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Optimizing Glazing Ratios: Enhancing Natural Lighting and Visual Comfort to Reduce Energy Consumption in Classrooms

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ABSTRACT

The quality and quantity of daylight and indoor thermal conditions have been confirmed by various studies to significantly influence the learning and teaching performance and health of both students and teachers within classrooms. As the problem of energy consumption in Egypt increases, the primary goal of using natural light in schools is to reduce energy consumption and costs, but it must also improve student performance. Achieving maximum natural illumination through appropriate glazing ratios is crucial for improving comfort and productivity. Enhancing the amount of natural light in classrooms has benefits, but it is important to cope with potential disadvantages to establish healthier and more sustainable learning environments. The excessive use of windows and insufficient shading and insulation may increase the absorption of solar heat and glare, while also reducing the visual comfort in classrooms. The study focuses on reducing energy consumption and the need for artificial lighting, increasing productivity and visual comfort, in addition to clarifying the effect of window-to-wall ratio and their effect on the ratios of natural lighting within the classrooms, to create healthier and more sustainable study environments. The Design Builder software was used to simulate the impact of different window opening sizes' impact on natural classroom lighting. Seven classroom models were designed, identical in all aspects except for the window opening size, which varied between 30% and 90% of the external wall area. The classroom dimensions were 9m by 6.7m, with the external wall (containing the windows) measuring 9m by 2.7m. The natural lighting performance was evaluated based on several metrics, including average illuminance (Lux), minimum maximum illuminance, daylight factor, glare index, and thermal comfort and energy inside the class.

Keywords: window-to-wall ratio, energy consumption, visual comfort, natural lighting, thermal comfort.

1. INTRODUCTION

Thermal comfort is particularly important in hot, dry climates, particularly in educational buildings. It significantly affects both energy consumption and interior building temperature. The impact of energy consumption in schools on indoor thermal comfort, energy efficiency, and environmental sustainability as a whole makes it a major problem in Egypt. Research has demonstrated that retrofitting strategies, like replacing windows and enhancing wall insulation, can significantly lower the energy used in educational facilities. (Aboulnaga et al. 2017) In addition, the structure of school buildings, particularly courtyard ratios, is a significant factor in influencing indoor temperature and energy usage; good courtyard ratios result in reduced yearly energy use and enhanced student thermal comfort. (El-Samea, Hassan, and Abdallah 2020)

1.1. AIMS AND OBJECTIVE

Given the above-provided information, it would be ideal to summarize the process for comprehending the classroom environment in international primary school buildings. The main goal of this study is to evaluate the energy consumption and thermal comfort levels in new international primary schools in Egypt utilizing the window ratio.

To do this, a field measuring exercise was carried out at the chosen school building. This was followed by computer modeling work using the "Design Builder" program to simulate the building's thermal performance and energy usage. The computed values from the field measurement and the simulation results were then compared for validation purposes.

2. METHODOLOGY

First, the theoretical approach is a study of the literature:

It discussed the research methodology of how different outdoor and interior components interact to create school settings that are both pleasant and energy-efficient. The graphic illustrates how these elements work together to affect how much energy schools use, focusing especially on the impact of natural light as shown in Figure (1).

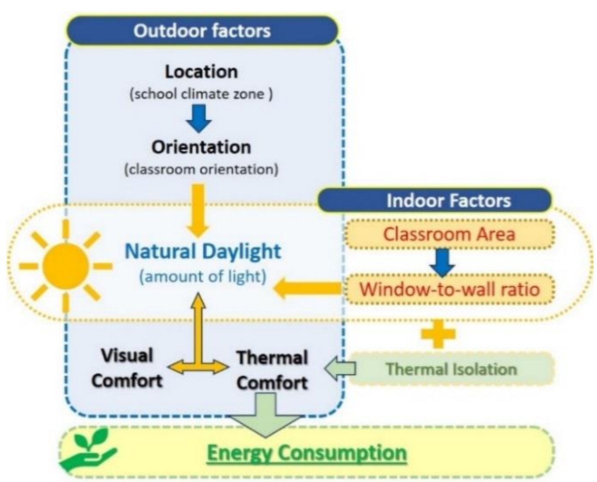

Figure (1): factors affecting energy consumption in school buildings (Outdoor Factors and Indoor Factors)**Source:** the Author

The Figure emphasizes the importance of natural sunshine in balancing thermal and visual comfort, affecting energy usage. It flows from outside to inside variables.

