direction of relationships between surface temperatures and computed thermal comfort parameters, including mean radiant temperature and operative temperature. In addition, repeated measures analysis of variance was applied to evaluate the significant differences in the thermal conditions for different floor levels and measurement periods of the day. Graphical and tabular presentations such as line graphs, bar charts, and scatter plots, were used to present the trends, variations, and relationship between the variables facilitating the effective interpretation of the impact of building heat gain on thermal comfort.

#### *Ethical Considerations*

This research followed all the ethical standards required in conducting research among human participants. The participation in the ASHRAE 55 thermal comfort survey was voluntary, and the students were made aware of the purpose of the research and their involvement before the data is collected. The students were required to give their consent to participate in the research. The students' answers will be treated with confidentiality and anonymity, and no personal information will be connected to the data. All the measurements in the classrooms were collected in a way that there were no interruption of the teaching and learning process. The privacy, rights, and well-being of the participants were respected during the research.

## **Results and Discussion**

**General note:** “+ t” on time intervals was applied for data presentation convenience.

#### *Indoor Thermal and Environmental Conditions*

<b>FEBRUARY</b>						
<b>Floor</b>	<b>Room number</b>	<b>T<sub>air</sub> (°C)</b>	<b>RH (%)</b>	<b>V<sub>a</sub> (m/s)</b>	<b>MRT (°C)</b>	<b>Wetbulb (°C)</b>
<b>8:00 + t am</b>						
3	2	25.35	66.18	0.19	27.70	21.35
3	5	28.44	67.98	0.19	28.12	21.46
2	3	27.61	64.23	0.20	28.10	22.51
2	5	26.04	67.83	0.18	27.59	21.58
1	1	30.68	52.93	0.19	29.80	23.05
1	2	30.66	53.45	0.19	29.77	22.99
<b>12:00 + t pm</b>						
3	2	33.25	51.08	0.18	36.50	24.45
3	5	36.06	46.21	0.19	35.89	25.14
2	3	30.31	65.61	0.19	31.23	25.35
2	5	29.83	64.48	0.17	29.47	24.33
1	1	33.35	47.93	0.18	31.25	24.48
1	2	33.38	47.75	0.18	31.28	24.45
<b>3:00 + t pm</b>						
3	2	33.25	50.71	0.18	36.29	24.25

3	5	35.88	46.80	0.19	35.93	25.14
2	3	30.08	64.96	0.19	31.01	25.21
2	5	30.29	66.33	0.18	30.13	25.23
1	1	33.06	48.75	0.18	31.35	24.36
1	2	33.08	48.61	0.18	31.37	24.26

Note.  $T_{air}$  = Air temperature; RH = Relative humidity; Va = air velocity; MRT = Mean radiant temperature.

Table 2. Average indoor thermal and environmental conditions in February.

<b>MARCH</b>						
Floor	Room number	T <sub>air</sub> (°C)	RH (%)	Va (m/s)	MRT (°C)	Wetbulb (°C)
8:00 + t am						
3	2	29.93	63.53	0.19	29.67	22.42
3	5	29.69	63.64	0.19	29.40	22.31
2	3	26.04	67.83	0.18	27.59	21.58
2	5	26.04	67.84	0.18	27.59	21.58
1	1	30.71	52.93	0.19	29.79	23.04
1	2	30.32	52.68	0.19	29.53	23.12
12:00 + t pm						
3	2	37.78	42.19	0.18	37.88	26.29
3	5	37.58	42.33	0.18	37.77	26.18
2	3	29.83	64.48	0.17	29.47	24.33
2	5	29.83	64.53	0.17	29.49	24.29
1	1	33.34	47.93	0.18	31.26	24.47
1	2	32.93	47.78	0.18	30.99	24.48
3:00 + t pm						
3	2	37.54	42.88	0.19	37.91	26.40
3	5	37.41	43.12	0.19	37.76	26.28
2	3	30.29	66.33	0.18	30.13	25.23
2	5	30.28	66.29	0.18	30.13	25.22
1	1	33.06	48.64	0.18	31.33	24.32
1	2	32.71	49.06	0.18	31.04	24.33

Note.  $T_{air}$  = Air temperature; RH = Relative humidity; Va = air velocity; MRT = Mean radiant temperature.

Table 3. Average indoor thermal and environmental conditions in March.

The indoor thermal and environmental conditions of the selected classrooms showed obvious temporal and vertical variations, both in February and March, with higher values recorded in March. Indoor air temperatures were found to be moderately high ranging from 26.83 °C to 30.67 °C at 8 + t AM on all floors in February whereas temperatures were higher especially on the third floor where the average indoor temperatures were recorded as 29.81 °C. Mean radiant temperature varied similarly, showing higher values, especially on the third floor, where it recorded temperatures ranging from 27.91 °C in February to 29.54 °C in March. The first floor consistently recorded relatively high temperatures in the mornings, indicating retention of heat.

