Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 7, 2025

EVALUATION OF THERMAL CONDITIONS AND STANDARDS A CASE OF SCHOOL BUILDINGS IN ORANGI TOWN, KARACHI

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DOI: https://doi.org/10.5281/zenodo.15796844

Keywords
Adaptive model, Building occupants, Indoor built environment, School building, Thermal conditions.

Article History
Received on 28 May 2025
Accepted on 28 June 2025
Published on 03 July 2025

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Abstract
The rapid global urbanization has led to significant climatic changes, with rising temperatures being a pervasive concern across various regions. In Karachi, these shifts have particularly impacted the thermal comfort within built environments. As a result, occupants increasingly spend more time indoors to mitigate extreme weather conditions. In educational settings, where students spend a large portion of their day, the thermal environment plays a crucial role in both their comfort and learning efficiency. There is well-established evidence linking indoor environmental conditions to student performance, highlighting the importance of a suitable thermal environment for fostering optimal learning outcomes. Considering this, it is critical to establish a satisfactory indoor environment in educational buildings. This study focuses on private school buildings in Orangi Town, Karachi, which are constructed on small plots. These schools have thermal environments that are not conducive to effective learning. The poor thermal conditions have adversely affected the behavior and productivity of building occupants, particularly students. Therefore, this research aims to assess the thermal conditions and various building-related factors that contribute to the discomfort. The methodology for this study includes mapping, field surveys, and quantitative measurements of indoor and outdoor temperatures and humidity levels from December 2023 to May 2024. Additionally, the study will use an adaptive model to identify comfort temperature standards for the surveyed school buildings and provide recommendations for creating a more comfortable and productive learning environment.

INTRODUCTION

Rapid urbanization has profound effects on the local climate, significantly impacting the built environment and its inhabitants. According to Puteh, Ibrahim, and Adnan (2012), urban growth often leads to changes in local or microclimates, contributing to broader phenomena such as urban climate change, acid rain, and rising global temperatures. These changes disrupt daily life and, importantly, have implications for thermal comfort in urban areas. One notable consequence of urbanization is the rise in ambient temperature, which negatively affects thermal comfort in both residential and institutional settings, including schools. Despite the growing importance of thermal comfort, especially in densely populated urban areas, there remains a scarcity of research linking thermal conditions with learning outcomes, particularly in the context of urban Pakistan.

In Karachi, one of the fastest-growing urban centers in Asia, rapid urbanization has brought significant socio-economic and cultural transformations. However, it has also led to environmental consequences, including increased thermal discomfort (Puteh et al., 2012). The city's built environment, particularly its educational infrastructure, has struggled to keep pace with population growth and climatic changes. School buildings, as complex structures, must address various environmental factors such as indoor air quality, thermal conditions, acoustics, and lighting to provide a healthy and conducive learning environment (Chatzidiakou et al., 2014). These elements are crucial as students spend a considerable amount of time indoors, where poor environmental conditions can hinder academic performance and well-being (Haddad et al., 2012).

Schools are also energy-intensive buildings, with substantial heating and cooling demands. Poor thermal performance in school buildings can reduce energy efficiency and compromise the comfort and health of students and staff (Haddad et al., 2012). Although thermal comfort has been widely studied in commercial, residential, and hospitality buildings, there has been limited focus on educational institutions. This is particularly concerning given that children are more sensitive to environmental conditions than adults, making it essential to ensure optimal indoor environments in schools (Haddad et al., 2012).

Karachi, with an estimated population of 21.6 million (Demographic and the Public Purpose, 2014), has experienced a rapid population increase—from 9.8 million in 1998 to 21.2 million in 2011, growing at an annual average rate of 5%. This population surge has created numerous challenges in the built environment, including housing shortages, inadequate school facilities, and insufficient infrastructure (Lenmak, 2017). In low-income areas such as Orangi Town—home to around 1.2 million residents—the growth has resulted in informal settlements and a lack of adequate educational infrastructure. Orangi Town contains 682 private and 76 government schools (Hasan, 1990), many of which suffer from substandard indoor environments.

Data from the Thermal and Technical Research Center (TTRC) indicate that several schools in Orangi Town, including Al-Rehman Grammar, Abid Grammar, New Grammar Children's School, and Iqra Real High School, do not provide environments conducive to effective learning. Inadequate indoor thermal conditions contribute to discomfort and reduced learning outcomes. In this context, it is vital to evaluate existing thermal environments and identify design interventions that can enhance indoor performance and support student well-being.

In contemporary societies, individuals spend nearly 90% of their time indoors. Students spend more time in schools than in any other building apart from their homes, underscoring the importance of acceptable thermal conditions in educational settings (Zomorodian et al., 2016). Thermal comfort is closely linked to energy efficiency, comfort, and overall productivity in school environments. In Karachi, due to socio-economic constraints, private schools are often constructed on undersized plots that do not meet the spatial or design requirements necessary for an optimal learning environment. Consequently, poorly designed buildings result in discomfort and reduced occupant productivity. Evaluating the existing thermal conditions and identifying relevant building design factors are crucial steps toward developing sustainable and comfortable school environments.

This study focuses on evaluating the thermal comfort standards and current indoor environmental conditions of selected school buildings in Orangi Town, Karachi. It aims to:

1. **Evaluate** the indoor and outdoor temperature and humidity of selected school buildings.
2. **Determine** the comfort temperature levels in the surveyed school buildings.
3. **Compare** the measured indoor and outdoor air temperatures and humidity levels with established thermal comfort standards.

1. Case studies

Orangi Town is situated in the District West of Karachi. The total area of Orangi Town is 60 km2 (22.78 sq mi). It is surrounded by different towns like New Karachi towards the north, the Shahrah-e-Zahid Hussain to the east, transversely the Gujjar Nala stream and Liaquatabad town on the south, and further, the SITE (Sindh Industrial and Trading Estate) area towards the west. Primarily, a **working-**

class residential area with a mix of formal and informal housing. Figure 1 shows the location of Orangi Town within Karachi, Pakistan, for better contextual understanding.

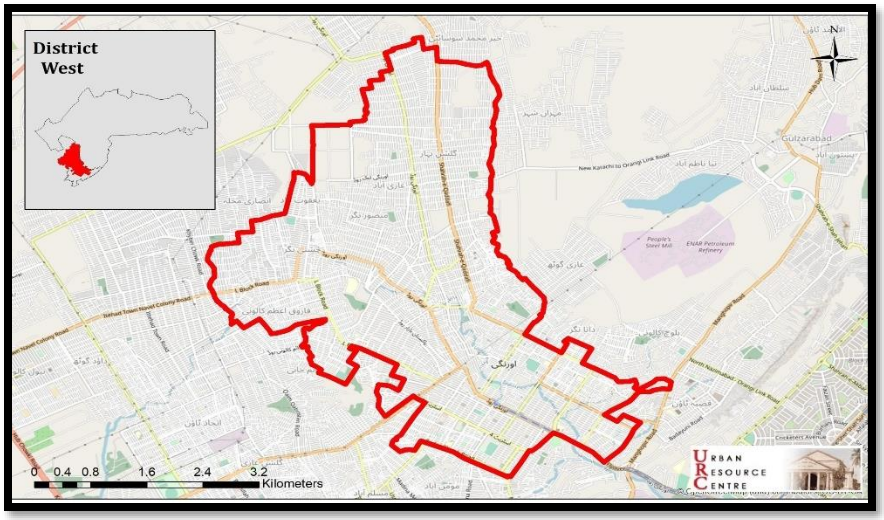


Fig 1. Location of Orangi Town in Karachi, Source: Urban Resource Centre (URC)

This study employed both subjective and objective research methodologies to evaluate the thermal comfort conditions in selected school buildings in Orangi Town, Karachi. Data collection focused on thermal parameters—specifically temperature and humidity—using field experiments and existing site documentation. An adaptive thermal comfort model was utilized for analyzing the measured values and comparing them with established comfort standards.

Fig 2. Location map of surveyed schools

Source: Akhtar, H.K. (2016). The Physical Environment of Orangi School Buildings: A Report

Figure 2 shows that the surveyed private school buildings, such as Abid Grammar School, Al-Rehman Secondary, Grammar Children, and Iqra Real High School are in Gulshan-e-Nazar, Orangi Town, Karachi. This area is the new extension of Orangi Town, but is approximately a 20-year-old settlement.

The criteria that were developed for selecting school structures have been available in proximity within a 2km area to minimize the effect of external weather conditions, and these buildings are constructed on small and varied-sized plots, like 120 sq. yd to 400 sq. yd.

2. Results and discussion

The quantitative part of the research represents the indoor and outdoor temperature readings and measures outdoor humidity levels for winters and summers. Table 1 shows the quantitative measurements of the indoor and outdoor temperature and humidity levels for the winter and summer seasons.

Table 1: Quantitative measurements of the indoor and outdoor temperature and humidity levels for the winter and summer seasons

	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	December	20.9	25.5	20.4	20.9	30%	36%
	January	24.8	28	21.9	27	55%	63%
AL-Rehman Secondary School	February	25	29	22	28	60%	70%
	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	December	22.5	27	21.6	26.5	30%	38%
New Grammar Children Secondary School	January	24.3	31.7	23.9	30.6	45%	51%
	February	26	33	25	32	55	65
	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	December	30.4	29.7	22.7	28.2	27%	36%
	January	27.3	31.6	22.4	30.3	40%	43%
Abid Grammar School	February	29	33	24	32	45%	55%
	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	December	33.4	29.4	22.5	27.1	29%	35%
Iqra Real High School	January	29.8	31	23.6	28.6	41%	54%
	February	30	32	24	29	50%	65%
	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	March	31.5	37	28	33	38%	44%
	April	32.5	38	31	36	42%	50%
AL-Rehman Secondary School	May	32.7	39.1	32.8	37	45%	55%
	Month	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	March	32	39	27	36	36%	43%
New Grammar Children Secondary School	April	33	40	30	38	41%	50%
	My	34	42	33	41.5	43%	55%
Abid Grammar School	**Month**	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	March	32	37	27	32	35%	45%

	April	33	38	30	35	40%	50%
	May	35.2	40	32.2	36	45%	54%
Iqra Real high School	**Month**	**Max Temp outdoor**	**Max Temp Indoor**	**Min Temp outdoor**	**Min Temp Indoor**	**Min-Humidity%**	**Max-Humidity%**
	March	31	34	27	31	39%	43%
	April	32	35	30	34	43%	50%
	May	32.9	37	32.4	35	45%	54%

The graphs below describe and graphically illustrate indoor and outdoor temperatures and humidity levels in the four schools.

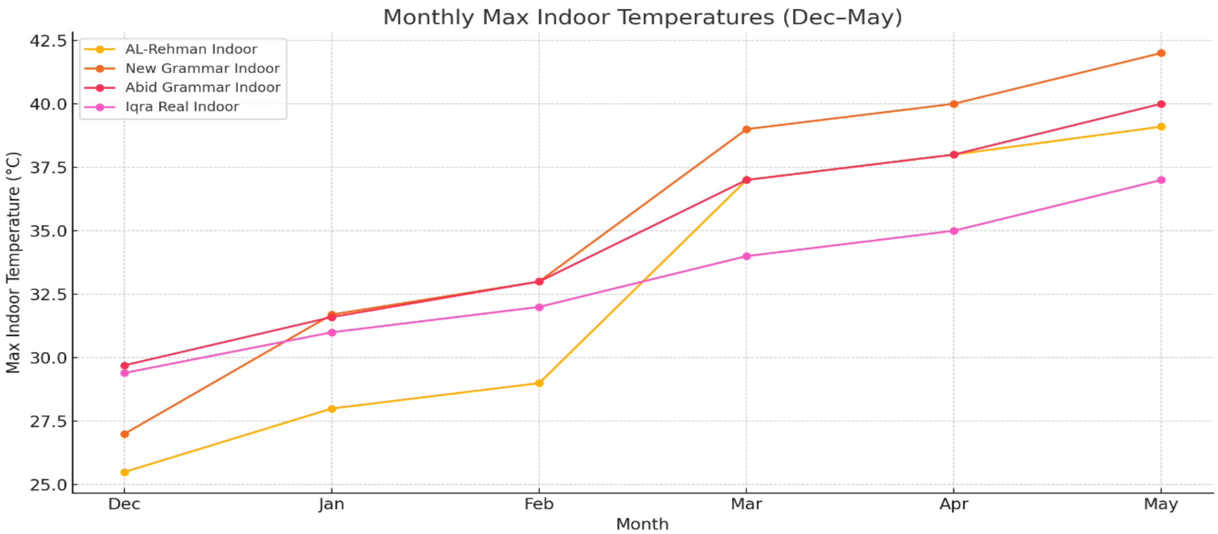


Fig 3. **Maximum indoor temperatures** from **December to May** for the four schools

Figure 3 shows that from December to February, the indoor temperatures range from 25-33 °C, which is already warm for learning environments. From March to May, there is a significant jump in all schools. Classrooms become very hot, especially in April and May. Indoor heat buildup is likely due to poor ventilation and building materials that trap heat. Classrooms become uncomfortably hot by March, potentially harming student performance and health.