Indoor Factors

Classroom Area: How heat and light are dispersed in a classroom depends on its size. Larger spaces could need more heating, cooling, and lighting than smaller spaces. (Labihi et al. 2024)
Window-to-Wall Ratio: This shows the number of windows that make up the walls of a classroom. Greater natural light penetration into an area via a higher window-to-wall ratio may reduce the need for artificial lighting, but it may also result in increased thermal gain or loss, which may affect the quantity of AC required. (Nasir et al. 2023)
Thermal Isolation: This refers to the building supplies and techniques utilized to insulate the classroom. By minimizing heat gain in the summer and heat loss in the winter, good thermal insulation may assist in maintaining a comfortable temperature and reduce the amount of energy needed for heating and cooling(Alegbe et al. 2023)

Outdoor Factors

Location (School Climate Zone); The physical location of a school is important because it affects outside parameters like temperature and availability of natural sunshine, which have a big influence on energy requirements for climate change and lighting (Serrano-Jiménez et al. 2021)

Orientation (Classroom Orientation): Orientation is a crucial factor in determining how much natural light enters classrooms within a school building during the day. Orienting a classroom correctly may maximize the use of natural sunshine, thereby decreasing the need for artificial lighting and increasing energy efficiency. Such considerations include facing east for morning sunlight and west for afternoon sunlight. (Erdemir and Yener 2022)
Natural Daylight: The presence of natural daylight in a classroom is essential for both thermal and visual comfort. Research highlights the significance of utilizing natural illumination to improve user comfort and minimize energy usage. (Othman et al. 2023)

Second: Study area and modelling:

The study concentrated on the architectural design phase and relied exclusively on the simulation of the existing model for a classroom and its associated computations. The case study building is a typical school building in Cairo, Egypt. The simulation tool "DESIGN BUILDER" was used to explore how the effect of window-to-wall ratio and their effect on the amount of natural lighting within the classrooms to reducing energy consumption by selecting two classrooms in different orientations to conduct an analytical study. We modelled the effect of different glazing ratios and window configurations on occupant comfort and energy demand using “Building Information Modelling" analyses using Revit software. Monitoring energy use in summer and winter helps determine the best direction to reduce energy demand in buildings. The study includes an analysis of daylight during different periods of working hours.

3. Background and Literature Review

3.1. Natural daylight

Natural daylight is a powerful tool for enhancing the learning environment. Researches consistently shows that classrooms bathed in natural light contribute significantly to improved student outcomes, health benefits, motivation, and work/learning performance. Rely on natural light sources has many benefits in Classrooms:

- Improving learning Performance: Studies have linked increased exposure to natural light with better test scores, particularly in subjects like math and reading.
- Reduced Absenteeism: Brighter classrooms can contribute to decreased sick days among both students and staff.
- Energy Efficiency: Optimal daylighting can reduce reliance on artificial lighting, saving energy and costs.

Designing for Natural Light

To maximize the benefits of natural light in classrooms, consider these design elements:

- Large Windows: Ample window space allows for maximum daylight penetration.
- Optimal Window Placement: Position windows to avoid glare and direct sunlight while maximizing natural light.
- Light Shelves: These interior reflective surfaces can distribute daylight deeper into the classroom.
- Daylight Sensors: Automated lighting systems can optimize artificial lighting based on available daylight.
- Shade Control: Blinds or curtains can regulate light levels to prevent discomfort.

Challenges and Considerations

While the benefits of natural light are undeniable, there are challenges to consider:

- Energy Costs: Excessive heat gain from large windows can increase cooling costs.
- Glare: Direct sunlight can cause discomfort and hinder visibility.
- Inequity: Classrooms with less natural light may create disparities among students.