A significant increase in thermal conditions was noticed by 12 + t PM in both months with much higher increases in March compared to February. The third floor showed an average indoor air temperature of about 34.66 °C and an average mean radiant temperature of 36.20 °C in February while in March, these conditions were intensified significantly with increases in air temperature up to 37.68 °C and mean radiant temperature up to 37.83 °C. These conditions were intensified in the uppermost floor of the building due to exposure to the roof. In contrast, the second floor showed lower temperatures in both months, with increases in March up to 29.83 °C for air temperature and up to 29.48 °C for mean radiant temperature due to shielding from exposure to solar radiation. In addition, relative humidity decreased with increasing temperatures in both months, with lower relative humidity observed on the third floor in March.

At 3 + t PM, the high thermal conditions persisted in all floors with March again registering higher thermal conditions than February. The third floor was again under the highest thermal stress, with average indoor air temperatures averaging 37.48

°C and average radiant temperatures averaging 37.84 °C, compared to 34.57 °C and 36.11 °C, respectively, in February. The second floor continued to experience the lowest thermal conditions compared to the other floors, while the first-floor experienced moderate conditions. Air velocity was again low and consistent in both months.

Overall, it was found that indoor thermal conditions rise gradually from morning till midday and remain high in the afternoon for both months though significantly higher for March. The third floor showed consistently high values of air and radiant temperatures, as expected from the dominant roof heat gain, and the second floor showed relatively low values because of its relatively low exposure. The differences found between the two months confirmed the sensitivity of naturally ventilated classrooms to climatic conditions especially during warmer periods of the year and reinforced the combined action of air and radiant temperatures on indoor thermal environments. Detailed analysis of heat gain from building surfaces is presented in Section 4.2.

*Effect of Heat Transfer from Building Envelope*

**FEBRUARY**

Floor	Ceiling Temp (°C)	Wall Temp (°C avg)	Floor Temp (°C)	Roof Temp (°C)	MRT (°C)	Top (°C)
<b>8:00 + t AM</b>						
3	27.34	26.96	28.44	27.31	27.91	27.20
2	27.83	27.66	26.83	N/A	27.84	27.13
1	28.11	28.68	30.56	N/A	29.78	30.03
<b>12:00 + t pm</b>						
3	40.62	34.02	33.78	55.26	36.20	35.23
2	30.15	29.79	30.00	N/A	30.35	30.01
1	29.29	30.22	33.23	N/A	31.27	32.11
<b>3:00 + t PM</b>						
3	40.59	33.84	33.78	54.60	36.11	35.14
2	30.46	29.96	30.17	N/A	30.57	30.18
1	29.48	30.43	33.04	N/A	31.36	32.01

Note: MRT = Mean Radiant temperature; Top = Operating temperature.

*Table 4. Average effect of heat transfer from building envelope in February.*

**MARCH**

Floor	Ceiling Temp (°C)	Wall Temp (°C avg)	Floor Temp (°C)	Roof Temp (°C)	MRT (°C)	Top (°C)
<b>8:00 + t AM</b>						
3	29.53	28.32	30.02	27.86	29.54	29.47
2	27.94	27.51	26.14	N/A	27.66	26.68
1	28.09	29.17	30.40	N/A	29.66	29.89
<b>12:00 + t pm</b>						
3	41.79	35.44	36.23	58.36	37.82	37.55
2	28.76	28.86	29.78	N/A	29.49	29.47
1	29.26	30.06	33.02	N/A	31.12	31.93
<b>3:00 + t PM</b>						
3	42.21	35.27	36.14	58.16	37.83	37.46
2	29.66	29.47	30.22	N/A	30.15	30.03
1	29.39	30.26	32.77	N/A	31.18	31.83

Note: MRT = Mean Radiant temperature; Top = Operating temperature.

*Table 5. Average effect of heat transfer from building envelope in March.*

*Building Heat Gain Analysis*

The contribution of the components of the building envelope to the indoor thermal condition was evaluated based on the surface temperature measurements for the ceiling, walls, and floor. In Chapter 3, the heat transfer equations were presented, although the focus of the evaluation in the present chapter was on the relative effect of the components based on the temperature difference observed.

The findings revealed that the temperature for the ceiling was higher than the temperatures for the walls and the floor, especially on the third floor during the midday and afternoon periods. This indicates that the roof-ceiling assembly was the major contributor to the heat gain from the effect of solar radiation. The higher the temperature for the ceiling, the higher the MRT and Top, especially on the upper floor. Wall temperatures experienced moderate increases, which affected indoor heat gain to a lesser degree compared to the ceiling. Floor temperatures experienced the least changes with the least effect.

These results indicate the dominant effect of the roof/ceiling on heat transfer within the building, which explains the considerable vertical variation in thermal conditions observed on the different floors. These results confirm the correlation analysis results which indicated a strong positive correlation between the roof temperature and thermal comfort parameters such as MRT and TSV.

