Civil Engineering and Architecture 13(3A): 2711-2726, 2025 http://www.hrpub.org
DOI: 10.13189/cea.2025.131337

Assessment of Indoor Thermal Conditions in High Schools in a Hot and Dry Climate: A Case Study in Muscat, Oman

Mutaib I. Alsaadi[1], Sharifah Fairuz Syed Fadzil[2], Najib T. Al-Ashwal[3,*], Aasem Alabdullatief[4], Ahmed M. Alhzmi[5]

[1]College of Engineering and Technology, University of Technology and Applied Sciences, Oman
[2]School of Housing, Building and Planning, Universiti Sains Malaysia, Malaysia
[3]Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Malaysia
[4]Department of Architecture and Building Sciences, College of Architecture and Planning, King Saud University, Saudi Arabia
[5]Department of Architecture, College of Architecture and Planning, Qassim University, Saudi Arabia

Received October 14, 2024; Revised April 17, 2025; Accepted May 28, 2025

Cite This Paper in the Following Citation Styles

(a): *[1] Mutaib I. Alsaadi, Sharifah Fairuz Syed Fadzil, Najib T. Al-Ashwal, Aasem Alabdullatief, Ahmed M. Alhzmi , "Assessment of Indoor Thermal Conditions in High Schools in a Hot and Dry Climate: A Case Study in Muscat, Oman," Civil Engineering and Architecture, Vol. 13, No. 3A, pp. 2711 - 1726, 2025. DOI: 10.13189/cea.2025.131337.*

(b): *Mutaib I. Alsaadi, Sharifah Fairuz Syed Fadzil, Najib T. Al-Ashwal, Aasem Alabdullatief, Ahmed M. Alhzmi (2025). Assessment of Indoor Thermal Conditions in High Schools in a Hot and Dry Climate: A Case Study in Muscat, Oman. Civil Engineering and Architecture, 13(3A), 2711 - 2726. DOI: 10.13189/cea.2025.131337.*

Abstract A comfortable indoor thermal environment is crucial in classrooms, because poor indoor thermal conditions can adversely affect students' cognitive performance and lead to lower academic achievement. This study aims to evaluate indoor thermal conditions in typical schools in Muscat, Oman, characterized by hot and dry climate during summer and winter. This study collected fieldwork data using suitable instruments to measure different climate components, including indoor air temperature and relative humidity. The results showed that outdoor air temperature significantly influenced indoor air temperature, with the indoor temperature being lower than the outdoor temperature during the day in winter and higher than the outdoor temperature in the evening during summer. Despite daily variations in outdoor temperature, there were only minor changes in the daily range of indoor temperature. Effective insulation, modifying building envelope and ventilation systems, and regularly monitoring indoor air quality can help provide a comfortable indoor thermal environment, supporting student academic performance and well-being. Future research can explore the effectiveness of different strategies and technologies in improving indoor thermal conditions in schools.

Keywords Hot and Dry Climate, Indoor Temperature, Education, Building Envelope, Classrooms

1. Introduction

Oman experienced rapid economic growth following the 1970s oil boom, but unfortunately, environmental design concepts and energy conservation were not a priority during this time. Instead of focusing on the quality of school building design, the government of Oman prioritized constructing as many school buildings as possible due to the massive growth of the population and the enrolment rate of students [1]. To expedite the construction process without overspending the allocated financial allowances for the Ministry, the Ministry of Education in Oman introduced typical school buildings to the country. However, the typical school buildings were built nationwide without considering the climatic diversities among the regions in Oman. As a result, most of the typical school buildings in Oman, particularly in Muscat, could not modify the external environment and instead rely heavily on mechanical equipment to cool and heat interior spaces [2]. This has led to the consumption of

sustainable school designs, Omani schools have yet to adopt these principles meaningfully. Research in developed countries has demonstrated the benefits of passive cooling strategies, optimal building orientation, and solar-integrated designs for reducing energy consumption. However, most studies on Omani school buildings have focused on functionality rather than environmental performance. This research seeks to address this gap by assessing indoor thermal conditions in typical school buildings in Muscat and exploring strategies to enhance sustainability through climate-responsive architecture.

2.3. Related Previous Studies

Many studies have focused on improving indoor building conditions in hot and dry climates. Different aspects were addressed in these studies, such as the thermal efficiency of envelope and construction materials, the compatibility of building design with the local environment, and the effects of passive strategies that provide thermal comfort for occupants.

Al-Masawa et al. [11] and Baeissa [12] studied the thermal characteristics of construction materials made of mud in Yemen. They found that mud bricks showed better thermal qualities that kept the indoor temperature within a comfortable range. Similarly, a study was conducted in Riyadh, Saudi Arabia, to assess the impact of orientation and thermal insulation thickness on indoor thermal comfort. The study found that the south-facing wall is the preferred orientation because of its lower annual transmission load and total cost compared to the west-facing wall, which is the least preferred direction [13].

Other studies, such as the one by Nahar et al. [14], focused on evaluating the cooling efficacy of several passive roof approaches, such as white cement painting, roof ponds, evaporative cooling, air void thermal insulation, and fractured white-glazed tile fragments. They found that evaporative cooling is the most effective method but requires much water. Instead of evaporative cooling, white-glazed roof tiles are recommended to improve comfort conditions in arid regions. Similarly, Kumar et al. [15] evaluated the performance of solar shading insulation, one of the solar passive cooling approaches. They found that the combination of solar shading, insulation, and air exchange is exceptionally effective in maintaining a lower indoor air temperature than in traditional buildings.