3.2. Window-to-wall ratio

The window is regarded as the most vulnerable thermal connection in a building envelope, allowing heat absorption during summer and heat loss during winter. Despite its tiny surface area, it has a greater impact on heat transfer compared to the walls, ceilings, and floors of the building. Consequently, it is regarded as a crucial factor that influences the energy consumption of buildings. (Muhaisen and Dabboor 2015) The window-to-wall ratio should not be decreased to the point where it excessively reduces natural light. Furthermore, this ratio should not be excessively high, since the influx of solar radiation may result in excessive heat accumulation and an increased probability of glare in the surrounding area to the window. (Sayadi, Hayati, and Salmanzadeh 2021) In addition to shading devices, three factors impact the extent of heat gain and heat loss through windows: the window-to-wall area ratio (WWR), the window orientation, and the thermal characteristics of the glass material. (James 1979)

٣,٢,١ *The proportions of windows to walls*

The proportions of windows to walls, the orientation of classrooms, and the thermal properties of glazing are among the most important factors affecting energy consumption inside schools as shown in Figure (2).

- Low Window-to-Wall Ratio (WWR ≤ 20%):

The researches suggests that a classroom model revealed that none of the classroom models with a window-to-wall ratio (WWR) of 10% were able to attain an acceptable level of daylight based on various daylight indices. In the classroom design including a solitary horizontal window with a Window-to-Wall Ratio (WWR) of 20%, it is capable of receiving daylight.(Daei Parizi, Nikpour, and Fallah 2025)

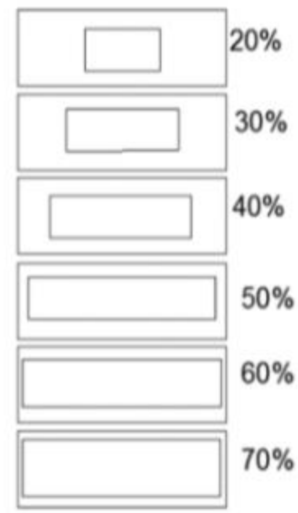

Figure (2): Window-to-Wall Ratio (WWR) and the position of the window on the façade
Source: (Sayadi, Hayati, and

- Moderate Window-to-Wall Ratio (20% < WWR ≤ 40%):

Maintaining a WWR within the 20% to 40% range in school buildings can help achieve a balance between energy efficiency and adequate natural light, contributing to overall energy savings and improved environmental performance. Research suggests that for optimal energy performance and daylighting, a WWR between 20% and 30% is recommended, with slight variations based on orientation and location, especially in higher altitude regions (Alwetaishi and Benjeddou 2021). Additionally, simulations on various building facades indicate a trend of decreasing energy consumption up to a WWR of 40%, beyond which diminishing returns are observed due to potential increases in lighting requirements (Ayuningtyas, Suryabrata, and Sarwadi 2019).

- High Window-to-Wall Ratio (WWR > 40%)

The researches suggests that classroom models that have a window-to-wall ratio (WWR) of 50% create a space that is excessively bright, potentially causing glare However, the other classroom models achieve a daylight within an acceptable range, except for the model with 5 horizontal windows very close to the acceptable range. Classroom models with a WWR of 60% can achieve an acceptable DF when 3 horizontal windows and a greater number of windows are used. (Daei Parizi, Nikpour, and Fallah 2025)

This study focuses on determining the optimal opening ratios inside classrooms according to the different classroom guidelines, which achieve the necessary thermal comfort and maximum benefit from natural lighting, which in turn reduces energy consumption.