*Variation in Indoor Environmental Parameters Across Floors*

**FEBRUARY**

Floor	T <sub>air</sub> (°C)	Wetbulb (°C)	RH (%)	Va (m/s)	MRT (°C)
<b>8:00 + t am</b>					
3	26.89	21.41	67.08	0.19	27.91
2	26.83	22.04	66.03	0.19	27.84
1	30.67	23.02	53.19	0.19	29.78
<b>12:00 + t pm</b>					
3	34.66	24.79	48.64	0.18	36.20
2	30.07	24.84	65.04	0.18	30.35
1	33.36	24.46	47.84	0.18	31.27
<b>3:00 + t pm</b>					
3	34.56	24.69	48.76	0.18	36.11
2	30.18	25.22	65.64	0.18	30.57
1	33.07	24.31	48.68	0.18	31.36

*Note: T<sub>air</sub> = air temperature; Wetbulb = wetbulb temperature; RH = Relative humidity, Va = Air velocity; MRT = Mean radiant temperature.*

*Table 6. Average Variation in Indoor Environmental Parameters Across Floors in February.*

**MARCH**

Floor	T <sub>air</sub> (°C)	Wetbulb (°C)	RH (%)	Va (m/s)	MRT (°C)
<b>8:00 + t am</b>					
3	29.81	22.37	63.59	0.19	29.54
2	26.04	21.58	67.83	0.18	27.59
1	30.52	23.08	52.81	0.19	29.66
<b>12:00 + t pm</b>					
3	37.68	26.23	42.26	0.18	37.82
2	29.83	24.31	64.50	0.17	29.48
1	33.14	24.47	47.86	0.18	31.12
<b>3:00 + t pm</b>					

3	37.48	26.34	43.00	0.19	37.83
2	30.28	25.22	66.31	0.18	30.13
1	32.88	24.33	48.85	0.18	31.18

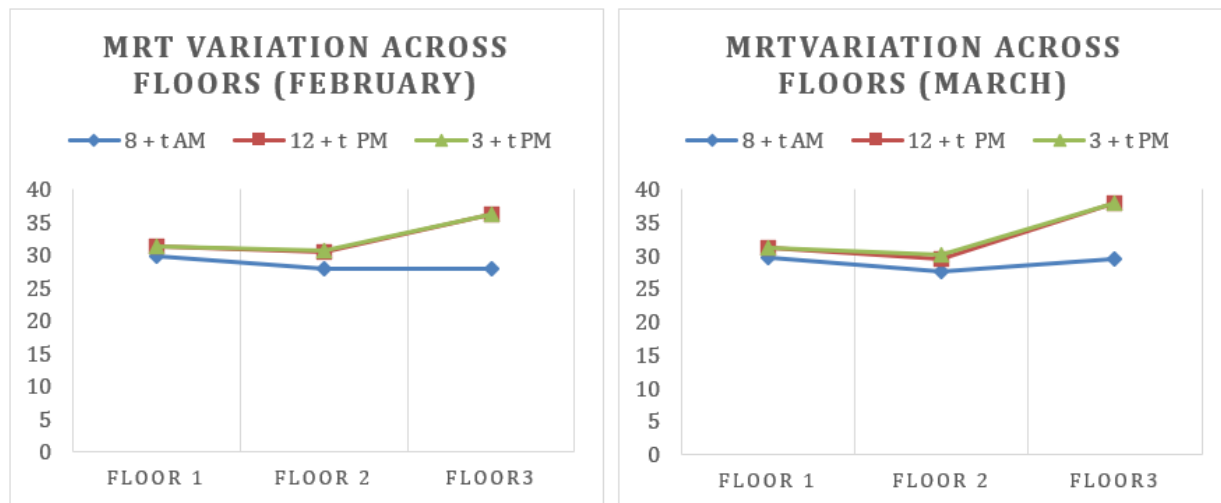
Note:  $T_{air}$  = air temperature;  $Wetbulb$  = wetbulb temperature;  $RH$  = Relative humidity,  $Va$  = Air velocity;  $MRT$  = Mean Radiant temperature.

*Table 7. Average Variation in Indoor Environmental Parameters Across Floors in March.*

The variation in indoor environmental parameters across floors indicated a pattern of vertical variation which was affected by building heat gain and exposure conditions. At 8 + t AM, the thermal conditions in both February and March were found to be moderate. The first floor had the maximum air temperatures in both months, which were 30.67 °C in February and 30.52 °C in March. The second and third floors had lower temperatures during this period which indicate minimal heat gain from the sun during the early morning. Mean radiant temperatures also followed the same pattern with slightly higher temperatures on the first floor indicating retained heat.