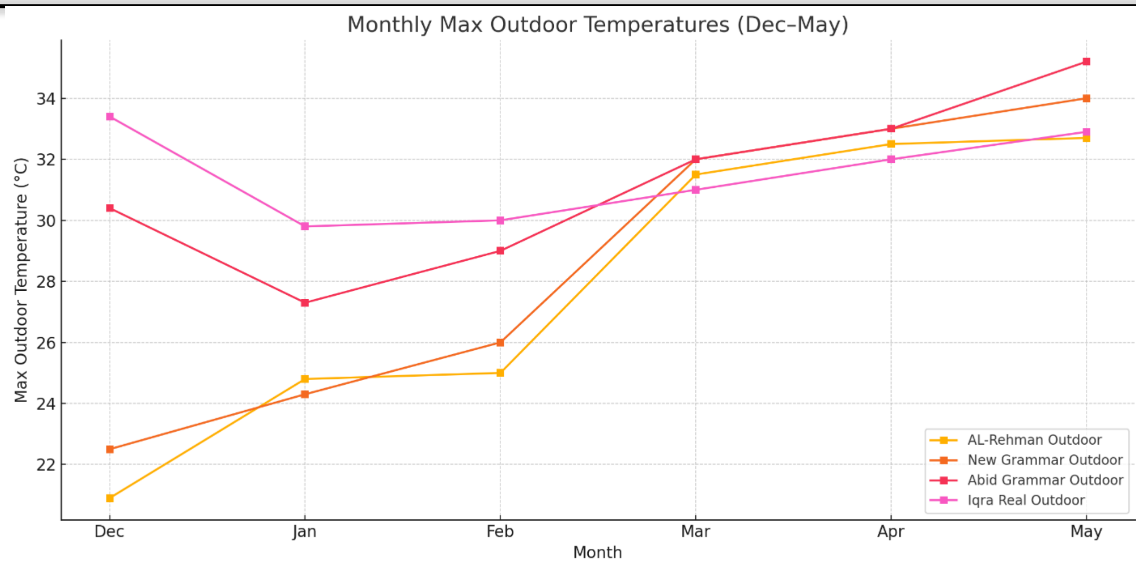


Fig 4. Maximum **outdoor temperatures** from **December to May** for the four schools

Figure 4 shows that Iqra Real High School has the highest outdoor temperatures in winter, peaking at 33.4°C in December. It needs immediate attention for winter heat control, indicating urban heat island exposure or low reflectivity surfaces. Abid Grammar School leads in summer, reaching 35.2°C in May. Itshould explore cool roofs or tree planting. Al-Rehman and New Grammar follow similar trends, rising steadily from the low 20s in December to ~33–34°C in May, and will still face discomfort without proactive climate resilience planning. All schools experience a temperature rise of 10–12°C between December and May.

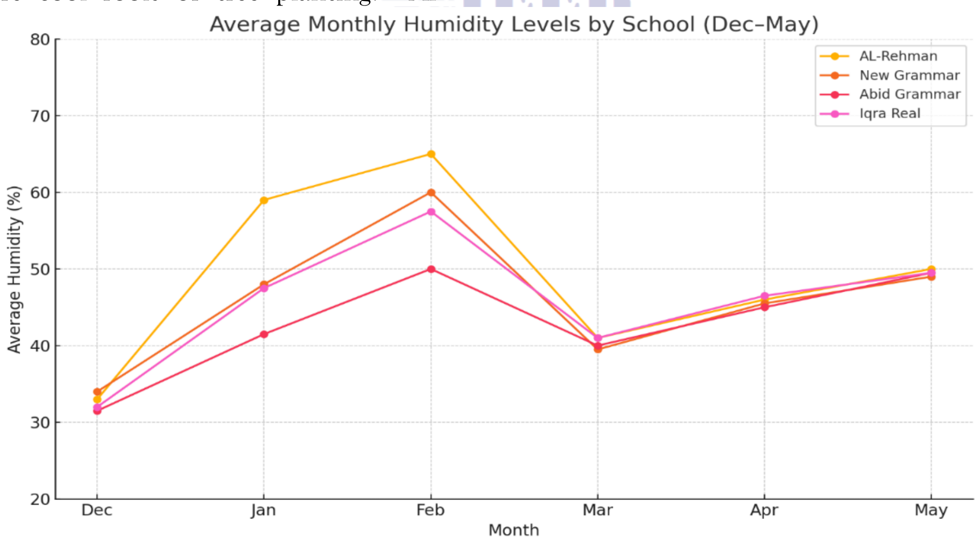


Fig 5. Maximum humidity levels from December to May for the four schools.

Figure 5 shows that February is consistently the most humid month of all schools. Abid Grammar has the driest conditions overall. Al-Rehman experiences the highest variability, suggesting environmental or design differences (e.g., vegetation, ventilation, or building materials). All schools show humidity decline in March, likely due to the seasonal transition from winter to dry spring. Ventilation strategies are therefore important in the spring and summer months to counteract the combined effects of rising temperature and humidity.

3.1. Adaptive Thermal Comfort Standards

To find the comfort temperature for the targeted area, an adaptive model has been used. The comfort temperature varies from season to season. The difference in comfort temperature between summer and winter is 4.7 degrees in Karachi, around 6-7 degrees in other cities of Pakistan. The equation is established for Karachi (Tc = 12.1 + 0.534 To), which is based on an adaptive approach. By applying this relationship, a comfortable temperature for the targeted area has been computed, and it was compared with the indoor temperature measurements of selected school cases. Table 2 shows the evaluation of comfort temperature for winter and summer seasons and describes the differences between the indoor air temperature and comfort temperature.

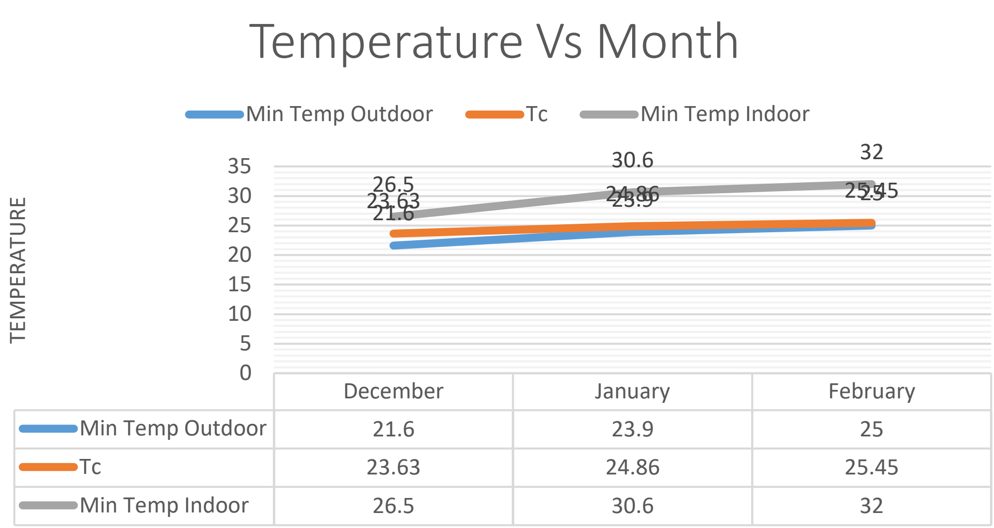
Table 2: Difference between Comfort Temperature and Indoor temperature of Selected Schools during winter and summer

AL-Rehman Secondary School	**Month**	**Max Temp outdoor**	**Min Temp outdoor**	**T_c**	**Max Temp Indoor**	**Min Temp Indoor**
	December	20.9	20.4	22.9	25.5	20.9
	January	24.8	21.9	23.79	28	27
	February	25	22	23.84	29	28
	NOTE: The min indoor temperature deviation for average comfort temperature = 23.5 degrees centigrade in winter.					
New Grammar Children Secondary School	**Month**	**Max Temp outdoor**	**Min Temp outdoor**	**T_c**	**Max Temp Indoor**	**Min Temp Indoor**
	December	22.5	21.6	23.63	27	26.5
	January	24.3	23.9	24.86	31.7	30.6
	February	26	25	25.45	33	32
	NOTE: The min indoor temperature deviation for average comfort temperature Tc = 24.64 degrees centigrade in winter.					
Abid Grammar School	**Month**	**Max Temp outdoor**	**Min Temp outdoor**	**T_c**	**Max Temp Indoor**	**Min Temp Indoor**
	December	30.4	22.7	24.22	29.7	28.2
	January	27.3	22.4	24.06	31.6	30.3
	February	29	24	25	33	32
	NOTE: The minimum indoor temperature deviation for average comfort temperature T_c = 24.42 degrees centigrade in winter.					
Iqra Real High School	**Month**	**Max Temp outdoor**	**Min Temp outdoor**	**T_c**	**Max Temp Indoor**	**Min Temp Indoor**
	December	33.4	22.5	24.11	29.4	27.1
	January	29.8	23.6	24.7	31	28.6
	February	30	24	24.916	32	29
	NOTE: The min indoor temperature deviation for average comfort temperature Tc = 24.57 degrees centigrade in winter.					
Al-Rehman Secondary School	**Month**	**Max Temp outdoor**	**Min Temp outdoor**	**T_c**	**Min Temp Indoor**	**Max Temp Indoor**
	March	31.5	28	27	33	37
	April	32.5	31	28.6	36	38

School	Month	Max Temp outdoor	Min Temp outdoor	T_c	Min Temp Indoor	Max Temp Indoor
	May	32.7	32.8	29.6	37	39.1
	NOTE: The indoor temperature deviation for average thermal comfort Tc = 28 degrees centigrade in summer.					
New Grammar Children Secondary School	Month	Max Temp outdoor	Min Temp outdoor	T_c	Min Temp Indoor	Max Temp Indoor
	March	32	27	26.5	36	39
	April	33	30	28.12	38	40
	May	34	33	29.7	41.5	42
	NOTE: The indoor temperature deviation for average thermal comfort Tc = 27 degrees centigrade in summer.					
Abid Grammar School	Month	Max Temp outdoor	Min Temp outdoor	T_c	Min Temp Indoor	Max Temp Indoor
	March	32	27	26.5	32	37
	April	33	30	28.12	35	38
	May	35.2	32.2	29.29	36	40
	NOTE: The indoor temperature deviation for average thermal comfort Tc = 27 degrees centigrade in summer					
Iqra Real High School	Month	Max Temp outdoor	Min Temp outdoor	T_c	Min Temp Indoor	Max Temp Indoor
	March	31	27	26.5	31	34
	April	32	30	28.12	34	35
	May	32.9	32.4	29.4	35	37
	NOTE: The indoor temperature deviation for average thermal comfort Tc = 27 degrees centigrade in summer.					

3.2. Difference between Comfort Temperature and the Indoor Temperature of Surveyed Schools in Winter.

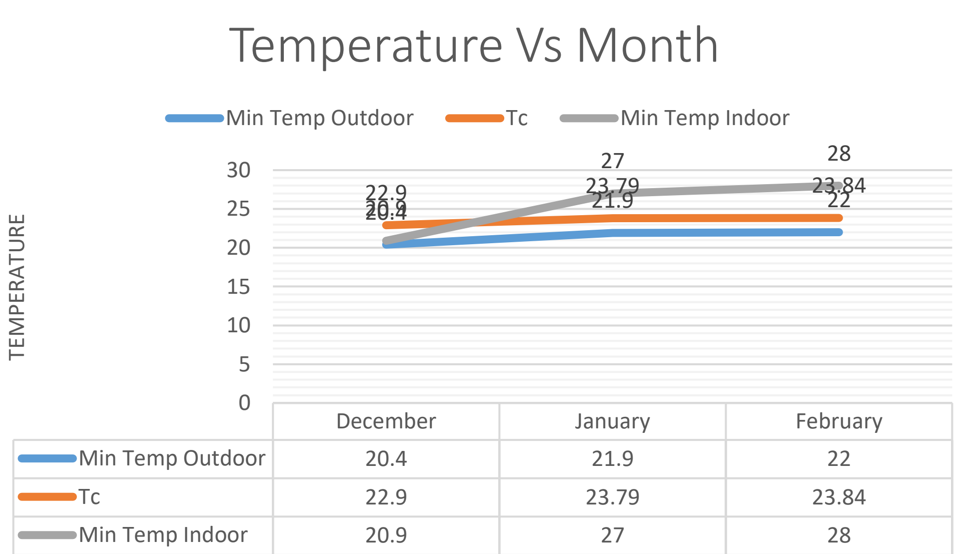
In thermal comfort studies, **comfort temperature** refers to the temperature range within which most occupants feel thermally comfortable, typically **20°C to 24°C in winter** according to ASHRAE standards.