3.3. Visual comfort

Academic achievement, student well-being, and educational facility energy efficiency are all significantly impacted by visual comfort in the classroom. In order to improve visual comfort, increase productivity, and lower operating costs, studies highlight the significance of correct lighting design (Budhiyanto and Chiou 2024). Improved lighting quality, less glare, and sufficient illumination levels for a range of learning activities may be achieved by employing techniques such optimizing natural lighting, changing roller blinds and louvres, and installing cutting-edge lighting control systems (Chi 2024)Research evaluating daylight performance in classrooms has demonstrated that, even in historically significant educational buildings, architectural modifications and adherence to certain lighting standards may result in better visual comfort and overall student satisfaction (Yunitsyna and Toska 2023)

3.4. Thermal comfort

The absence of efficient building designs and excessive energy use in school classrooms in Egypt make thermal comfort a key concern. (Anber 2022) Research highlights the necessity for using novel passive cooling techniques or energy-efficient cooling systems to regulate interior temperatures and improve students' thermal comfort, as around 45% of classroom hours are above the acceptable temperature range. (Hammad, Abdelkader, and Atef Faggal 2017b) The objective is to enhance thermal comfort and minimize the cooling requirements in educational buildings. The findings emphasize the need to implement sustainable and efficient measures to establish thermally optimal interior conditions for children in Egyptian school buildings. (Hammad, Abdelkader, and Atef Faggal 2017a)

3.5. Energy Consumption in Schools

Energy use in schools is a serious problem that has an impact on the environment and the economy. According to research, air conditioning (AC) systems are the main energy users in educational buildings, using more than 80% of the total energy consumed annually (Hossin and AlShehhi 2024) Furthermore, the analysis of school buildings revealed that, on average, schools use 15% more energy than anticipated, with actual energy consumption exceeding the theoretical levels listed in energy performance certificates (EPC) (Sinakovics et al. 2024). These findings underscore the need to address energy consumption in educational facilities for sustainable development and the necessity of implementing energy-saving measures in schools to cut costs, reduce greenhouse gas emissions, and enhance overall energy efficiency. The yearly energy consumption of elementary schools in Egypt varies according to design, building time, and thermal comfort techniques. According to research, the architecture of the buildings affects how much energy is used in Egyptian elementary schools, and courtyard ratios have an effect on both internal temperature and energy use (El-Samea, Hassan, and Abdallah 2020)Furthermore, the year of construction is important because buildings constructed between 1971 and 1990 had the highest energy consumption and CO_2 emissions, underscoring the possibility of saving energy through efficiency improvements (Nikolic and Skerlic 2020).In addition, energy consumption models that take into account variables such as the quantity of classes offer insights into the overall

3.5.1. Strategies for Reducing Energy Consumption in Schools

By understanding and implementing these strategies, educational institutions may achieve substantial energy savings, contribute to global environmental goals, and provide a healthier and more efficient learning environment for everyone involved as shown in Figure (3).

- Energy-Efficient Lighting**:** Energy-efficient lighting may help schools use less power. Examples of such lighting include LED lights, motion sensors, and daylight harvesting systems..(Patil and Tanavade 2024)

- HVAC Systems**:** By utilizing energy-efficient heating, ventilation, and air conditioning systems and carrying out periodic maintenance, energy efficiency may be raised and overall consumption can be lowered. (Patil and Tanavade 2024)
- Insulation and Building Design: Investing in energy-efficient building materials and superior insulation to maintain constant interior temperatures can reduce the need for heating and cooling. (Al-Saadi et al. 2023)
- Sustainable Design Principles: It is possible to minimize energy usage and provide a comfortable learning environment by using sustainable design features like energy-efficient windows, passive solar architecture, and green roofs. (Kalpana and Kumar 2024)

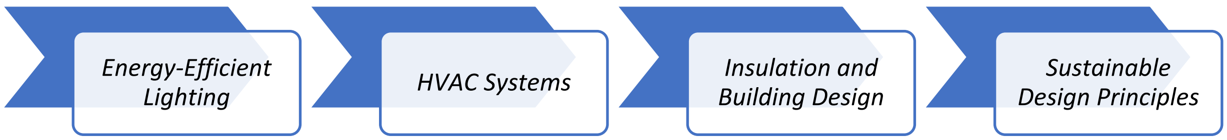

Figure (3): shows Strategies for Reducing Energy Consumption in Schools
source: author

4. Case Study

4.1. Location:

The school is situated in Tanta, one of Egypt's largest cities. It is located close to the Alexandria Agricultural Road the school is near other residential buildings.as shown in Figure(4-5).