Significant changes in the readings on different floors were more pronounced by 12 + t PM particularly on the third floor. The air temperature in February on the third floor was 34.66 °C compared to 37.68 °C in March. Similarly, MRT on the third floor was 36.20 °C in February, which increased to 37.82 °C in March. These readings were substantially higher compared to the readings on the second floor, which were close to 30 °C in terms of air temperature and lower than 30 °C in terms of MRT in March. The first-floor readings were intermediate which indicates a partial influence of heat gain. Relative humidity readings decreased along with the increase in temperature, particularly on the third floor, but on the second floor, they were higher compared to the third floor.

At 3 + t PM, it is noted that high thermal conditions were maintained on all floors. The third floor showed the highest thermal readings for both months. In March, the air temperature and MRT on the third floor were 37.48°C and 37.83°C, respectively. The second floor showed the lowest thermal conditions, while the first floor showed moderate thermal conditions. The rate of air velocity on all floors and at all time periods remained constant. This showed that there was no effect of natural ventilation on alleviating the thermal conditions.



*Figure 3. Mean radiant temperature variation across all floors in February and March.*

Overall, the results showed that the thermal conditions differed significantly on each floor with the third floor being the most affected in terms of heat gain especially during peak hours. It was also noted that the second floor recorded the lowest temperatures and the highest relative humidity throughout the study suggesting a buffering effect due to lower solar exposure. The first floor recorded moderate conditions but higher temperatures in the early morning period. This confirmed that the vertical variation in indoor environmental conditions was affected significantly by heat gain especially in the building which results from roof exposure and solar radiation, which increased in the middle of the day and continued in the afternoon.

Parameter Variation Across Floors in February and March

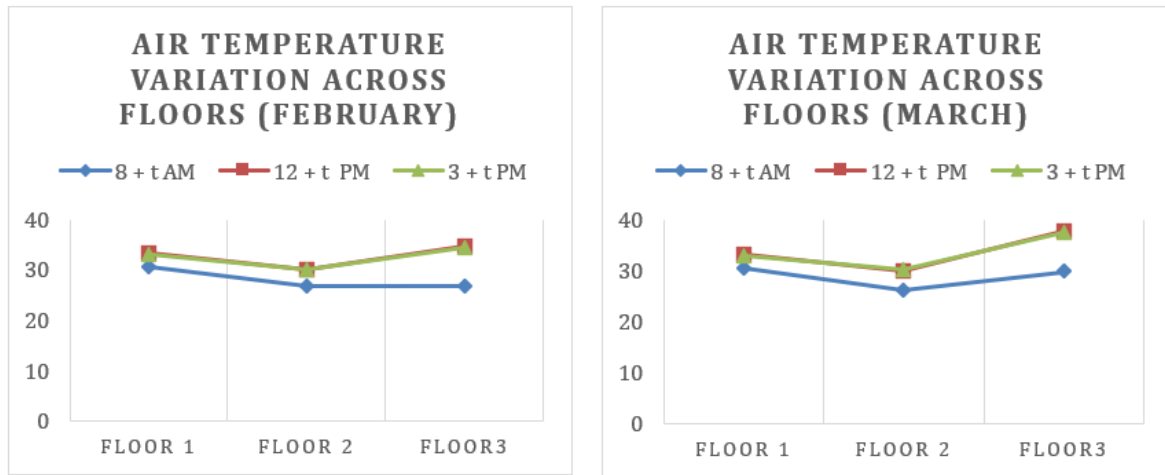


Figure 4. Air temperature variation across all floors in February and March.

As shown in Figure 3, indoor air temperature varied clearly across floors with the third floor consistently recording the highest values, which peaked at 34.66 °C (Feb) and 37.68 °C (Mar) at 12 + t PM which indicates strong heat gain from the roof and solar exposure. The first floor showed moderate temperatures (30–33 °C) while the second floor remained the coolest (26–30 °C) reflecting its buffered position between floors.

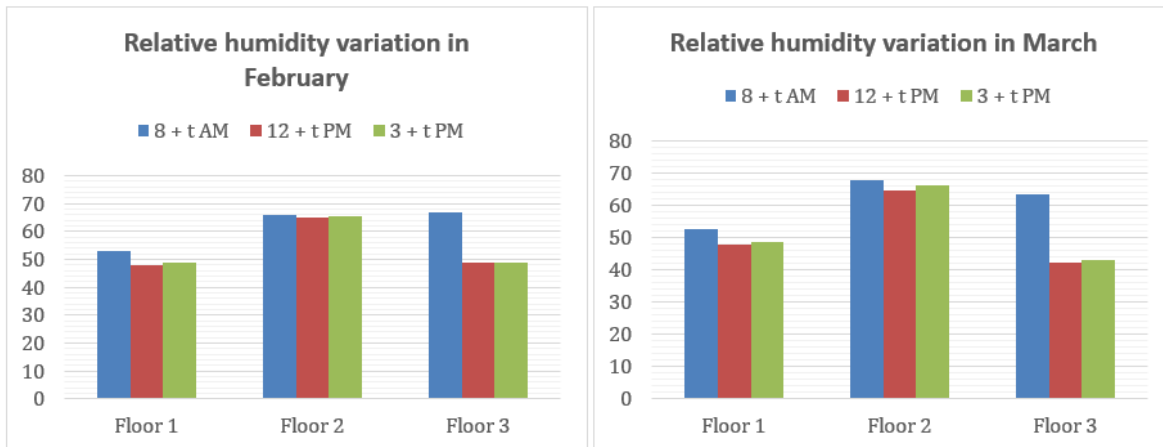


Figure 5. Relative Humidity variation across all floors in February and March.