In another study, Amer [16] focused on reducing indoor air temperature in arid areas by applying several passive modifications to the roof. They found that when the ceiling is painted white or a layer of thermal insulation is installed, the indoor air temperature is reduced by 2 ℃ compared to the ambient temperature. The interior temperature was within 1 ℃ of the exterior temperature using evaporative cooling or a solar chimney.

Finally, some studies, such as the ones by Al Hamdi and Kaki [17], investigated the thermal performance of old mud brick buildings and new buildings built with concrete, as well as the application of several passive cooling/heating methods, including water roof pond system, wind catcher, natural ventilation, and several passive heating systems. These studies found that mud brick houses outperformed, achieving lower indoor temperatures than concrete block houses. They also concluded that these passive cooling/heating methods help reduce energy consumption.

These studies demonstrate the importance of considering different factors, such as construction materials, orientation, insulation, and passive cooling/heating methods, in improving indoor building conditions in hot and dry climates. By adopting these measures, it is possible to achieve comfortable indoor temperatures while minimizing energy consumption and reducing the environmental impact of buildings.

While existing studies have extensively examined thermal performance, passive cooling techniques, and sustainable materials, most research has focused on residential and commercial buildings. However, a critical gap exists in evaluating indoor thermal conditions in school buildings, particularly in Oman.

Despite the well-documented impact of high temperatures on learning environments, few studies have assessed how standardized school buildings in hot, arid climates perform regarding indoor temperature regulation. Most existing research focuses on potential passive cooling strategies rather than empirical assessments of current school buildings and their environmental performance.

This study tried to fill this gap by evaluating indoor thermal conditions in typical school buildings in Muscat, Oman. Specifically, it assessed the impact of existing construction materials, building orientation, and design features on indoor temperatures. By providing quantitative data on actual thermal conditions, this study will offer a baseline understanding of the challenges students and educators face in Oman's school buildings. The findings will contribute to ongoing discussions about the need for climate-responsive school infrastructure and inform future research on potential design modifications.

3. Methods and Materials

This study collected fieldwork data using suitable instruments to measure different climate components, including relative humidity and indoor air temperature. The data collection phase was conducted in both the summer and winter seasons according to the chosen case studies in this research. From an architectural perspective, the experimental method used in this study provided reliable data in actual buildings under actual climate conditions. Field measurements are considered the best approach for obtaining a more comprehensive understanding and deeper evaluation of building performance since they represent natural experimental conditions under actual climate conditions [18], [19].

3.1. Case Studies: Government Schools in Muscat

The primary aim of this study was to establish a robust basis by conducting field measurements to assess indoor thermal comfort conditions in classrooms within Oman's hot, dry climate. Fieldwork measurements were crucial for gathering accurate, raw data and acquiring essential thermal, climatic, and energy information from selected buildings. The data helped identify indoor thermal conditions and highlight relevant issues related to classroom temperatures. The main focus of the fieldwork was on measuring indoor air temperature, as it is a critical parameter for evaluating thermal comfort. This study specifically examined indoor thermal conditions in multiple high schools in Muscat, emphasizing the importance of fieldwork data in thermal analysis studies.

According to the Statistical Yearbook 2020, Oman has 1927 schools classified into four main categories: 1149 Government Schools, 3 Special Education Schools, 730 Private Schools, and 45 International Schools (Foreign Communities). Of these schools, Muscat alone has 462 schools, with 171 being Government Schools, 268 being Private Schools, 3 being Special Education Schools, and 20 being International/Foreign Community Schools. For this study, we have chosen to focus on Government Schools, as they constitute a significant proportion of the total schools in Muscat and have typical design features that make it practical to generalize the study results to all schools in the city.

In order to ensure the accuracy and reliability of the field measurements, it was imperative to carefully select suitable case studies among the available government schools in Muscat. The selection process was based on several key factors, including the most common building orientation, case studies with similar typical designs, and the cooperation of school management.

After obtaining approval for the field measurements from the school management, a rigorous selection process was undertaken, and three government high schools were ultimately chosen as the case studies for this research. Each selected school shared a similar design and orientation and was deemed representative of the typical government schools in Muscat. A comprehensive description of each selected school is provided in the following section to provide a better understanding of the study's methodology and findings.

This study addressed three government schools in Muscat: Fatima Bint Al-Waleed School, Ruaa Lmustagbal School, and Gawhart Muscat School. Fatima Bint Al-Waleed School was established in Alseeb, Muscat, in 2005. The school boasts a built-up area of 4184 m^2 with 20 classrooms and 10 additional classrooms for future extensions. The school's orientation is 304 degrees from the north. Figure 3 provides a site plan and various views of the school to help contextualize its layout and features.

Figure 3. Site plan and different views of Fatima Bint Al-Waleed School

Ruaa Lmustagbal School was built in Muscat's Almubillah area in 2016. The school has a total built-up area of 4184 m^2 with 20 classrooms, and it is oriented at 112 degrees from the north. Figure 4 illustrates the school's site plan and different views.

Figure 4. Site plan and different views of Ruaa Lmustagbal School

Gawhart Muscat School, located in Alseeb, Muscat, was constructed in 2016 with a built-up area of 3998 m^2 and equipped with 20 classrooms with the potential for 10 classrooms for future extension. The school is oriented at 148 degrees from the north. Figure 5 displays the site plan and various views of the school. These three schools were selected based on their similar typical designs and common building orientation. The cooperation of the school management was also a crucial factor in selecting these case studies for field measurements.