	December	January	February
Min Temp Outdoor	21.6	23.9	25
Tc	23.63	24.86	25.45
Min Temp Indoor	26.5	30.6	32

Fig 6. Al Rehman Grammar School

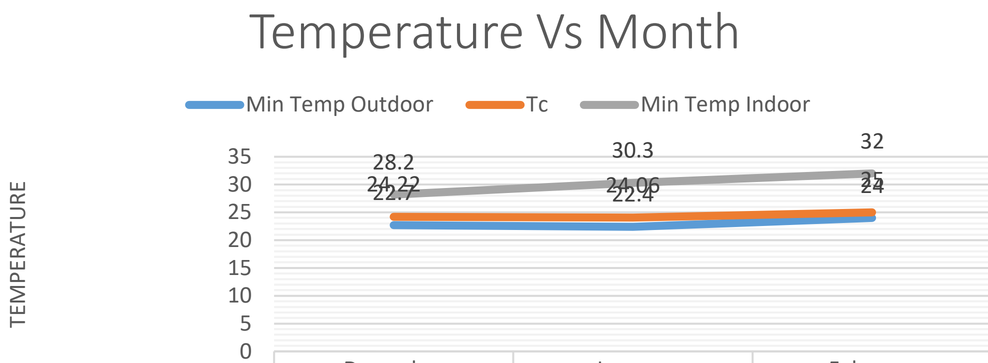
The indoor temperature of Al-Rehman Grammar School is constantly higher than both the outdoor temperature and comfort temperature, which represents an uncomfortable indoor thermal environment, as shown in Figure 6. This type of thermal environment has a negative impact on the working performance of the learners and school staff.



	December	January	February
Min Temp Outdoor	20.4	21.9	22
Tc	22.9	23.79	23.84
Min Temp Indoor	20.9	27	28

Fig 7. New Grammar Children Secondary School

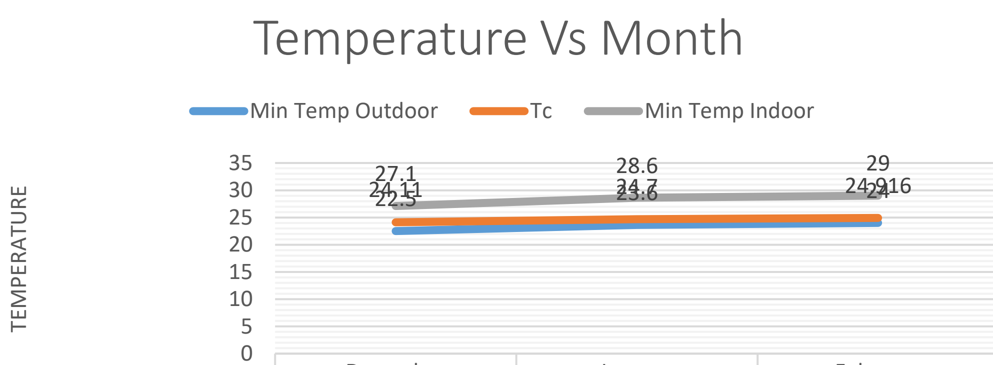
The minimum indoor temperature range of 20-28 °C is slightly greater than the average comfort temperature of 23 °C in winter. The indoor temperature exceeds the thermal comfort standard, indicating thermal discomfort and deprived ventilation, as shown in Figure 7. This leads to negative impacts on mental health, employee performance, and restless conditions, especially in school settings.



	December	January	February
Min Temp Outdoor	22.7	22.4	24
Tc	24.22	24.06	25
Min Temp Indoor	28.2	30.3	32

Fig 8. Abid Grammar School

The minimum indoor temperature range of 28-32°C deviates from the average comfort temperature (24°C). The classrooms of this school represent peak indoor temperature in February as compared to the comfort temperature, as shown in Figure 8. The elevated indoor temperature depicts inadequate ventilation, lack of shading, reduced insulation, and low natural light associated with increased reliance on the artificial lighting system, as well as psychological and visual discomfort for the learners.



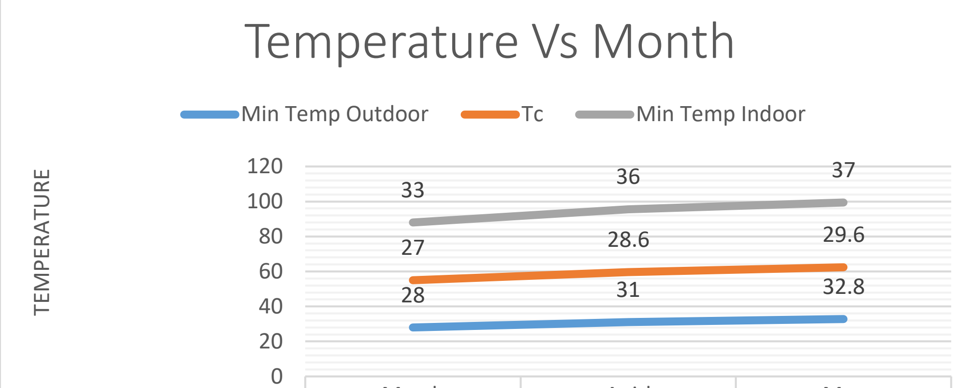
	December	January	February
Min Temp Outdoor	22.5	23.6	24
Tc	24.11	24.7	24.916
Min Temp Indoor	27.1	28.6	29

Fig 9. Iqral Real High School

The minimum indoor temperature range of 27-29°C is much higher than the average comfort temperature of 24.5°C in winter, as shown in Figure 9. This leads to exceeding indoor thermal discomfort, which critically affects the health, learning performance, and overall well-being of the students and staff. The major contributing factors in thermal discomfort are fenestration design, low natural light, and inadequate shading and insulation.

3.3. Difference between Comfort Temperature and Indoor Temperature in summer

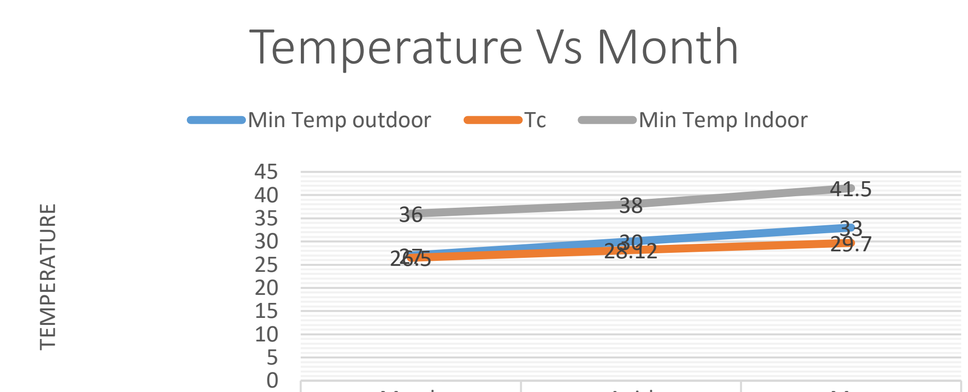
Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 7, 2025



	March	Apirl	May
Min Temp Indoor	33	36	37
Tc	27	28.6	29.6
Min Temp Outdoor	28	31	32.8

Fig 10. Al-Rehman Secondary School

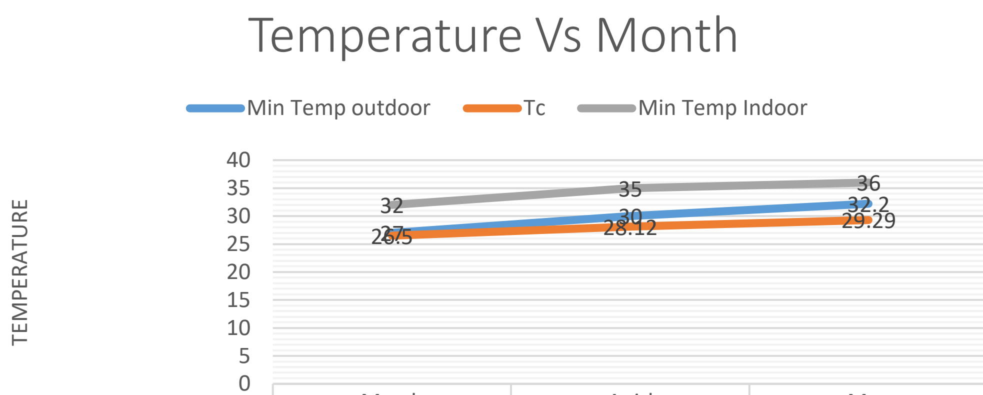
The minimum indoor temperature range of 33-37°C is much higher than the average comfort temperature of 28°C in summer, as shown in Figure 10. The summer analysis of this chart indicates the severe thermal discomfort conditions, especially in May, which have unscrupulous health effects like heat stress, decreased cognitive performance, and increased absenteeism in school. The data represents the uncomfortable building design setting, which points to urgent architectural and environmental interventions to ensure a healthier, more productive, and better indoor thermal environment.



	March	Apirl	May
Min Temp outdoor	27	30	33
Tc	26.5	28.12	29.7
Min Temp Indoor	36	38	41.5

Fig 11. New Grammar Children School

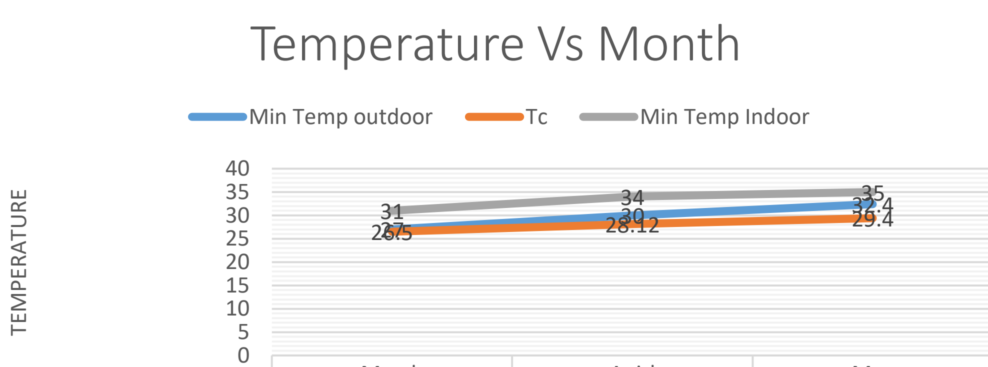
The minimum indoor temperature range (36-41.5°C) is much higher than the average comfort temperature of 28 °C in summer, as shown in Figure 11. The data of the chart indicates that the building envelope of the new grammar school is failing to mitigate excessive heat and transfer thermal heat inside the classrooms, which is negatively impacting the learners' performance and daily school activities. The architectural design of the school needs to develop courtyards for better ventilation and natural light, improve window placement and sizes, and introduce a proper shading system on the windows.



	March	Apirl	May
Min Temp outdoor	27	30	32.2
Tc	26.5	28.12	29.29
Min Temp Indoor	32	35	36

Fig 12. Abid Grammar School

The data on the chart indicates an uncomfortable thermal performance during the peak summer season, as shown in Figure 12. The indoor thermal environment is constantly warmer than the outdoor temperature, and comfort onset, signifying an essential need for project enhancements to improve thermal comfort and energy demand of the building.



	March	Apirl	May
Min Temp outdoor	27	30	32.4
Tc	26.5	28.12	29.4
Min Temp Indoor	31	34	35

Fig 13. Iqra Real High School

The minimum indoor temperature (31-35°C) is higher than the average comfort temperature, Tc = 28°C, in summer, as shown in Figure 13. This highlights a warmer environment in summer seasons. This trend is gradually increasing from 31 to 35 degrees centigrade. The increase in the indoor temperature calculation is moderate compared to the comfort temperature. But it is necessary to develop better design strategies for improving the indoor thermal conditions of schools.

3.4. Hypothesis testing for the Evaluation of Thermal conditions of Selected Schools

Analysis of the thermal performance of selected school buildings is based on two main variables like temperature and humidity. Firstly, descriptive statistics were used to identify the standard deviation, range, and minimum or maximum values of selected variables for testing the hypothesis. Furthermore, correlation analysis was performed to find the relationship of the various variables to each other.

The hypothesis was formulated in winter and summer independently for the evaluation of thermal conditions of surveyed schools.

Hypothesis1:

Indoor temperature is 2°c greater than or equal to the outdoor temperature in winter. Numerically.

H_0: μ1 > μ2

H_1: μ1 ≤ μ2

Where μ1 denotes indoor temperature and μ2 denotes outdoor temperature, and ∝ was chosen to be 0.01

Hypothesis2:

Indoor temperature is greater than or 4°centigrate less than the outdoor temperature in summer. Numerically.