Relative humidity (RH) varied across floors and reflected both heat gain and classroom occupancy. The second floor consistently recorded the highest RH (65–67% in Feb and Mar) which can be attributed to its cooler conditions and cumulative moisture from students. The third floor showed lower RH during midday and afternoon (48–43%), corresponding to higher air temperatures from roof solar exposure, which caused air to dry slightly despite occupancy. The first floor maintained moderate RH (48–53%), reflecting intermediate thermal conditions and typical classroom occupancy. These patterns indicate that RH was influenced by floor level and solar heat gain contribution with peak temperatures on the top floor reducing RH even with students present.

*Relationship Between Heat Gain and Thermal Comfort*

<b>FEBRUARY</b>				
<b>Floor</b>	<b>MRT (°C)</b>	<b>Top (°C)</b>	<b>Roof Temp (°C)</b>	<b>TSV</b>
8:00 + t AM				
3	27.91	27.20	27.31	1.06
2	27.84	27.13	N/A	1.00
1	29.78	30.03	N/A	1.25
12:00 + t pm				
3	36.20	35.23	55.26	2.75
2	30.35	30.01	N/A	2.38
1	31.27	32.11	N/A	2.38
3:00 + t PM				
3	36.11	35.14	54.60	2.81
2	30.57	30.18	N/A	2.63
1	31.36	32.01	N/A	2.44

*Note. MRT = Mean radiant temperature; Top = operating temperature; TSV = thermal sensation vote.*

*Table 8. Relationship Between Heat Gain and Thermal Comfort in February.*

<b>MARCH</b>				
<b>Floor</b>	<b>MRT (°C)</b>	<b>Top (°C)</b>	<b>Roof Temp (°C)</b>	<b>TSV</b>
8:00 + t AM				
3	29.54	29.47	27.86	1.06
2	27.66	26.68	N/A	1.06
1	29.66	29.89	N/A	1.31
12:00 + t pm				
3	37.82	37.55	58.36	2.69
2	29.49	29.47	N/A	2.44
1	31.12	31.93	N/A	2.31
3:00 + t PM				
3	37.83	37.46	58.16	2.81
2	30.15	30.03	N/A	2.88
1	31.18	31.83	N/A	2.38

*Note. MRT = Mean radiant temperature; Top = operating temperature; TSV = thermal sensation vote.*

*Table 9. Relationship Between Heat Gain and Thermal Comfort in March.*

The measured MRT and operative temperature (Top) values showed a clear indication of building heat gain and the contribution of occupants. The 3rd floor showed the highest values of MRT and Top which reached 36.20°C in Feb and 37.82°C in Mar at 12:00 PM since it was exposed to a lot of solar radiation and roof heat gain. The first floor showed moderate values of MRT and Top which is 31-32°C while the second floor was relatively cooler at 30°C, as it was buffered by floors above and below it. The addition of 30+ students in each classroom increased the values of the effective radiant temperature (Top) slightly compared to MRT by 0.2-0.4°C, which showed that the human body contributes to heat gain in naturally ventilated classrooms.

*Trend of the Thermal sensation (TSV) values.*

Highest values of TSV were observed on the top floor in the midday and afternoon hours (≈2.75-2.81 in Feb and 2.69-2.81 in Mar), which showed that people felt “slightly warm” and “warm.” Lower floors showed slightly lower values of TSV, i.e., ≈2.31-2.44, which corresponded to relatively lower values of operative temperature and MRT.

*Effect of thermal parameters to Thermal sensation votes.*

	MRT (°C)	Top (°C)	Roof Temp (°C)	RH (%)
TSV	0.579	0.596	0.903	0.385
MRT (°C)	1	0.977	0.986	0.753
Top (°C)	0.977	1	0.96	0.83
RH (%)	0.753	0.83	0.924	1

*Note. Pearson r values. MRT = Mean radiant temperature; Top = operative temperature; TSV = thermal sensation vote; RH = Relative humidity.*

*Table 10. Pearson correlation between variables (TSV vs thermal parameters).*

The results of the Pearson correlation analysis showed a significant correlation between building heat gain, indoor thermal conditions, and occupants' thermal comfort. For instance, the mean radiant temperature and the operative temperature showed a moderate positive correlation with thermal sensation votes, with correlation values of 0.579 and 0.596, respectively, indicating that occupants felt more warmth in a warmer thermal condition.