Figure (4): location of the school
Source: Google Maps

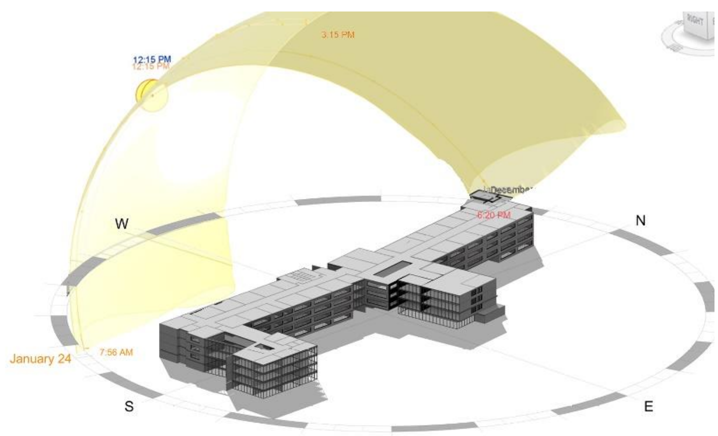

Figure (5): location of the school

Source: Revit simulation

4.2. Description

The classrooms are strategically located around various functional areas, with differing access to outside landscape and the daylight based on their orientation. The design efficiently defines classroom spaces from recreational and administrative facilities, ensuring convenient access to outdoor and communal areas. as shown in Figure 6.

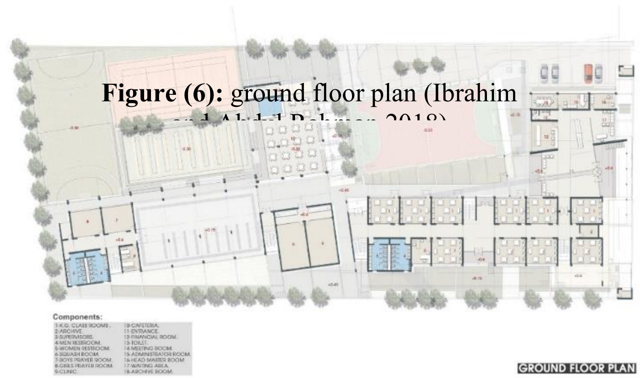

Figure (6): ground floor plan (Ibrahim and Abdel Rahman, 2018)

All windows are similar in size across the building's different orientations, maintaining a uniform rectangular shape despite the different orientations of the classrooms. The facades are missing sun blockers and the classrooms rely only on curtains to reduce light. On the upper floors, the classroom windows appear larger, allowing more natural light into the classrooms or interior spaces. These windows are designed to enhance ventilation and create a bright learning environment for the upper floors. as shown in Figure 7.

4.3. climate zone

Tanta is situated at an altitude of zero meters (0 feet) above sea level and has a Subtropical desert climate, classified as BWh. The annual temperature of the district is 25.35ºC (77.63ºF), which is 0.45% higher than the average temperature of Egypt. Tanta has an average annual precipitation of 3.2 millimetres (0.13 inches) and experiences rainfall on 9.95 days a year, which accounts for 2.73% of the total period. As shown in Table 1

Table 1 shows the Climate Zone Characteristics (Khalil 2021)

Sky Cover Range	Tanta experiences clear skies with minimal cloud cover during the summer			
Solar Radiation	High solar radiation is present throughout the year,			
Temperature	**Average high**		**Average low**	
	Summer	winter	Summer	winter
	32°C to 36°C.	**17°C to 21°C**	**20°C to 24°C**	**8°C to 12°C**
Relative Humidity	Moderate to high throughout the year, with higher humidity in winter.			
Rain Range	Low overall, with most rain occurring in winter.			
Wind Wheel	Predominantly from the north and northwest in summer, with slightly higher wind speeds and more variability in winter.			