H_0: μ1 > μ2

H_1: μ1 < μ2

Where μ1 indicates indoor temperature and μ2 symbolizes outdoor temperature, and ∝ was chosen to be 0.01

3.4.1. Testing of Hypothesis-1

In the case of the winter season, the Z test was applied to compare the means of the outdoor and indoor temperatures of all selected samples. Table 3 below represents the results of testing hypothesis 1

Table 3: Z-Test Two Sample for Means (winter)

Al Rehman Secondary School	Outdoor temp	Indoor temp
Mean	22.5	26.4
Known Variance	3.824	8.66
Observations	6	6
Hypothesized Mean Difference	0	
Z	2.703730201	
P(Z<=z) one-tail	0.003428297	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	0.006856594	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, null hypothesis is accepted at P< 2.575, and it is concluded that the indoor temperature is 2°c greater than the outdoor temperature in winter.		
New Grammar Secondary School	**Outdoor temp**	**Indoor temp**
Mean	23.88333333	30.13333333
Known Variance	2.605666667	7.478666667
Observations	6	6
Hypothesized Mean Difference	0	
Z	4.82094355	
P(Z<=z) one-tail	7.14404E-07	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	1.42881E-06	
z Critical two-tail	2.575829304	
Result: This result represents that the critical value falls in the acceptance region; therefore, null hypothesis is accepted at P< 2.575, and it is concluded that the indoor temperature is 2°c greater than the outdoor temperature in winter.		

Abid Grammar School	Outdoor temp	Indoor temp
Mean	25.96666667	30.8
Known Variance	11.57866667	3.028
Observations	6	6
Hypothesized Mean Difference	0	
Z	3.097753194	
P(Z<=z) one-tail	0.000974969	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	0.001949937	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, the null hypothesis is accepted at P< 2.575, and it is concluded that the indoor temperature is 2°c greater than the outdoor temperature in winter.		
Iqra Real School	**Outdoor temp**	**Indoor temp**
Mean	27.21666667	29.51666667
Known Variance	19.66567	3.065667
Observations	6	6
Hypothesized Mean Difference	0	
Z	-1.181655745	
P(Z<=z) one-tail	0.118671162	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	0.237342325	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, Ho: µ1 > µ2 is accepted at P< 2.575, and it is concluded that the indoor temperature is 2°c greater than the outdoor temperature in winter.		

3.4.2. Testing of Hypothesis-2

Table 4 illustrates the results of testing hypothesis 2 by applying a z-test.

Table 4: Z-Test Two Sample for Means (summer)

Samlpe:1 Al-Rehman Secondary School	Outdoor Temp	Indoor Temp
Mean	31.41666667	36.68333333
Known Variance	3.317667	4.361667
Observations	6	6
Hypothesized Mean Difference	0	
Z	-4.655321499	
P(Z<=z) one-tail	1.61738E-06	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	3.23476E-06	
z Critical two-tail	2.575829304	
Result: This result shows that the value of "z" falls in the rejection region, hence the null hypothesis is rejected at P> 2.57, and it is concluded that the indoor temperature is 4 centigrade less than the outdoor temperature.		
New Grammar Children Secondary School	**Outdoor Temp**	**Indoor Temp**
Mean	31.5	39.41666667

Known Variance	6.7	5.041667
Observations	6	6
Hypothesized Mean Difference	0	
Z	-5.65917475	
P(Z<=z) one-tail	7.60513E-09	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	1.52103E-08	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, the null hypothesis is accepted at P< 2.575, and it is concluded that the indoor temperature is greater than the outdoor temperature.		
Abid Grammar School	**Outdoor Temp**	**Indoor Temp**
Mean	31.56666667	36.33333333
Known Variance	7.830667	7.466667
Observations	6	6
Hypothesized Mean Difference	0	
Z	-2.985262554	
P(Z<=z) one-tail	0.001416675	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	0.00283335	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, the null hypothesis is accepted at P< 2.57, and it is concluded that the alternate hypothesis is rejected.		
Iqra Real School	**Outdoor Temp**	**Indoor Temp**
Mean	30.88333333	34.33333333
Known Variance	4.697667	3.866667
Observations	6	6
Hypothesized Mean Difference	0	
Z	-2.887672402	
P(Z<=z) one-tail	0.001940519	
z Critical one-tail	2.326347874	
P(Z<=z) two-tail	0.003881039	
z Critical two-tail	2.575829304	
Result: This result shows that the critical value falls in the acceptance region; therefore, the null hypothesis is accepted at P< 2.575, and it is concluded that the indoor temperature is greater than the outdoor temperature.		

3.5. Descriptive Statistical Analysis

3.5.1. Outcomes Drawn from Measurements of Winter

Table 1.5 demonstrates the descriptive statistical analysis of winter readings, which shows the mean, standard deviation, variance, range, moreover minimum and maximum values of indoor temperature, outdoor temperature, and humidity.

Table 1.5: Descriptive Statistics Computation for Winter

AL-Rehman Secondary School	Outdoor Temp	Indoor Temp	Outdoor Humidity%

Mean	22.5	26.4	0.523333333
Median	21.95	27.5	0.575
Standard Deviation	1.95550505	2.942787794	0.158577005
Sample Variance	3.824	8.66	0.025146667
Range	4.6	8.1	0.4
Minimum	20.4	20.9	0.3
Maximum	25	29	0.7
Sum	135	158.4	3.14
Count	6	6	6
New Grammar Children Secondary School	**Outdoor Temp**	**Indoor Temp**	**outdoor-Humidity%**
Mean	23.88333333	30.13333333	20.27333333
Median	24.1	31.15	0.48
Standard Deviation	1.614207752	2.734715098	30.93428109
Sample Variance	2.605666667	7.478666667	956.9297467
Range	4.4	6.5	64.7
Minimum	21.6	26.5	0.3
Maximum	26	33	65
Sum	143.3	180.8	121.64
Count	6	6	6

Abid Grammar School	**Outdoor Temp**	**Indoor Temp**	**outdoor -Humidity%**
ean	25.96666667	30.8	0.41
Median	25.65	30.95	0.415
Standard Deviation	3.402743991	1.740114939	0.093594872
Sample Variance	11.57866667	3.028	0.00876
Range	8	4.8	0.28
Minimum	22.4	28.2	0.27
Maximum	30.4	33	0.55
Sum	155.8	184.8	2.46
Count	6	6	6
Iqra Real high School	**Temp outdoor**	**Temp Indoor**	**Outdoor -Humidity%**
Mean	27.21666667	29.51666667	0.456666667
Median	26.9	29.2	0.455
Standard Deviation	4.434598817	1.750904528	0.132312761
Sample Variance	19.66566667	3.065666667	0.017506667
Range	10.9	4.9	0.36
Minimum	22.5	27.1	0.29
Maximum	33.4	32	0.65
Sum	163.3	177.1	2.74
Count	6	6	6

3.5.2. Outcomes Drawn from Measurements of Summer

Table 6 describes the descriptive statistical analysis of summer measurements, which includes the standard deviation, variance, range, in addition to the minimum and maximum values of selected variables.

Table 6: Descriptive Statistics Computation for summer

AL-Rehman Secondary School	**Temp outdoor**	**Temp Indoor**	**outdoor Humidity%**
Mean	31.41666667	36.68333333	29.16666667
Standard Error	0.743602343	0.852610371	9.202061967
Median	32	37	40
Standard Deviation	1.821446312	2.088460358	22.5403564
Sample Variance	3.317666667	4.361666667	508.0676667
Range	4.8	6.1	49.55
Minimum	28	33	0.45
Maximum	32.8	39.1	50
Sum	188.5	220.1	175
Count	6	6	6
New Grammar Children Secondary School	**Temp outdoor**	**Temp Indoor**	**outdoor Humidity%**
Mean	31.5	39.41666667	28.49666667
Median	32.5	39.5	38.5
Mode	33	#N/A	#N/A
Standard Deviation	2.588435821	2.245365598	22.15458117
Sample Variance	6.7	5.041666667	490.8254667
Range	7	6	49.57
Minimum	27	36	0.43
Maximum	34	42	50
Sum	189	236.5	170.98
Count	6	6	6
Abid Grammar School	**Temp outdoor**	**Temp Indoor**	**outdoor Humidity%**
Mean	31.56666667	36.33333333	28.49833333
Median	32.1	36.5	37.5
Standard Deviation	2.798332837	2.732520204	22.26011718
Sample Variance	7.830666667	7.466666667	495.5128167
Range	8.2	8	49.55
Minimum	27	32	0.45
Maximum	35.2	40	50
Sum	189.4	218	170.99
Count	6	6	6
Iqra Real High School	**Temp outdoor**	**Temp Indoor**	**outdoor Humidity%**
Mean	30.88333333	34.33333333	0.456666667
Standard Error	0.88484148	0.802772972	0.022161027
Median	31.5	34.5	0.44
Standard Deviation	2.167410129	1.966384161	0.054283208
Sample Variance	4.697666667	3.866666667	0.002946667
Range	5.9	6	0.15
Minimum	27	31	0.39

Maximum	32.9	37	0.54
Sum	185.3	206	2.74
Count	6	6	6

3.6. Correlation of Variables affecting Surveyed Schools' Thermal Conditions in winter

A correlation test was performed on the selected variables (humidity, outdoor, and indoor temperature) to identify the relationship between them. However, the above-mentioned variables are directly affected by the thermal conditions of the building. The following graphs demonstrate a positive and moderate range of correlation coefficients among the selected variables, and their results are reported below.

Al-Rehman Secondary School

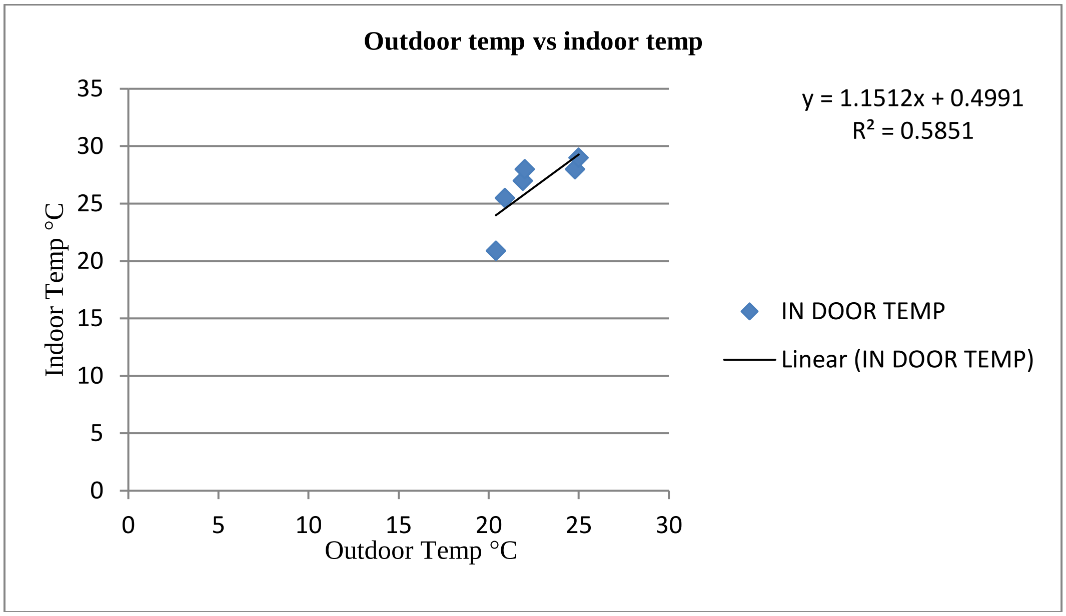


Chart 1a: Correlation of Outdoor and Indoor Temperature in Al Rehman School in winter

The x and y axis represents outdoor and indoor temperature, and all the readings plotted on the graph are close to each other, hence it is proven that a positive correlation (r=0.764) has been found between them, as presented in Chart 1a.

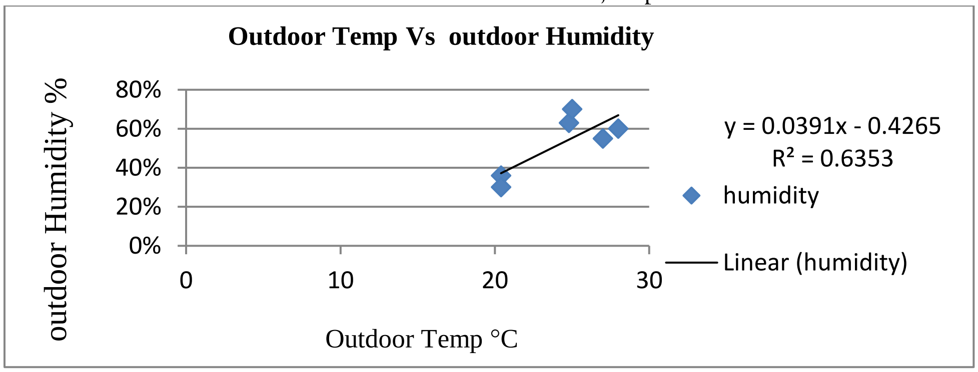


Chart 1b: Correlation of Outdoor Temperature and Outdoor Humidity in Al Rehman School in winter.