A very strong positive correlation was found between roof temperature and thermal sensation votes with a correlation coefficient of 0.903 which indicates that the roof temperature had the most impact on the thermal discomfort felt by the occupants. Moreover, the roof temperature showed an almost perfect correlation with the mean radiant temperature with a correlation coefficient of 0.986 and a very strong correlation with the operative temperature with a correlation coefficient of 0.960 indicating the impact of roof heat transfer on the radiant and operative temperature in the building.

Relative humidity had a negative correlation with all the thermal parameters especially with the operative temperature and roof temperature where the correlation values were -0.830 and -0.924, respectively, suggesting a situation where the higher the temperature, the lower the relative humidity. In conclusion, the findings suggest that the heat gain in the building envelope, especially the roof, is a major contributor in the regulation of the thermal conditions and the comfort level in naturally ventilated classrooms.

*Analysis of variance of each parameter between floors (first to third floor).*

Variable	Time	Between Groups (SS)	df	Mean Square	F	Sig.	Interpretation
Air Temperature (°C)	8 + t AM	292.091	2	146.045	95.97	0.000	Significant; temperatures differ across floors.
	12 + t PM	676.442	2	338.221	250.83	0.000	Significant; vertical temperature differences increase by noon.
	3 + t PM	584.500	2	292.250	242.37	0.000	Significant; top floors remain hottest.
MRT (°C)	8 + t AM	66.303	2	33.151	101.82	0.000	Significant; higher floors have higher radiant temperatures.
	12 + t PM	990.081	2	495.040	847.88	0.000	Significant; MRT differences peak at midday.
	3 + t PM	890.653	2	445.327	976.76	0.000	Significant; vertical trend persists.
Operative Temperature (°C)	8 + t AM	159.373	2	79.686	104.75	0.000	Significant; operative temperature higher on upper floors.
	12 + t PM	796.910	2	398.455	534.09	0.000	Significant; midday heat gain increases operative temperature.
	3 + t PM	706.713	2	353.357	535.60	0.000	Significant; top floors remain warmer.
Average TSV	8 + t AM	1.118	2	0.559	4.823	0.010	Significant; students' thermal sensation varies by floor.
	12 + t PM	2.431	2	1.216	5.219	0.007	Significant; perceived warmth higher at noon.

Relative Humidity (%)	3 + t PM	3.196	2	1.598	5.692	0.005	Significant; top floors perceived as warmer by students.
	8 + t AM	3916.755	2	1958.377	383.70	0.000	Significant; RH lower on upper floors.
	12 + t PM	7541.605	2	3770.803	394.51	0.000	Significant; midday RH differences persist.
	3 + t PM	8086.918	2	4043.459	459.71	0.000	Significant; top floors driest at afternoon.

Note. MRT = Mean radiant temperature; TSV = Thermal sensation vote.

Table 11. One-Way ANOVA – Air Temperature, MRT, Operative Temperature, TSV, and Relative Humidity Across Floors.

*Key findings:*

1. All variables always show significant differences across floors ( $p < 0.05$ ).
2. Air temperature, MRT, and operative temperature consistently increase with floor level, reflecting vertical heat gain in the building.
3. Average TSV confirms students on higher floors feel warmer.
4. Relative humidity decreases on upper floors, highlighting the effect of heat accumulation and reduced moisture retention.
5. The magnitude of differences peaks around 12 PM, coinciding with maximum solar and roof heat gain, and slightly decreases by 3 PM.

*Trend of thermal parameters on each floor*

Variable	Time	Significant Differences ( $p < 0.05$ )	Interpretation
Air Temperature (°C)	8 + t AM	F3 > F1 > F2	Vertical gradient already present in morning; top floor warmest.
	12 + t PM	F3 > F1 > F2	Strongest differences; top floor significantly hottest.
	3 + t PM	F3 > F1 > F2	Pattern persists; heat retained in upper floor.
MRT (°C)	8 + t AM	F3 > F1 > F2	Radiant heat higher on upper floors even in morning.
	12 + t PM	F3 >> F1 > F2	Very strong radiant heat on top floor due to solar gain.
	3 + t PM	F3 >> F1 > F2	High MRT sustained in afternoon.
Operative Temperature (°C)	8 + t AM	F3 > F1 > F2	Combined effect of air + radiant heat follows vertical trend.
	12 + t PM	F3 >> F1 > F2	Peak thermal stress at top floor.
	3 + t PM	F3 >> F1 > F2	Elevated operative temperature persists.
Average TSV	8 + t AM	F3 > F2 ≈ F1	Slight perception differences; top floor warmer.
	12 + t PM	F3 > F2 > F1	Students on top floor feel significantly warmer.
	3 + t PM	F3 > F2 > F1	Strongest perception of heat at top floor.
Relative Humidity (%)	8 + t AM	F2 > F3 > F1	Lower floors more humid; upper floors drier.
	12 + t PM	F2 > F1 > F3	Top floor driest at peak heat.
	3 + t PM	F2 > F1 > F3	Drying effect persists in afternoon.