Figure 5. Site plan and different views of Gawhart Muscat School

3.2. Field Work

3.2.1. On-Site Thermal Measurements Procedure

The fieldwork evaluates the indoor air temperature by conducting different measurements at various locations in several selected classrooms at each school. The fieldwork consists of two main phases. First, the classrooms should be prepared to be suitable for the measurements. Second, taking measurements inside the classrooms based on the standard related to indoor thermal measurements using the appropriate equipment.

3.2.2. Thermal Measurement Instruments

The Testo 174H data logger was employed to measure air temperature and relative humidity hourly, as depicted in Figure 6. Positioned at a height of 1.1m in each classroom, following ASHRAE Standards, the logger offered flexible sampling intervals ranging from 10 seconds to over one day. This allowed for frequent monitoring or adjustments of parameters and extended intervals without memory constraints. These loggers were strategically installed in selected classrooms across different schools, providing crucial measurements for assessing thermal performance and modelling the base case. Table 1 outlines the key specifications and features of the data logger used in the fieldwork measurements.

Figure 6. Testo 174H data logger

Table 1. Main attributes of the Testo 174H data logger

Attribute	Value
Measurement Parameters	Humidity, Temperature
Sensor Type	Capacitive, NTC
Number of Input Channels	2
Maximum Temperature Measurement	+70 ℃
Best Temperature Measurement Accuracy	±0.5 ℃
Minimum Operating Temperature	-20 ℃
Maximum Operating Temperature	+70 ℃
Humidity Measurement Resolution	0.1%RH
Best Humidity Measurement Accuracy	±0.03 %RH
Temperature Measurement Resolution	0.1 ℃
Number of Readings Per Channel	16000

4. Results Analysis

The fieldwork encompassed two distinct periods, specifically winter and summer, with data collection between 24-30 November 2019 and 21-27 April 2021. Winter observations were conducted during school operational hours, while summer data collection was hindered due to the COVID-19 pandemic, resulting in school closures. Three classrooms were selected from varying levels within each school to capture diverse thermal conditions. The assessment aimed to represent the year's warmest (summer) and coolest (winter) periods. Indoor temperature recordings were conducted passively, without an active air conditioning system. The Muscat weather station sourced outdoor temperature data for the corresponding periods. A summary of the field measurements is provided in Table 2.

Table 2. Summary of the field measurements

Classroom	Level	Orientation	Winter Indoor Temp. 24 to 30 November					Summer Indoor Temp. 21 to 27 April				
			Max.	Min.	Avg.	Median	Std. Deviation	Max.	Min.	Avg.	Median	Std. Deviation
Fatima Bint Al-Waleed School (Orientation of the entrance from North: 304º)												
A-C-1	First Floor	North-East	28.5	22.3	23.5	23.5	0.18	35.2	31.2	33.5	33.9	1.07
A-C-2	Second Floor	North-East	29.3	23.4	25.8	25.7	0.26	34.8	31.7	33.2	33.5	0.81
A-C-3	First Floor	South-West	28.4	23.4	24.6	24.6	0.18	34.4	30.3	33.9	33.1	0.86
Ruaa Lmustagbal School (Orientation of the entrance from North: 112º)												
B-C-1	Ground Floor	South-West	27.2	23.3	25.1	25.0	0.23	34.5	31.1	33.0	33.25	0.78
B-C-2	First Floor	South-West	28.1	23.3	24.1	24.0	0.21	34.4	31.0	32.8	33.2	0.91
B-C-3	Ground Floor	North-East	28.1	23.8	25.3	25.2	0.24	35.0	31.4	33.4	33.7	0.97
Gawhart Muscat School (Orientation of the entrance from North: 148º)												
C-C-1	Second Floor	North-East	26.3	22.1	24.6	24.5	0.25	33.8	30.3	32.3	32.4	0.78
C-C-2	First Floor	South-West	27.9	23.0	24.7	24.7	0.19	34.2	30.3	32.5	33.1	1.06
C-C-3	Second Floor	South-West	28.5	22.3	23.5	23.4	0.15	35.5	31.5	33.9	34.3	1.08

4.1. Fatima Bint Al-Waleed School

In the study, three classrooms were selected in this school based on their different orientations and levels. Figure 7 shows the locations of these classrooms. Data were collected during summer and winter to comprehensively understand indoor thermal conditions and compare the indoor temperature measurements of the selected classrooms across the different seasons. This helped to identify any trends or patterns in indoor temperature fluctuations and to determine whether the classrooms could maintain a comfortable indoor thermal environment.

4.1.1. The Summer Results

The results are depicted in line charts showcasing indoor and outdoor air temperatures obtained during fieldwork. The Y-axis denotes air temperature in degrees Celsius (℃), while the X-axis illustrates days and hours of data collection from classrooms. Analysis of indoor air temperature across all classrooms (Figure 8) revealed an average difference of approximately 2.3 ℃ between 10:00 am and 5:00 pm. Temperatures ranged from 7 ℃ at 12:00 pm to 0.1 ℃ at 9:00 am. Between 5:00 pm and 9:30 am, indoor air temperature averaged 2.3 ℃ above outdoor temperatures. In contrast, outdoor temperatures ranged from 27.4 ℃ at 4:00 am to 39.2 ℃ at noon, with indoor temperatures peaking at 34.7 ℃ at 3:00 pm. Despite wide daily fluctuations in outdoor temperatures, indoor temperatures exhibited minimal variations, indicating effective thermal mass stabilization. However, indoor and outdoor temperatures fell within discomfort ranges, surpassing the upper limits of thermal comfort.