The x and y axis depicts outdoor temperature and humidity, and all readings plotted on the graph are close to each other. A strong positive correlation (r =0.8786) was observed between them, as presented in Chart 1b.

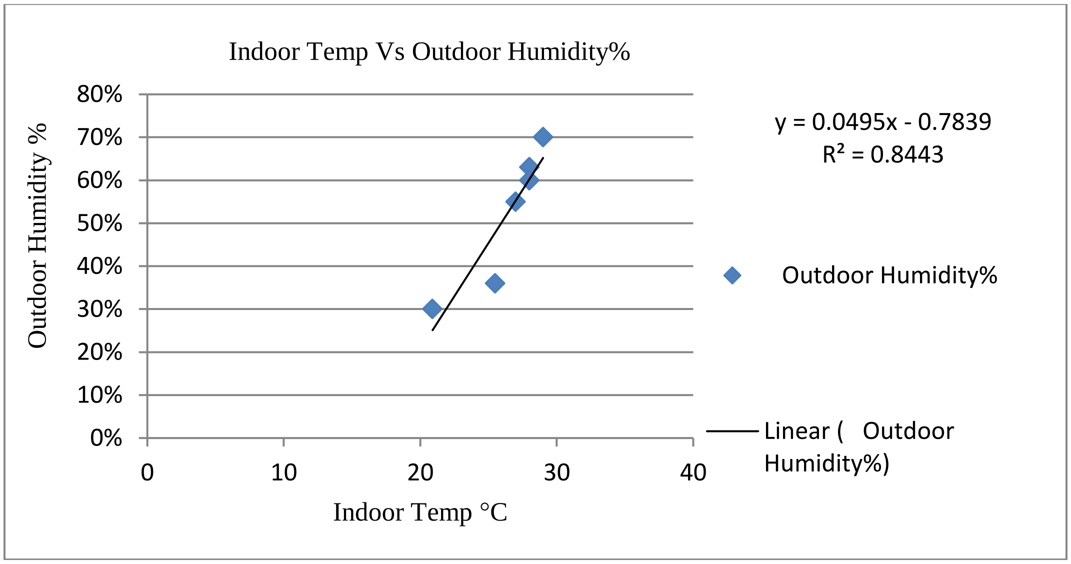


Chart 1c: Correlation of Indoor Temperature and Outdoor Humidity in Al Rehman School in winter

However, a correlation test is also performed on indoor temperature and humidity. The x and y axes of the graph show that strong positive correlation (r=0.918) between internal temperature and external humidity, as presented in Chart 1c.

3.6.1. New Grammar Children Secondary School

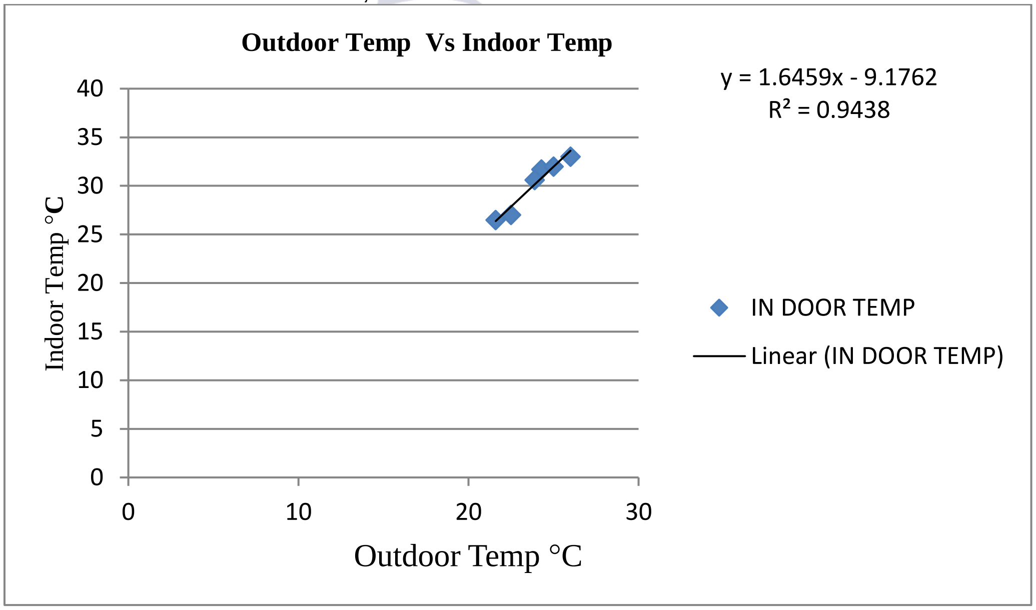


Chart 2a: Correlation of Outdoor and Indoor Temperature in New Grammar Children High School in winter.

The horizontal and vertical axes of the graph represent outdoor and indoor temperature readings that measure the strong positive correlation coefficient (r = 0.97) between these two variables, as presented in Chart 2b.

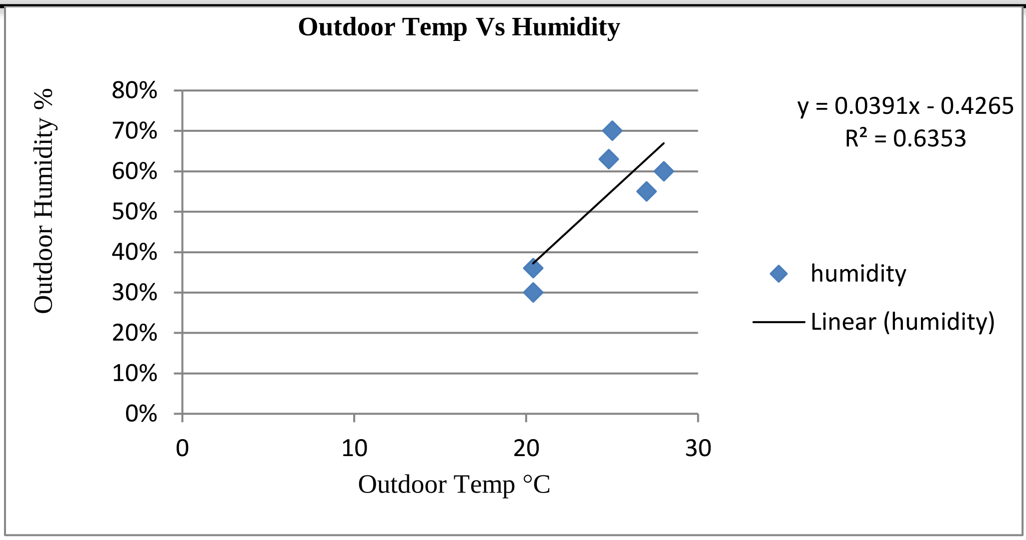


Chart 2b: Correlation of Outdoor Temperature and Humidity in New Grammar Children High School in winter.

The strong positive correlation coefficient (r = 0.8) measures the strength and linear relationship between the outdoor temperature and humidity, as presented in Chart 2b.

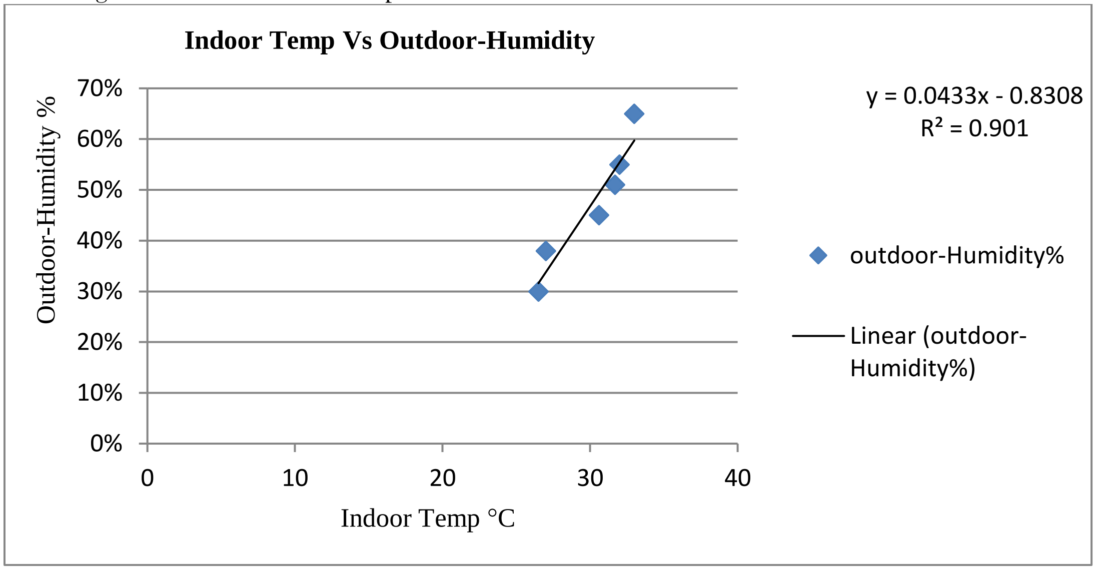


Chart 2c: Correlation of Indoor Temperature and Outdoor Humidity in New Grammar Children High School in winter.

The graph measures the strong positive correlation (r=0.1) between the indoor temperature and outdoor humidity, as presented in Chart 2c.

Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 7, 2025

3.6.2. Abid Grammar School

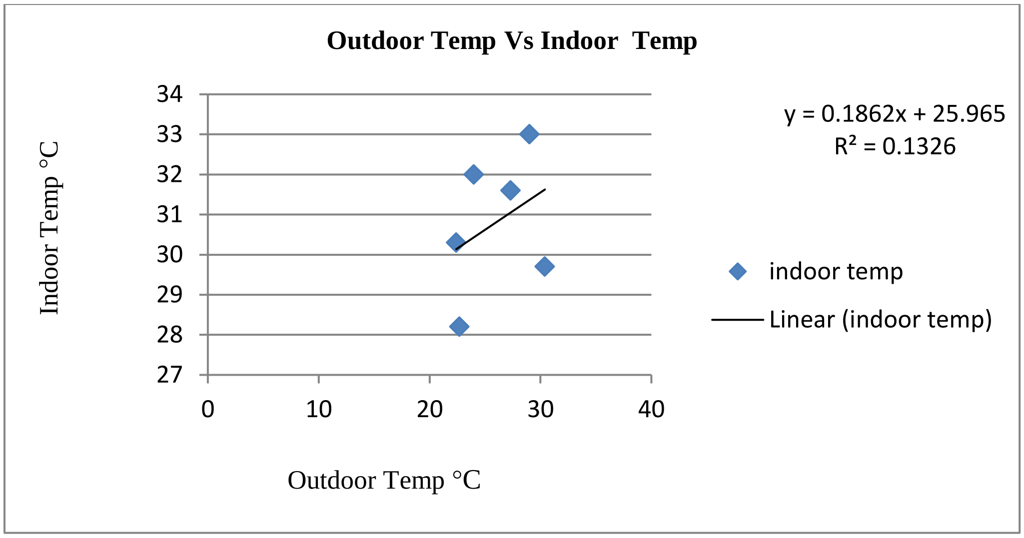


Chart 3a: Correlation of Outdoor and Indoor Temperature in Abid Grammar School in winter

The horizontal and vertical axis on the graph represents a moderate correlation coefficient r=0.4 between outdoor and indoor temperature, as presented in Chart 3a.

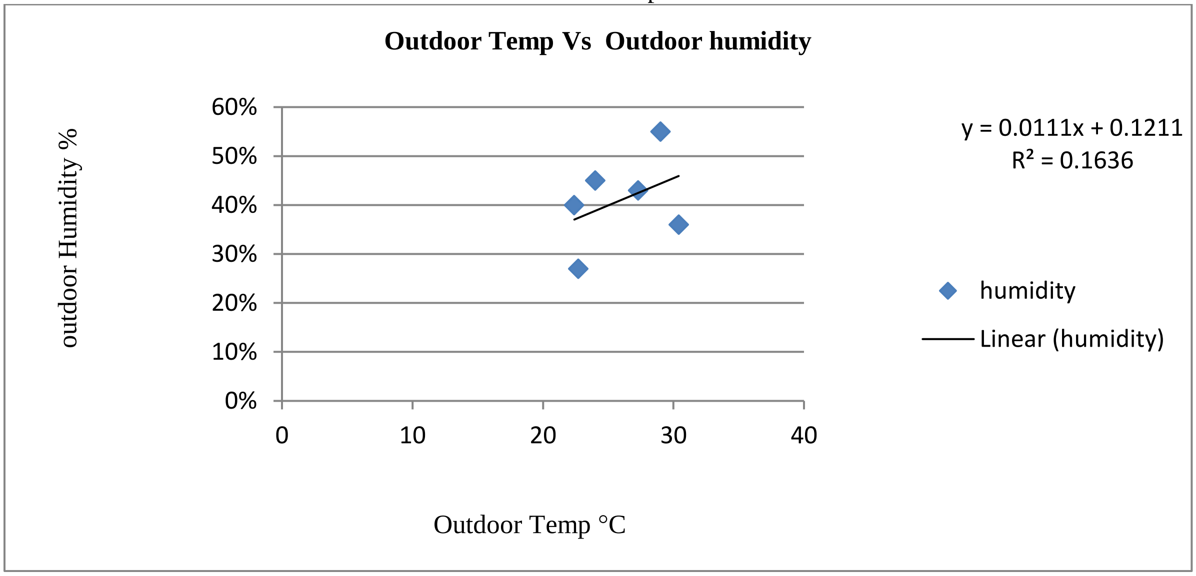


Chart 3b: Correlation of Outdoor Temperature and Outdoor Humidity in Abid Grammar School in winter.