Table 12. Summary of Tukey HSD Post Hoc Results Across Floors (8 + t AM, 12 + t PM, 3 + t PM).

In addition, the post hoc test results showed that there were consistent and significant differences in the thermal conditions on each floor throughout the measurement periods. In terms of air temperature, mean radiant temperature, and operative temperature, a vertical trend was noted. Third floor showed the highest values; First floor showed the next highest and Second floor showed the lowest values. These results were most pronounced at 12:00 PM which indicates the peak solar heat gain through the building envelope.

In terms of thermal sensation votes (TSV), the results showed that the upper floor showed significantly warmer thermal conditions particularly in the midday to afternoon periods. However, relative humidity showed an inverse trend indicating higher values were recorded on the lower floors and significantly lower values were recorded on the top floor which indicates the drying effect of higher temperature. Overall, the results confirm that vertical location within the building significantly influences indoor thermal conditions and occupant comfort, primarily due to heat transfer through the roof and upper building envelope.

## Conclusion and Recommendations

### *Summary of Findings*

This study evaluated the indoor thermal conditions of selected classrooms across three floors of an academic building and examined the influence of building heat gain on thermal comfort. Based on the analysis of the collected data, the following findings were established:

### *Indoor Thermal and Environmental Conditions*

The measured thermal parameters of the indoor environment indicated significant variations with time and floor levels. At 8 + t AM, the air temperatures were moderate, ranging from 26 °C to 31 °C, with higher values already recorded on the upper floors. However, as the day progressed, a significant increase in the temperatures was recorded with the maximum values recorded between 12:00 PM and 3:00 PM especially on the third floor where the temperatures were above 37 °C during March.

The mean radiant temperature and operative temperatures followed the same pattern with significantly higher values recorded on the upper floors, especially during the midday period. The relative humidity recorded an inverse pattern, where the values were high on the lower floors and lower on the upper floor especially during the peak period. The air velocity recorded a constant value on all floors and at all periods which indicate that the ventilation conditions had minimal variation therefore produce minimal effects.

Wet bulb temperature trends supported these findings. Reflecting increased heat stress during midday and afternoon periods. Overall, the indoor conditions in the classrooms frequently exceeded acceptable thermal comfort ranges on the upper floor during peak hours.

### *Effect of Heat Transfer from Building Components*

The results clearly indicated that heat transfer from building components such as the roof significantly contributes towards the alteration of the thermal environment in the building. The roof surface temperature on the third floor was extremely high, with a maximum value of more than 55 °C in February and 58 °C in March during midday. This caused a rise in heat conduction in the building space.

There was a rise in the wall and ceiling surface temperature during the peak hour of the day. This further enhanced the heat gain in the classrooms through radiant heat. The effect of the building components significantly enhanced the heat environment in the building space, especially on the third floor. This is because the building was more exposed to solar radiation on this floor.

### *Variation in Indoor Environmental Parameters Across Floors*

Statistical analysis was used to confirm the presence of significant differences in indoor environmental conditions on the three floors during all measurement periods. ANOVA analysis results showed that air temperature, mean radiant temperature, operative temperature, relative humidity, and thermal sensation votes were significantly different on each floor level.

Post hoc analysis using Tukey HSD results showed a consistent vertical trend where the highest values were recorded on the third floor, followed by the first floor, and the second floor had the lowest values. However, the highest values were recorded during 12 + t PM, showing the effect of solar heat gain on indoor conditions.

The results of this study confirm that the vertical position of a person within a building has a significant effect on indoor conditions, and the higher the floor, the greater the thermal stress.

### *Relationship Between Heat Gain and Thermal Comfort*

Correlation analysis revealed strong relationships between heat gain factors and thermal comfort parameters. Roof temperature showed a strong positive correlation with mean radiant temperature and operative temperature which indicate that increased roof heat directly contributes to higher indoor thermal conditions.

Thermal sensation votes (TSV) were also positively correlated with MRT and operative temperature which demonstrate that as indoor temperatures increased, occupants reported feeling significantly warmer. Relative humidity, on the other hand, has a negative correlation with temperature, which shows that as the temperature increases, the relative humidity decreases.

This study has clearly shown the impact of building heat gain, especially the roof, on the overall thermal conditions in the building and the thermal sensations felt by the occupants.

### *Synthesis*

Overall, it can be established that indoor thermal environment in the selected classrooms is greatly influenced by building heat gain which results in significant vertical and temporal variations. The third floor experienced the greatest thermal stress, especially during midday periods, because of exposure to solar radiation and heat transfer through the roof. This resulted in reduced thermal comfort among the occupants, as indicated by increased thermal sensation votes.