4.1.2. The Winter Results

The results in Figure 9 illustrate indoor temperature readings during the selected winter week in all classrooms of the chosen school. Notably, indoor air temperature averaged lower from 10:00 am to 2:00 pm than outdoor air temperature, ranging from 5.4 ℃ to 0.1 ℃. Conversely, indoor air temperature surpassed outdoor air temperature during unoccupied periods by an average of 1.3 ℃. Compared to outdoor temperatures ranging from 17.7 ℃ at 4 am to 28.8 ℃ at noon, indoor temperatures averaged 22.3 ℃ at 6 am and peaked at 29.5 ℃ at 2 pm. Despite wide daily variations in outdoor temperatures, indoor temperatures showed minimal fluctuations, indicating effective stabilization by the building's thermal mass.

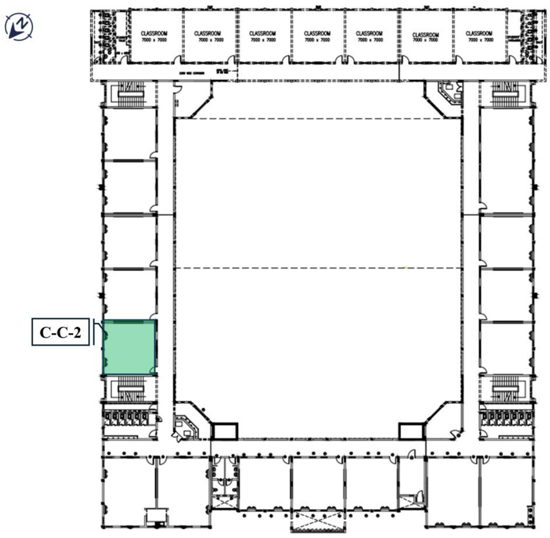
The observed indoor temperature results are consistent with previous research that emphasizes the impact of thermal mass on indoor temperature fluctuations [20], [21]. Buildings with high thermal mass can absorb, store, and release heat, delaying temperature fluctuations and creating a more stable indoor temperature. The study by Deng et al. [20] on the impact of thermal mass on indoor temperature showed that building materials with high thermal mass, such as concrete, can effectively reduce the impact of outdoor temperature changes on indoor temperature. Another study by Le Dréau and Heiselberg [21] examined the impact of thermal mass on the indoor temperature in a residential building and found that the thermal mass of the building played a significant role in reducing indoor temperature fluctuations.

The findings are consistent with previous research on indoor and outdoor air temperature, which has demonstrated that the indoor temperature in a building is affected by outdoor air temperature, building materials, building orientation, ventilation, and other factors [28], [29], [30]. A comfortable indoor temperature is crucial for ensuring occupant comfort, productivity, and health, and this study's results suggest that further measures may be necessary to maintain comfortable indoor temperatures.

4.3.2. The Winter Results

Results indicated that the average indoor air temperature in all classrooms was notably lower than outdoor air temperature from 10:00 am to 5:00 pm, with an average temperature difference of approximately 2.3 ℃. Temperature variance ranged from 7 ℃ to 0.1 ℃ at 12:00 pm and 9:00 am, respectively (see Figure 15).

Conversely, the indoor air temperature was higher than the outdoor air temperature from 5:00 pm to 7:00 am. Despite a wide daily range of external air temperature, there were only slight changes in the classrooms' daily air temperature range. The lowest outdoor air temperature recorded between 4:00 am and 6:00 am was 27.4 ℃, while the highest recorded between 12:00 pm and 2:00 pm was 39.2 ℃. The average indoor air temperature recorded at 6:00 am was 31.9 ℃, while the maximum recorded at 3:00 pm was 34.7 ℃. Studies suggest various approaches to improving indoor thermal conditions, such as improving the insulation of walls, reducing air infiltration, and improving the performance of heating, ventilation, and air conditioning (HVAC) systems [31], [32], [33].



First Floor Second Floor

Figure 13. Location of the investigated classrooms in Gawhart Muscat School

Figure 14. Indoor air temperature during the summer period in Gawhart Muscat School

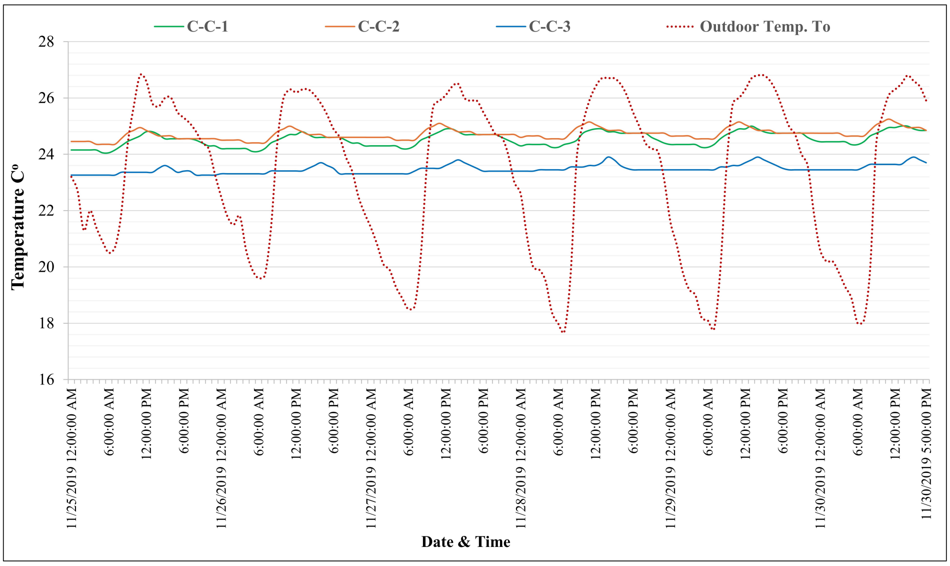


Figure 15. Indoor air temperature during the winter period in Gawhart Muscat School