The above scatter graph measures a moderate correlation coefficient (r=0.404) between outdoor temperature and humidity. As plotted readings on the x-axis and y-axis represent a weak linear relationship, as presented in Chart 3b.

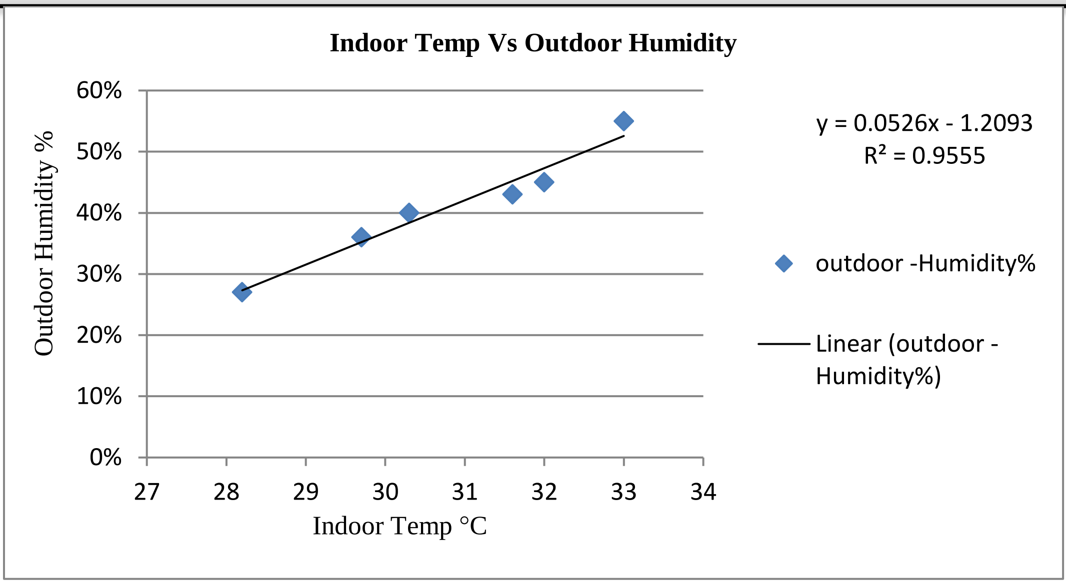


Chart 3c: Correlation of Indoor Temperature and Outdoor Humidity in Abid Grammar School in winter.

The indoor temperature and outdoor humidity represent the x-axis and y-axis on the graph, and plotted readings measure a strong positive correlation coefficient r=0.1 between them, as presented in Chart 3c.

3.6.3. Iqra Real School

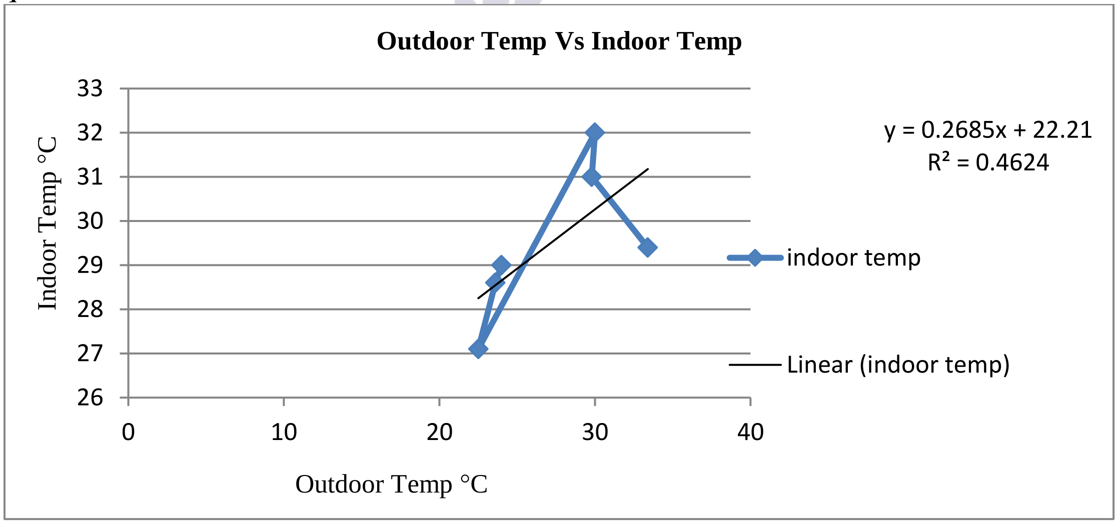


Chart 4a: Correlation of Outdoor and Indoor Temperature in Iqra Real School in winter.

The horizontal and vertical axis on the graph represents outdoor and indoor temperature, and the above graph establishes a strong positive correlation coefficient (r=0.679) between them, as shown in Chart 4a.

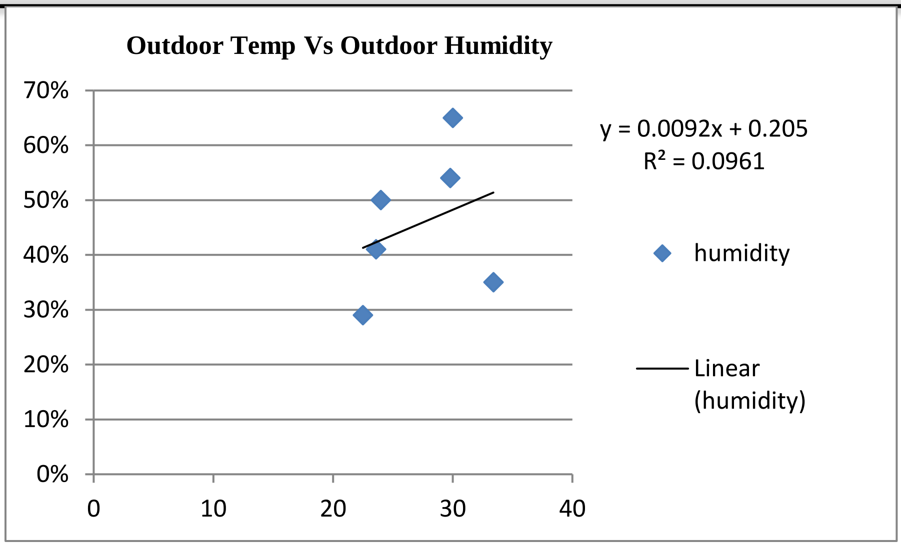


Chart 4b: Correlation of Outdoor Temperature and Outdoor Humidity in Iqra Real School in winter.

The x and y-axis show the outdoor temperature in centigrade, and the outdoor humidity in percentage on the graph. However, plotted readings are measuring a moderate linear relationship, r=0.3, among variables, as presented in Chart 4b.

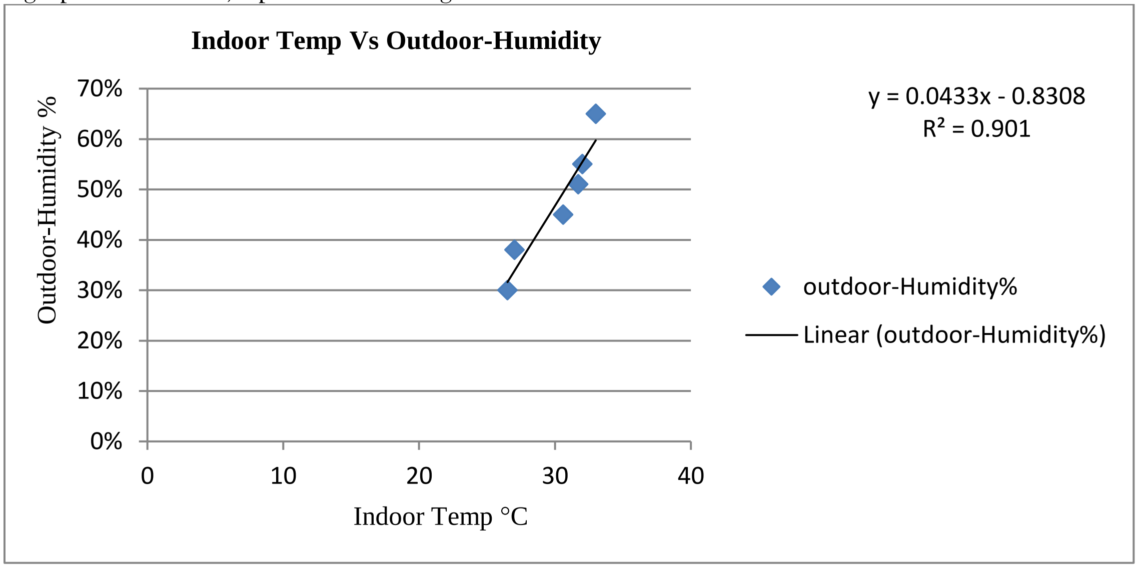


Chart 4c: Correlation of Indoor Temperature and Outdoor Humidity in Iqra Real School in winter.

The above graph shows a measured positive linear correlation coefficient r=0.9 between indoor temperature and outdoor humidity, as presented in Chart 4c.

3.7. Correlation of Variables affecting Surveyed Schools' Thermal conditions in summer

The following figures demonstrate the strength and direction of the linear relationship among variables that affect the thermal conditions of surveyed buildings in the summer season. The correlation test describes a strong positive and moderate range of relationships among the selected variables.

3.7.1. Al-Rehman Secondary School

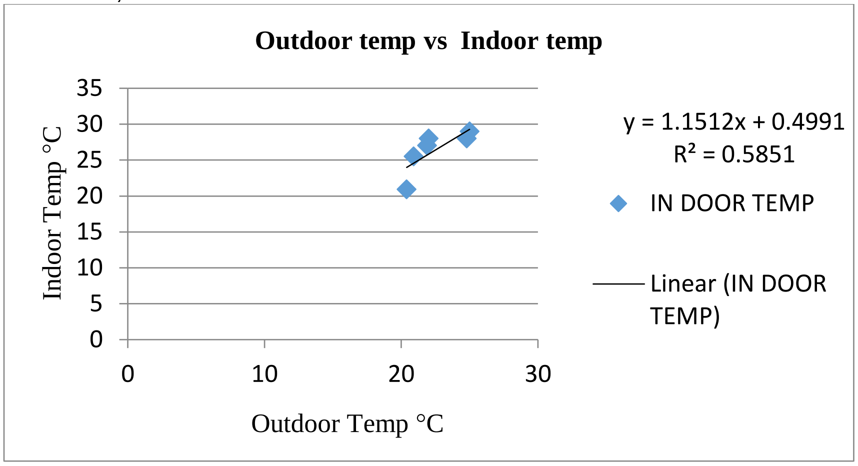


Chart 5a: Correlation of Outdoor and Indoor Temperature in Al Rehman School in summer.

XY scatter plot measures the strength and direction of the linear relationship r=0.764 between outdoor and indoor temperature. The value r=0.76 symbolizes a positive correlation between both axes, as presented in Chart 5a.

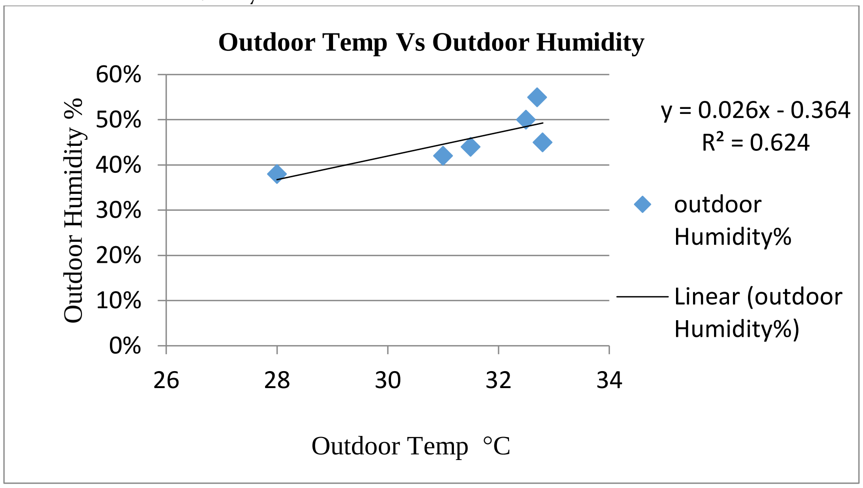


Chart 5b: Correlation of Outdoor Temperature and Outdoor Humidity in Al Rehman School in summer.