### *Conclusion*

The study concluded that indoor thermal and environmental conditions in the selected classrooms varied significantly throughout the day and across floors mostly influenced by both building design and the hot and humid tropical climate of Rodriguez, Rizal. Air temperature, mean radiant temperature (MRT), and operative temperature increased from morning to afternoon. Peaking between 12:00 PM and 3:00 PM, while relative humidity decreased and air velocity remained low which provides minimal natural cooling. Heat transfer from building components especially, the roof, was the primary contributor to indoor heat gain. Exacerbated by the region's high solar radiation and consistently warm temperatures. The third floor consistently recorded the highest thermal parameter highlighting the compounded effect of vertical heat gain under tropical conditions. Differences across floors were statistically significant which show that vertical location within the building significantly influences indoor thermal conditions due to direct solar exposure and roof heat gain. A significant relationship was also observed between building heat gain and students' thermal comfort. Higher roof and surface temperatures corresponded with higher operative temperatures and mean thermal sensation votes (TSV) which indicate warmer perceived conditions. Overall, the study confirms that naturally ventilated classrooms in tropical areas like Rodriguez, Rizal, are particularly susceptible to heat gain from building surfaces with upper floors experiencing the greatest thermal disadvantage during peak daytime hours.

### *Recommendations*

Based on the findings of this study, the following recommendations are proposed to improve indoor thermal comfort in naturally ventilated classrooms in Rodriguez, Rizal:

1. **Active Cooling Interventions:** Install exhaust fans or solar-powered whirlybirds (see appendix for the model) to improve air circulation, especially in upper-floor classrooms and those exposed to high solar heat gain. These devices help dissipate heat from the ceiling and roof surfaces which lower the operative temperature and improving students' comfort during peak afternoon hours. DepEd academic buildings have a cathedral type ceiling which helps dissipate heat through an air gap from the roofing. However, naturally ventilation has its limitations, in those cases, like this study, proper intervention should be carried out.
2. **Cross-Ventilation and Natural Airflow:** Optimize window and door opening to maximize cross-ventilation. Ensuring unobstructed airflow paths helps to remove hot air and reduce thermal stratification, particularly during low-wind periods common in tropical climates. It is recommended that curtains to be installed on the window for aesthetic purposes should have a lighter color to deflect heat effectively. The size of the curtain must also not cover the whole area of the window to let the air flow naturally.
3. **Reflective and Insulating Materials:** Use reflective or light-colored paints (BOYSEN® Cool Shades™ Heat Reflective Colored Roof Coating or LuminX Roof Cooling Paint) for roofs and exterior walls to minimize solar heat absorption. Top floors of DepEd building should have an insulating material separating the ceiling and roofing. It can be noted that the absence of these insulations directly affects the learning environment of the students.

4. Occupancy Management and Safety Limits: To protect students' health, classroom occupancy or scheduling should be reconsidered when operative temperatures exceed 35–36 °C or when thermal sensation votes indicate discomfort ("warm" to "hot"). Alternative arrangements such as moving classes to cooler spaces or adjusting school hours, may be necessary during heat waves which is typical during summer season in the Philippines. Recommended student occupancy per classroom based on this study should not exceed 30 students per classroom.

5. Operational Practices: Encourage simple practices like keeping classroom doors and windows open to keep ventilation unobstructed. Routine cleaning and maintenance of ventilation openings ensure maximum airflow efficiency.

6. Long-Term Design Considerations: For future classroom construction, consider high thermal mass materials for walls, insulated ceilings, and proper roof ventilation. The insulation materials were noticeably lacking on Deped-built buildings. Consider also provisions for installation of active cooling devices such as exhaust fans, especially, in the airgap between ceiling and roofing.

7. Awareness and Training: Educate teachers and school staff on the importance of maintaining indoor comfort and strategies to reduce heat exposure, including rotating students to cooler areas during extreme heat events. Initiate a training seminar about the hazards of heatwaves during summer.

8. Policy Recommendations: Local education authorities may consider setting guidelines for maximum allowable indoor temperatures and relative humidity in classrooms. Heat action plans can be developed for schools in Rodriguez, Rizal to protect students during periods of extreme heat in the dry season. It is also recommended that there should be a compulsory class suspension should these parameters exceed safe human occupancy limit.

By implementing a combination of passive, active, and operational strategies, schools in Rodriguez, Rizal can improve indoor thermal comfort and reduce health risks associated with high indoor temperatures in tropical climates. Using the empirical data collected from this study, local government should update their policies with regards to well-being of the people in schools, especially during summer.

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## Competing Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

## Data Availability Statement

The datasets generated during the current study are not publicly available due to privacy and ethical restrictions involving human participants but are available from the corresponding author upon reasonable request.

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## Appendices

No appendices are attached to this study.