5. Discussion

The analysis of temperature distributions in Fatima Bint Al-Waleed School, Ruaa Almustagbal School, and Gawhart Muscat School reveals notable differences in classroom thermal conditions, as illustrated in the histogram graph in Figure 16. In Fatima Bint Al-Waleed School, the temperature in Classroom A-C-1 fluctuates between approximately 30.5 ℃ and 33.5 ℃, whereas Classroom A-C-2 ranges from 30.3 ℃ to 33.4 ℃, and Classroom A3 records the highest range from 31.5 ℃ to 34.4 ℃. The histogram indicates a gradual temperature increase throughout the recorded period, with Classroom A-C-3 showing consistently higher temperatures than the other two classrooms. This suggests that Classroom A3 might have greater exposure to external heat sources or insufficient ventilation than Classrooms A-C-1 and A-C-2.

Similarly, in Ruaa Almustagbal School, Classroom B-C-1 experiences a temperature range of 30.5 ℃ to 33.6 ℃, Classroom B-C-2 varies between 30.4 ℃ and 33.5 ℃, while Classroom B-C-3 maintains a slightly broader range from 31.5 ℃ to 34.5 ℃. The temperature variations across the classrooms follow a similar pattern to those observed in Fatima Bint Al-Waleed School, with Classroom B-C-3 consistently recording the highest temperatures. This pattern may indicate that specific classrooms in each school have distinct thermal performance characteristics, potentially due to differences in building orientation, shading, or air circulation.

Gawhart Muscat School exhibits a slightly different trend, where Classroom C-C-1 records temperatures between 30.5 ℃ and 33.3 ℃, Classroom C2 ranges from 30.3 ℃ to 33.3 ℃, and Classroom C-C-3 has the widest range, from 31.5 ℃ to 35.5 ℃. The histogram for this school shows more pronounced peaks, suggesting frequent fluctuations in classroom temperatures. Classroom C-C-3 experiences the highest temperature variations among all the schools, which could be attributed to higher solar exposure, inadequate ventilation, or inefficient cooling systems.

Comparing all three schools, a common trend is observed where the third classroom in each school (A-C-3, B-C-3, and C-C-3) consistently records the highest temperatures. This pattern suggests that specific classroom locations within the buildings might be more susceptible to thermal gain. Furthermore, Gawhart Muscat School demonstrates the highest overall temperature fluctuations, indicating a need for enhanced thermal management strategies. Potential solutions to improve indoor thermal comfort include optimizing natural ventilation, utilizing reflective or insulated materials, and implementing shading devices to mitigate excessive heat gain. Addressing these factors is essential to maintaining comfortable learning environments and ensuring students' well-being.

The analysis of indoor and outdoor temperature variations across the three schools provides key insights into the thermal performance of classrooms under different seasonal conditions. The results indicate that, despite fluctuations in outdoor temperatures, indoor temperatures remained relatively stable due to the thermal mass effect of the buildings. However, indoor temperatures frequently exceeded recommended thermal comfort levels in both summer and winter, potentially impacting students' learning experiences. These findings align with previous studies emphasizing the role of thermal mass in moderating indoor temperature fluctuations, particularly in regions with extreme climate conditions [34], [35].