The x and y-axis represent outdoor temperature, and outdoor humidity on the graph, and a positive correlation coefficient r=0.789 measures between both variables, as presented in Chart 5b.

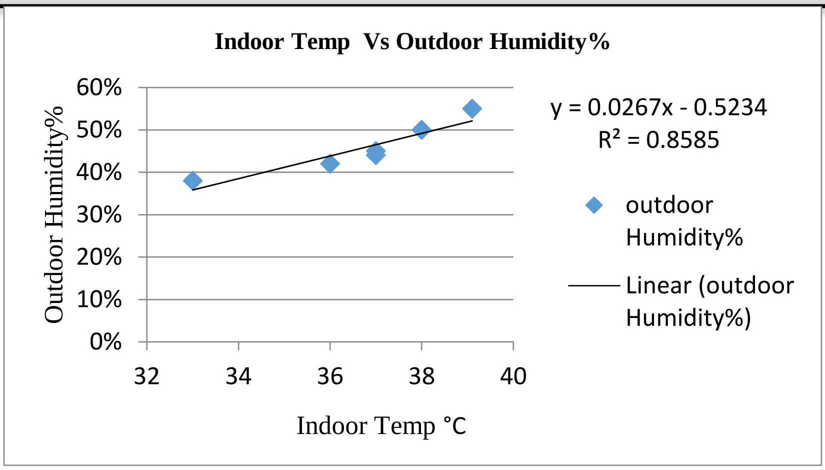


Chart 5c: Correlation of Indoor Temperature and Outdoor Humidity in Al Rehman School in summer.

XY scatter plot represents the indoor temperature and outdoor humidity linear relationship, and the plotted readings measure a strong positive correlation (r=0.9) among variables, as presented in Chart 5c.

3.7.2. New Grammar Children Secondary School

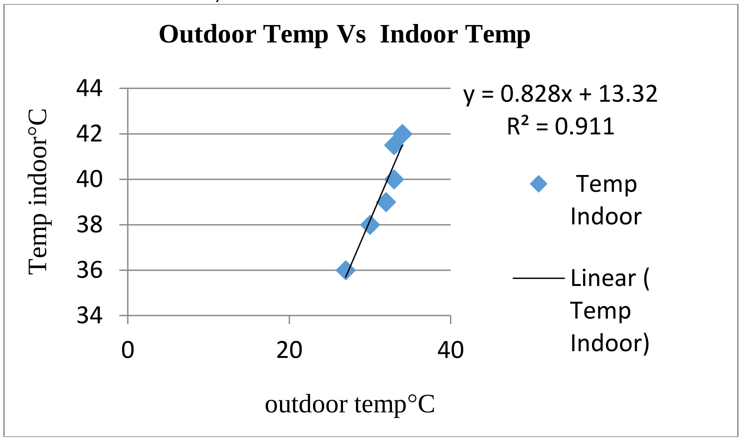


Chart 6a: Correlation of Outdoor and Indoor Temperature in New Grammar Children High School in summer.

The above graph represents outdoor temperature on the x-axis and indoor temperature on the y-axis, and plotted readings measure a strong positive correlation r=0.1 between external and internal temperature, as presented in Chart 6a.

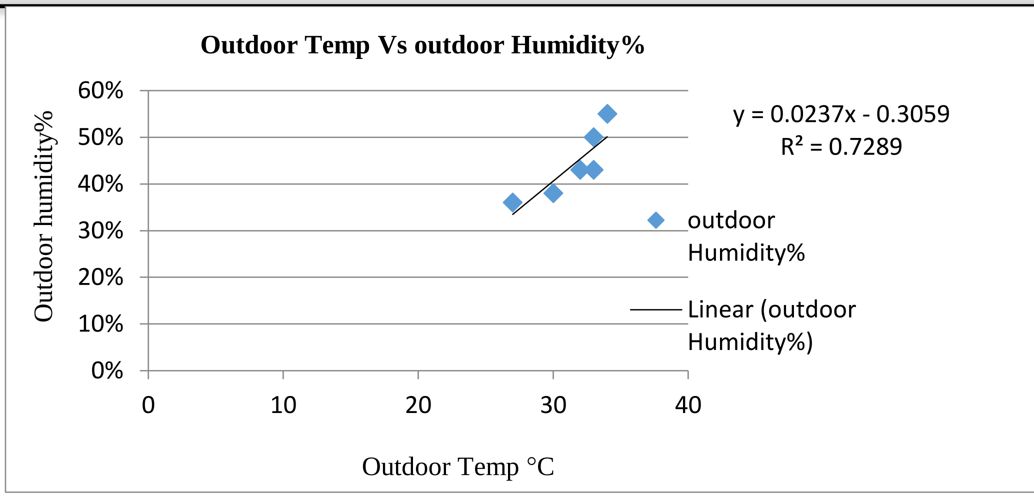


Chart 6b: Correlation of Outdoor Temperature and Humidity in New Grammar Children High School in summer.

The x and y axis shows a strong positive correlation, r=0.9, between outdoor temperature and outdoor humidity. The plotted readings measure the strength and direction of the linear relationship between variables, as presented in Chart 6b.

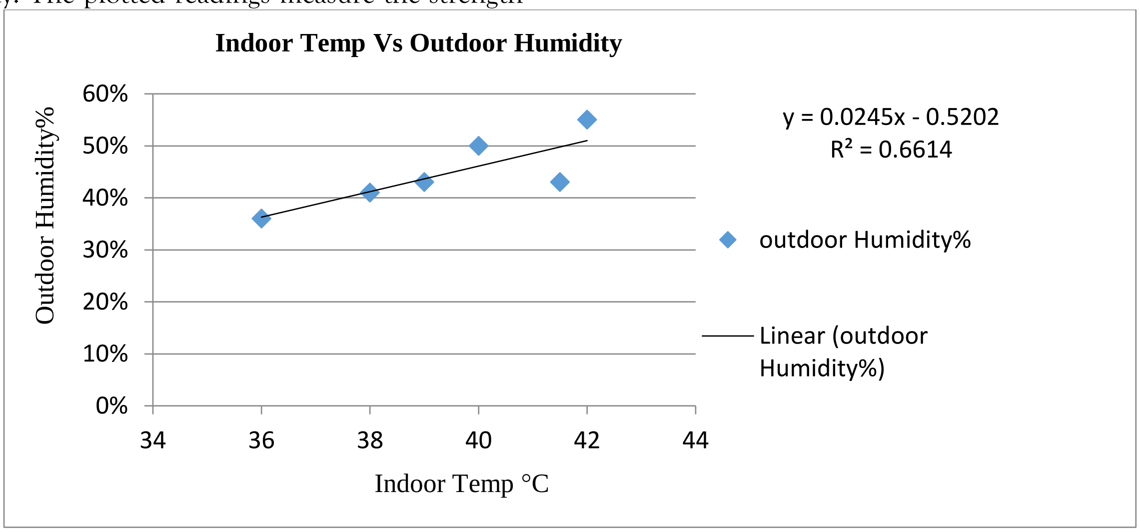


Chart 6c: Correlation of Indoor Temperature and Outdoor Humidity in New Grammar Children High School in summer.

A strong positive correlation coefficient r=0.813 measures between indoor temperature and outdoor humidity on the scatter graph, and the above graph represents a strong linear relationship among variables, as presented in Chart 6c.

3.7.3. Abid Grammar School

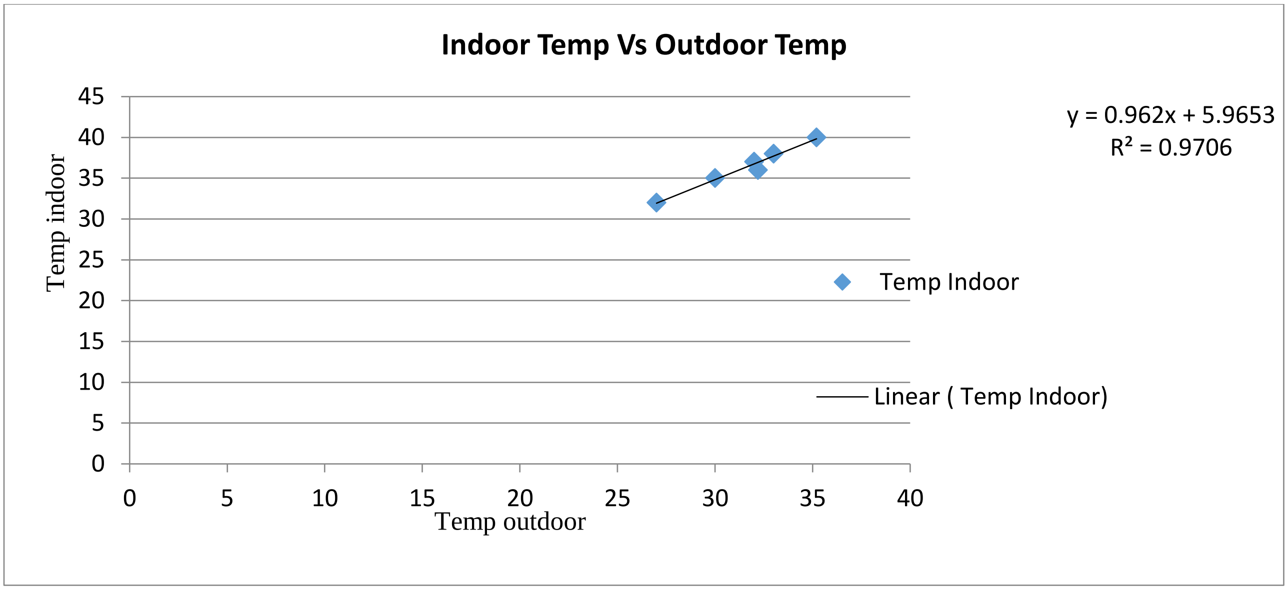


Chart 7a: Correlation of Outdoor and Indoor Temperature in Abid Grammar School in summer.

A strong positive correlation(r=0.98) was observed between outdoor and indoor temperature, and the plotted readings on the XY axis represent the potency of a linear relationship, as presented in Chart 7a.

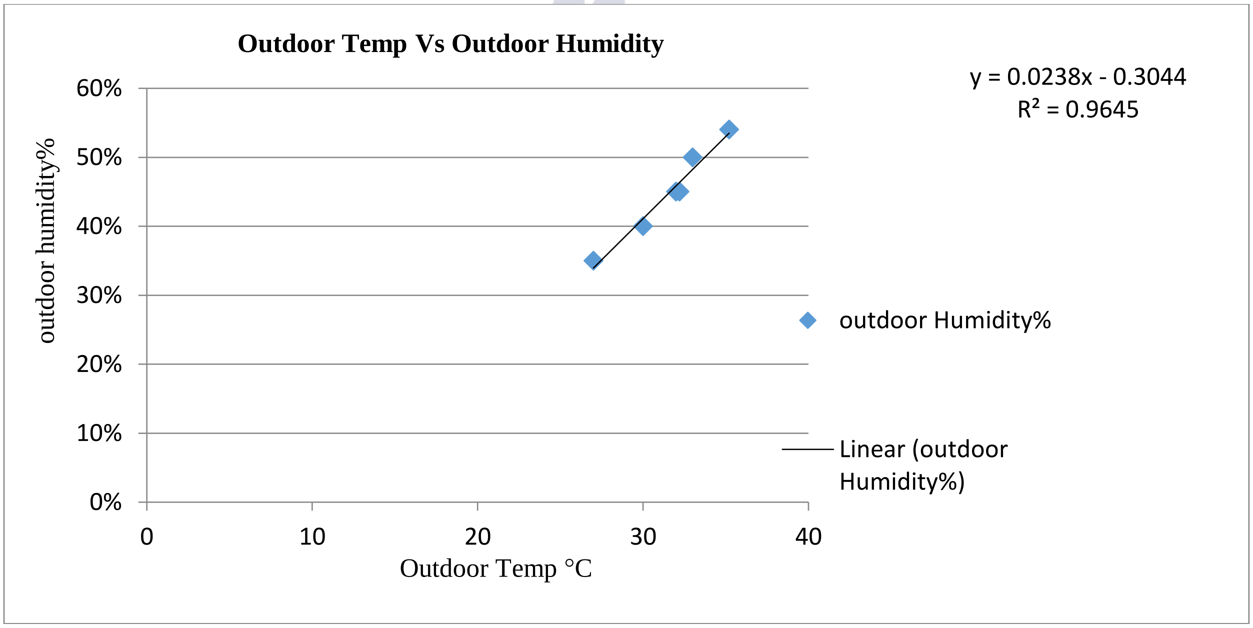


Chart 7b: Correlation of Outdoor Temperature and Outdoor Humidity in Abid Grammar School in summer.