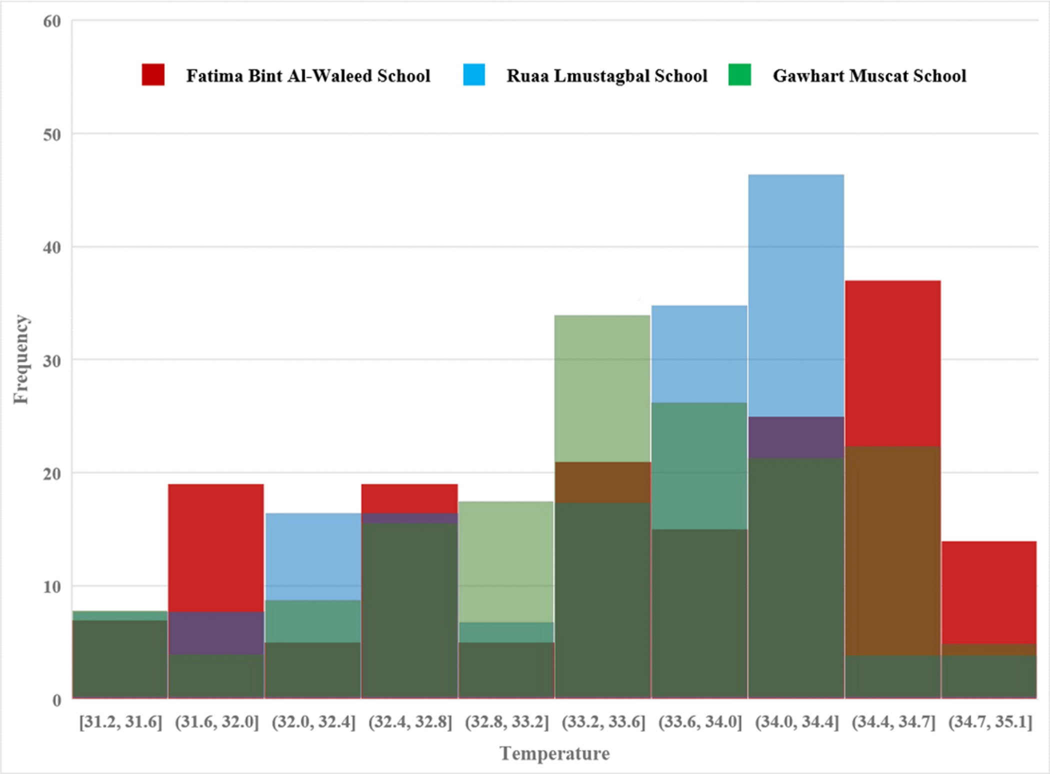


Figure 16. Histogram graph of measures indoor temperature

During the summer period, classrooms exhibited higher indoor temperatures than the outdoor environment in the early morning and late evening, while daytime indoor temperatures remained slightly lower than outdoor temperatures. This trend suggests that thermal mass contributes to heat retention during the day and releases stored heat at night, causing a delay in temperature fluctuations. Similar findings were reported by Kükrer and Eskin [36], who examined thermal performance in educational buildings and found that high thermal inertia materials contribute to temperature stabilization but may also lead to overheating in warm climates. Furthermore, studies by Abdallah [37] have demonstrated that passive cooling strategies, such as enhanced ventilation and shading, can significantly mitigate heat accumulation, which is a factor that should be considered in improving classroom environments.

In winter, the results revealed that indoor temperatures were often lower than outdoor temperatures during the day but higher at night. This highlights the limited ability of the buildings to retain heat during operational hours, which could negatively affect thermal comfort and, consequently, students' cognitive performance. Previous research has established that maintaining optimal indoor temperatures is crucial for students' concentration and productivity [38]. Additionally, studies conducted by Lakhdari et al. [39] in Middle Eastern educational facilities confirmed that inadequate thermal insulation and inefficient heating mechanisms contribute to indoor thermal discomfort during winter.

Despite the relative stabilization of indoor temperatures, the findings underscore the necessity for enhanced thermal management strategies in school buildings. Effective solutions could include improved insulation materials, passive ventilation strategies, and advanced shading techniques, as supported by recent studies on sustainable school design [40]. Moreover, optimizing natural ventilation through architectural modifications, as suggested by de la Hoz-Torres et al. [41], could enhance thermal comfort while reducing reliance on mechanical cooling and heating systems.

In conclusion, the study highlights the significant role of building thermal mass in influencing indoor temperature stability. However, the observed temperature profiles indicate that indoor thermal conditions in these classrooms frequently fall outside the recommended comfort range. Addressing these issues through targeted interventions, such as improved building materials, passive cooling strategies, and optimized ventilation, is critical to ensuring a more comfortable and conducive learning environment. Future research should evaluate the effectiveness of various thermal mitigation strategies in similar climatic conditions, further contributing to the development of energy-efficient and thermally comfortable educational spaces.

6. Conclusions

This study investigated the indoor air temperature in three schools in different areas of Muscat, Oman, during the winter and summer seasons. The fieldwork was conducted in selected classrooms, and temperature sensors were used to collect data. Based on the findings, it can be concluded that the indoor air temperature in all examined schools was significantly affected by the outdoor air temperature. During winter, the indoor air temperature was considerably lower than the outdoor air temperature from 10:00 am to 5:00 pm, whereas, during the summer, the indoor air temperature was higher than the outdoor air temperature from 5:00 pm to 7:00 am. However, despite the daily variation in outdoor air temperature, there were only slight changes in the daily range of indoor air temperature. These results suggest that typical school classrooms may require better insulation and ventilation systems to maintain a comfortable indoor thermal environment throughout the year. Previous studies have shown that poor indoor thermal conditions can negatively impact students' cognitive performance, leading to lower academic achievement. Therefore, it is essential to ensure that schools provide a comfortable indoor thermal environment that supports students' academic performance and well-being. This can be achieved through effective insulation, modifying the building envelope and ventilation systems, and regularly monitoring indoor air quality. Future research can also explore the effectiveness of different strategies and technologies in improving indoor thermal conditions in schools and their impact on student academic performance and health. Overall, the findings of this study underscore the significance of addressing indoor thermal conditions in schools to promote a healthy and conducive learning environment for students.

REFERENCES

[1] Aljabri, H., “The planning and urban design of liveable public open space in Oman: a case study of Muscat,” Doctoral dissertation, Heriot-Watt University, 2014.

[2] Al-Badi, A. H. and Al-Saadi, S. N., “Toward energy-efficient buildings in Oman,” *International Journal of Sustainable Energy*, vol. 39, no. 5, pp. 412–433, May 2020, doi: 10.1080/14786451.2019.1685521.

[3] Alalouch, C., Al-Saadi, S. N., AlWaer, H., and Al-Khaled, K., “Energy saving potential for residential buildings in hot climates: The case of Oman,” *Sustain Cities Soc*, vol. 46, p. 101442, 2019, doi: 10.1016/j.scs.2019.101442.

[4] Al Abriaa, H. M. A. and Vimbia, V., “Green Building–Energy Conservation using IoT,” *Journal of Student Research*, vol. 8, no. 3, pp. 29–33, 2019, doi: 10.47611/jsr.vi.905.

[5] Alam, M. S., Alam, M. N., Murshed, M., Mahmood, H., and Alam, R., “Pathways to securing environmentally sustainable economic growth through efficient use of energy: a bootstrapped ARDL analysis,” *Environmental Science and Pollution Research*, vol. 29, no. 33, pp. 50025–50039, 2022, doi: 10.1007/s11356-022-19410-9.

[6] Almasri, R. A. and Alshitawi, M. S., “Electricity consumption indicators and energy efficiency in residential buildings in GCC countries: Extensive review,” *Energy Build*, vol. 255, p. 111664, 2022, doi: 10.1016/j.enbuild.2021.111664.

[7] Yousif, J. H., Al-Balushi, H. A., Kazem, H. A., and Chaichan, M. T., “Analysis and forecasting of weather conditions in Oman for renewable energy applications,” *Case Studies in Thermal Engineering*, vol. 13, p. 100355, 2019, doi: 10.1016/j.csite.2018.11.006.

[8] Al-Ruhaili, H. S. S., Salleh, M. J. Bin, and Ibrahim, M. B. Bin, “Challenges women face in leadership positions: a quantitative approach in cycles’1 and 2 schools in Oman,” *IJASOS-International E-journal of Advances in Social Sciences*, vol. 6, no. 16, pp. 356–363, 2020, doi: 10.18769/ijasos.616048.

[9] Mohamed Emam, M. and Al-Mahdy, Y. F. H., “Teachers’ efficacy for inclusive practices in the Sultanate of Oman: Effect of gender and teaching experience,” *Sch Psychol Int*, vol. 41, no. 2, pp. 170–192, 2020, doi: 10.1177/0143034319895062.

[10] Al Shabibi, A., Al Mantheri, A., and Al Rashdi, B., “Impact of teacher professional development on student attitudes and experiences in school learning–A case study of Oman,” *International Journal of Learning, Teaching and Educational Research*, vol. 18, no. 10, pp. 48–67, 2019, doi: 10.26803/ijlter.18.10.4.

[11] Al-Masawa, M. I., Manab, N. A., and Omran, A., “The Effects of Climate Change Risks on the Mud Architecture in Wadi Hadhramaut, Yemen,” in *The Impact of Climate Change on Our Life: The Questions of Sustainability*, A. Omran and O. Schwarz-Herion, Eds., Singapore: Springer Singapore, 2018, pp. 57–77. doi: 10.1007/978-981-10-7748-7_3.

[12] Baeissa, A. A., “Mud-brick high-rise buildings architectural linkages for thermal comfort in Hadhramaut Valley, Yemen,” *Int Trans J Eng Manag Appl Sci Technol*, vol. 5, no. 3, pp. 167–182, 2014, Accessed: Nov. 11, 2024. [Online]. Available: http://tuengr.com/V05/0167.pdf

[13] Alaboud, M. and Gadi, M., “Evaluation of Indoor Thermal Environmental Conditions of Residential Buildings in Saudi Arabia,” *Energies (Basel)*, vol. 15, no. 5, 2022, doi: 10.3390/en15051603.

[14] Nahar, N. M., Sharma, P., and Purohit, M. M., “Performance of different passive techniques for cooling of buildings in arid regions,” *Build Environ*, vol. 38, no. 1, pp. 109–116, 2003, doi: 10.1016/S0360-1323(02)00029-X.

[15] Kumar, R., Garg, S. N., and Kaushik, S. C., “Performance evaluation of multi-passive solar applications of a non air-conditioned building,” *International journal of environmental technology and management*, vol. 5, no. 1, pp. 60–75, 2005, doi: 10.1504/IJETM.2005.006507.

[16] Amer, E. H., “Passive options for solar cooling of buildings in arid areas,” *Energy*, vol. 31, no. 8, pp. 1332–1344, 2006, doi: 10.1016/j.energy.2005.06.002.

[17] Al Hamdi, N. A. R. and Kaki, W. B. A. R., “Thermal performance in contemporary traditional buildings case study in the city of Diriyah,” in *7th International*

Architecture Conference: Housing of the Poor, problems and solutions, 2007.

[18] Odiyur Vathanam, G. S. *et al.*, "A review on effective use of daylight harvesting using intelligent lighting control systems for sustainable office buildings in India," *Sustainability*, vol. 13, no. 9, p. 4973, 2021, doi: 10.3390/su13094973.

[19] Koulamas, C., Kalogeras, A. P., Pacheco-Torres, R., Casillas, J., and Ferrarini, L., "Suitability analysis of modeling and assessment approaches in energy efficiency in buildings," *Energy Build*, vol. 158, pp. 1662–1682, 2018, doi: 10.1016/j.enbuild.2017.12.002.

[20] Deng, J., Yao, R., Yu, W., Zhang, Q., and Li, B., "Effectiveness of the thermal mass of external walls on residential buildings for part-time part-space heating and cooling using the state-space method," *Energy Build*, vol. 190, pp. 155–171, 2019, doi: 10.1016/j.enbuild.2019.02.029.

[21] Le Dréau, J. and Heiselberg, P., "Energy flexibility of residential buildings using short term heat storage in the thermal mass," *Energy*, vol. 111, pp. 991–1002, 2016, doi: 10.1016/j.energy.2016.05.076.

[22] Sharaf, F., "The impact of thermal mass on building energy consumption: A case study in Al Mafraq city in Jordan," *Cogent Eng*, vol. 7, no. 1, p. 1804092, 2020, doi: 10.1080/23311916.2020.1804092.

[23] Kumar, S., Singh, M. K., Kukreja, R., Chaurasiya, S. K., and Gupta, V. K., "Comparative study of thermal comfort and adaptive actions for modern and traditional multi-storey naturally ventilated hostel buildings during monsoon season in India," *Journal of Building Engineering*, vol. 23, pp. 90–106, 2019, doi: 10.1016/j.jobe.2019.01.020.