The XY scatter plot measures a strong positive correlation (r=0.98) between outdoor temperature and outdoor humidity. The plotted readings on the graph represent the strength and direction of linear relationship between variables, as presented in Chart 7b.

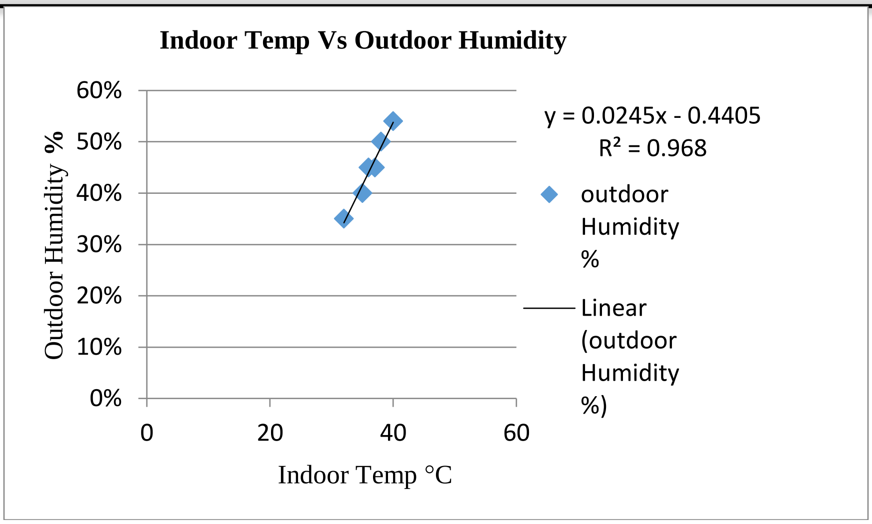


Chart 7c: Correlation of Indoor Temperature and Outdoor Humidity in Abid Grammar School in summer.

The x and y axis represents indoor temperature and outdoor humidity on a scatterplot. The plotted points on the graph show a positive correlation coefficient(r=0.1) between both axes, as presented in Chart 7c.

3.7.4. Iqra Real School

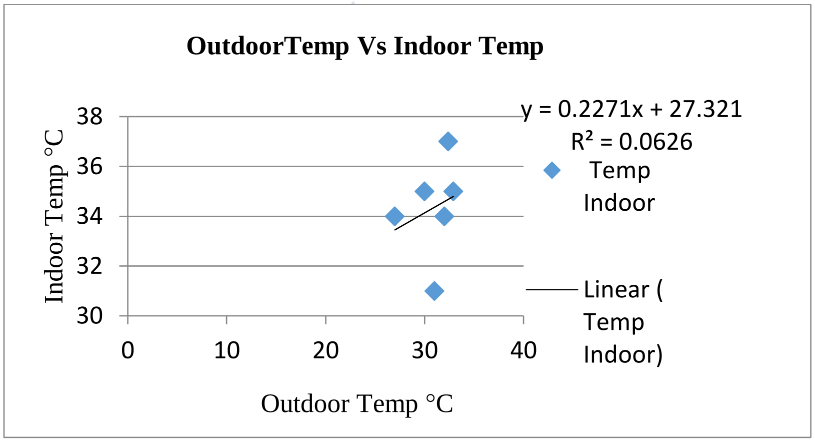


Chart 8a: Correlation of Outdoor and Indoor Temperature in Iqra Real School in summer.

XY scatterplot represents a moderate correlation r=0.3 between outdoor and indoor temperature, as presented in Chart 8a.

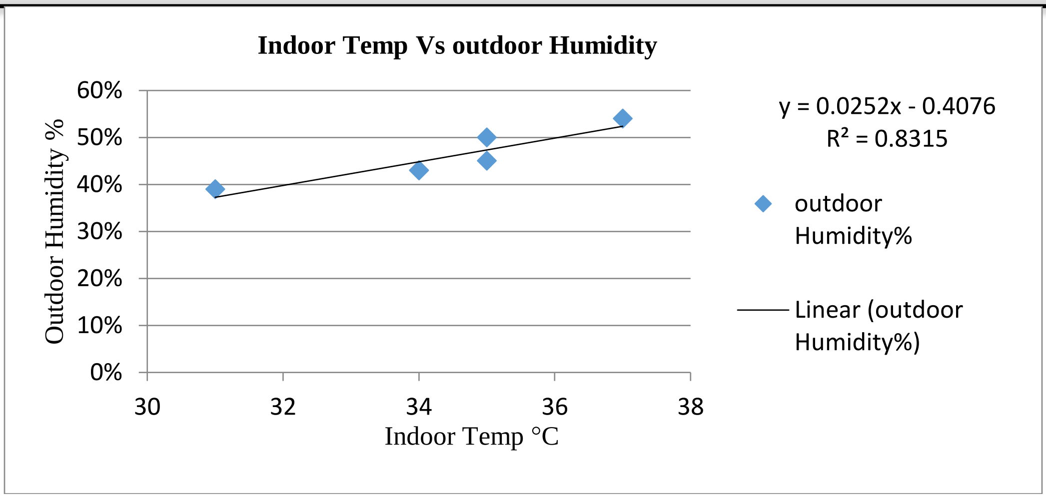


Chart 8b: Correlation of Outdoor Temperature and Outdoor Humidity in Iqra Real School in summer.

The horizontal and vertical axis represents the potency of the linear relationship, and the plotted points measure a positive correlation coefficient r=0.9 between indoor temperature and outdoor humidity, as presented in Chart 8b.

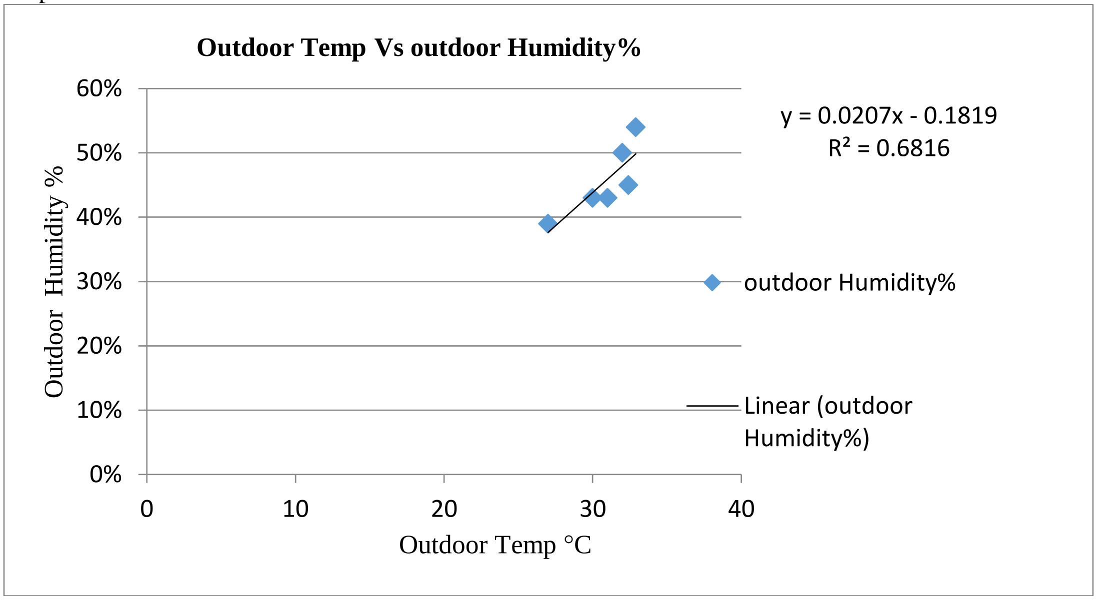


Chart 8c: Correlation of Indoor Temperature and Outdoor Humidity in Abid Grammar School in summer.

The x and y axes show the strength of the linear relationship between outdoor temperature and outdoor humidity, and the plotted points on the graph represent a positive correlation coefficient (r=0.825) among the variables, as presented in Chart 8c.

3.8. Discussion

This study systematically investigated the relationship between building performance, indoor environmental quality (IEQ), and learning outcomes in selected private schools located in Orangi Town, Karachi. The results reinforce the well-established premise that an efficient learning environment is fundamentally tied to the thermal conditions within educational spaces. Thermal comfort plays a pivotal role in shaping the health, concentration, and productivity of occupants, particularly students, who spend significant hours within these built environments. Discussions include:

3.8.1. Building Performance and Thermal Discomfort

The evaluation of the surveyed schools revealed that the existing buildings are underperforming in terms of thermal comfort. These design flaws prevent the indoor environment from achieving acceptable thermal comfort levels, as defined by global and adaptive thermal comfort models. As a result, occupants frequently experience discomfort, which is likely to hinder both learning effectiveness and overall well-being. Several physical attributes of the school structures contribute to this inefficiency:

- Poorly insulated building envelopes lead to excessive heat gain during summer and inadequate retention of warmth during winter.
- Inappropriate placement and design of windows and openings hinder natural ventilation and increase heat trapping.
- Low-quality material finishes, such as uncoated concrete, metal roofing, and low thermal mass walls, exacerbate temperature fluctuations.

3.8.2. Evaluation of indoor and outdoor temperature and humidity levels

The inside and outside temperature and moisture levels of school buildings were recorded for winter and summer seasons separately, as shown in Table 1.1. In the case of winter, Al Rehman school's minimum temperature was 20.9°C and maximum indoor temperature 29°C were recorded during the field survey, which is slightly higher than the outdoor temperature range (20.9°C-25°C). Moreover, "New grammar school, the minimum 26.5°C and maximum 33°C inside temperature was examined, which is much higher than the outside temperature range (21.6°C-26°C). Furthermore, in the winters, a 6°C difference between the indoor and outdoor temperature was documented throughout the survey of Abid Grammar School. Additionally, Table 1.1 showed that the Iqra real school's indoor temperature is 5°C higher than the outdoor temperature in winter. It was observed that the indoor temperature measurements of all selected schools in the summers are much higher than the outdoor temperature readings (as shown in Table 1.1), and the indoor temperature is highest during April and May. The results of indoor and outdoor measurements (Table 1.1) of temperature and humidity levels of surveyed school buildings depicted that the surveyed school buildings thermally perform better in the winter as compared to the summer seasons; therefore, design modifications are required in the building design.

3.8.3. Comfort temperature range

The next stage of the study was to determine the comfort temperature (T_c) ranges in the winters and summers of the carefully chosen area. Thermal comfort (T_c) was computed through the adaptive model equation ($T_c = 12.1 + 0.534\ T_o$) by Nicol and Humphreys. This method showed that the interdependence of variables is involved in the calculation of comfort temperature. Table 1.2 shows the difference between the comfort temperature and indoor temperature of selected schools during winters and summers. The comfort temperature (T_c = 23.5°C) is calculated for winter, and (T_c = 28 °C) is tabulated for summer.

In this study, the researcher concentrated on the evaluation of the thermal conditions of surveyed school buildings with the adaptive relationship approach method that produces satisfactory results and presents a clear relationship between the selected variables. The findings of the results are as follows.

Table 1.2 depicts that the minimum indoor temperature range (27-32°C) is greater as compared to calculated thermal comfort (Tc =23.5°C) in the winters. Similarly, in the case of the summer season, the minimum indoor temperature range (33°C-41.5°C) is much greater than the calculated comfort temperature Tc=28°C.

4. Conclusions

The study concluded that an efficient learning environment is linked to building performance and indoor environmental quality parameters. Thermal comfort provides comfortable indoor conditions for occupants. However, the schools studied are not providing an acceptable thermal condition for the individuals due to inappropriate physical conditions of the building envelope, opening design, and material finishes. Furthermore, field visits revealed that the indoor spaces of school buildings are not adequate to support the functions of an acceptable learning space and working environment; therefore, it is required to modify the building design of the selected school to achieve an energy-efficient building design.

The main conclusion was that the adaptive relationship model produces satisfactory results in the calculation of comfort temperature range (Tc = 23.5°C-24.4°C in winters and 28°C in summers) for the local climate of the selected area. Furthermore, indoor temperature readings of all selected schools deviate from the calculated comfort temperature range in the winter season, additionally, indoor temperatures are highly deviated from the calculated thermal comfort in the summer. (Table 1.2). However, correlation analysis is also used to find the relationship among selected variables (indoor and outdoor temperature, or outdoor humidity) for winter and summer seasons separately. Thus, its results report a strong positive correlation range, r=0.1-0.7 and a moderate range of correlation coefficient, r=0.4-0.6, between selected variables. Additionally, this research work identifies that the above quality of thermal environment has negatively affected occupant behavior and productivity, due to which urgent design decisions are required to provide a better thermal environment in the selected school buildings.

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