[24] Zhao, W., Lestinen, S., Mustakallio, P., Kilpeläinen, S., Jokisalo, J., and Kosonen, R., "Experimental study on thermal environment in a simulated classroom with different air distribution methods," *Journal of Building Engineering*, vol. 43, p. 103025, 2021, doi: 10.1016/j.jobe.2021.103025.

[25] Kwong, Q. J., Adam, N. M., and Sahari, B. B., "Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review," *Energy Build*, vol. 68, pp. 547–557, 2014, doi: 10.1016/j.enbuild.2013.09.034.

[26] Dorizas, P. V., Assimakopoulos, M.-N., and Santamouris, M., "A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools," *Environ Monit Assess*, vol. 187, no. 5, p. 259, 2015, doi: 10.1007/s10661-015-4503-9.

[27] Wargocki, P., Porras-Salazar, J. A., and Contreras-Espinoza, S., "The relationship between classroom temperature and children's performance in school," *Build Environ*, vol. 157, pp. 197–204, 2019, doi: 10.1016/j.buildenv.2019.04.046.

[28] Nguyen, J. L., Schwartz, J., and Dockery, D. W., "The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity," *Indoor Air*, vol. 24, no. 1, pp. 103–112, 2014, doi: 10.1111/ina.12052.

[29] Franck, U., Krüger, M., Schwarz, N., Grossmann, K., Röder, S., and Schlink, U., "Heat stress in urban areas: Indoor and outdoor temperatures in different urban structure types and subjectively reported well-being during a heat wave in the city of Leipzig," *Meteorologische Zeitschrift*, vol. 22, no. 2, pp. 167–177, 2013, doi: 10.1127/0941-2948/2013/0384.

[30] Kolaitis, D. I., Malliotakis, E., Kontogeorgos, D. A., Mandilaras, I., Katsourinis, D. I., and Founti, M. A., "Comparative assessment of internal and external thermal insulation systems for energy efficient retrofitting of residential buildings," *Energy Build*, vol. 64, pp. 123–131, 2013, doi: 10.1016/j.enbuild.2013.04.004.

[31] Lau, S. S. Y., Zhang, J., and Tao, Y., "A comparative study of thermal comfort in learning spaces using three different ventilation strategies on a tropical university campus," *Build Environ*, vol. 148, pp. 579–599, 2019, doi: 10.1016/j.buildenv.2018.11.032.

[32] Wang, Y., Kuckelkorn, J., Zhao, F.-Y., Liu, D., Kirschbaum, A., and Zhang, J.-L., "Evaluation on classroom thermal comfort and energy performance of passive school building by optimizing HVAC control systems," *Build Environ*, vol. 89, pp. 86–106, 2015, doi: 10.1016/j.buildenv.2015.02.023.

[33] Xia, Y., Lin, W., Gao, W., Liu, T., Li, Q., and Li, A., "Experimental and numerical studies on indoor thermal comfort in fluid flow: A case study on primary school classrooms," *Case Studies in Thermal Engineering*, vol. 19, p. 100619, 2020, doi: 10.1016/j.csite.2020.100619.

[34] Alghamdi, S., Tang, W., Kanjanabootra, S., and Alterman, D., "Effect of Architectural Building Design Parameters on Thermal Comfort and Energy Consumption in Higher Education Buildings," *Buildings*, vol. 12, no. 3, 2022, doi: 10.3390/buildings12030329.

[35] Vivek, T. and Balaji, K., "Heat transfer and thermal comfort analysis of thermally activated building system in warm and humid climate – A case study in an educational building," *International Journal of Thermal Sciences*, vol. 183, p. 107883, 2023, doi: 10.1016/j.ijthermalsci.2022.107883.

[36] Kükrer, E. and Eskin, N., "Effect of design and operational strategies on thermal comfort and productivity in a multipurpose school building," *Journal of Building Engineering*, vol. 44, p. 102697, 2021, doi: 10.1016/j.jobe.2021.102697.

[37] Abdallah, A. S. H., "Passive design strategies to improve student thermal comfort in Assiut University: A field study in the Faculty of Physical Education in hot season," *Sustain Cities Soc*, vol. 86, p. 104110, 2022, doi: 10.1016/j.scs.2022.104110.

[38] Ranjbar, A., "Analysing the effects of thermal comfort and indoor air quality in design studios and classrooms on student performance," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, Sep. 2019, p. 42086. doi: 10.1088/1757-899X/609/4/042086.

[39] Lakhdari, K., Sriti, L., and Painter, B., "Parametric optimization of daylight, thermal and energy performance of middle school classrooms, case of hot and dry regions," *Build Environ*, vol. 204, p. 108173, 2021, doi: 10.1016/j.buildenv.2021.108173.

[40] Su, B., Jadresin Milic, R., McPherson, P., and Wu, L., "Thermal Performance of School Buildings: Impacts beyond Thermal Comfort," *Int J Environ Res Public Health*, vol. 19, no. 10, 2022, doi: 10.3390/ijerph19105811.

[41] de la Hoz-Torres, M. L., Aguilar, A. J., Ruiz, D. P., and Mart ńez-Aires, M. D., "An investigation of indoor thermal environments and thermal comfort in naturally ventilated educational buildings," *Journal of Building Engineering*, vol. 84, p. 108677, 2024, doi: 10.1016/j.jobe.2024.108677.