5. Evaluation and results of natural daylight (Revit Simulation)

The researcher extends outcomes of the natural daylighting in Revit to provide a thorough analysis of the interplay between sunlight and the indoor areas of a school in the design of the third floor. Revit has advanced daylighting simulation features to accurately model and predict the performance of natural illumination in specific regions. This is achieved by taking into account factors like solar radiation, sky cover, and the presence of shading devices. The study examines different times of the day and seasons of the year to gain a comprehensive understanding of how natural light will affect the structure during its entire existence. as shown in Figure

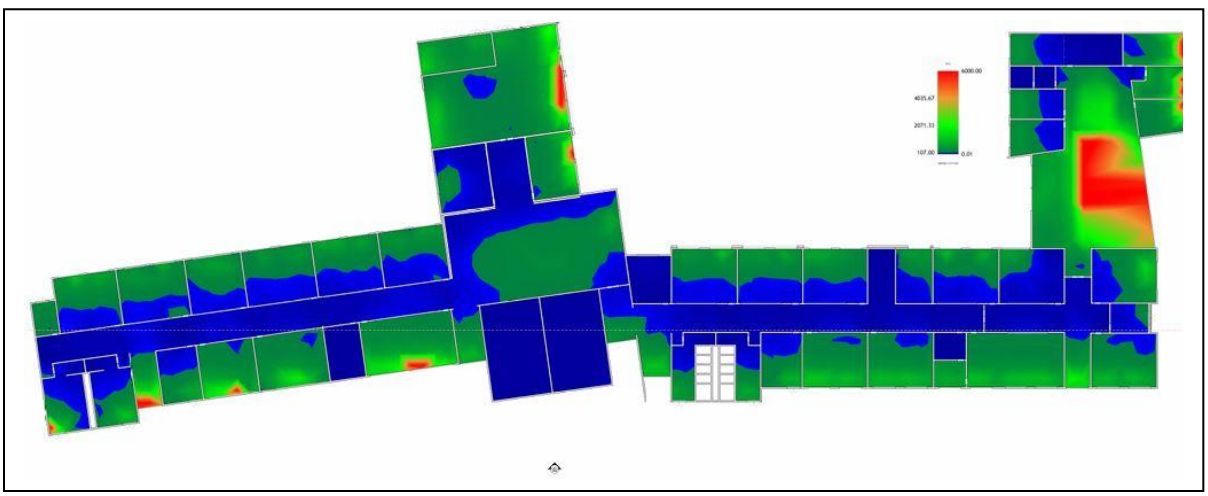

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Figure (8) shows how natural light will affect the structure during its entire existence **source:** author

Figure 8 shows the simulation results obtained through the utilization of the Insight plug-in (Autodesk Revit 2024) for the purpose of analyzing the distribution of natural lighting. The result of the analysis reveals a diverse dispersion of daylight across the structure, with certain regions perhaps experiencing excessive illumination (red zones) while others are insufficiently illuminated (blue zones).

- **Red Zones:** represent spaces that are exposed to a substantial quantity of direct sunlight. These areas may require intervention to mitigate discomfort caused by light or the accumulation of heat.
- **Spaces including Green Zones:** The presence of green zones indicates that these spaces are optimally illuminated by natural sunshine. These are optimal for most daytime activities, as they decrease the need on artificial illumination.
- **Blue zones:** are designated locations that have inadequate daylight, often on gloomy days or in the late afternoon.

5.1. Explanation of Day-light Analysis Results

the Lux values of daylight illuminance for all classrooms and spaces utilized for various functions within the school building. The Daylight Illuminance levels varied from the highest to the lowest.

Table (2) shows how different classrooms and labs within a building perform in terms of natural light distribution. The table is structured to include various columns that assess the performance of each room based on several daylighting criteria,

Table (1): Analysis of the amount of natural day-light in various classrooms from 9am to 3pm

<_InsightLighting Room Schedule>

Custom Analysis Whole Building Results: Ţanţā, Egypt

9/21 9am: 51% & 9/21 3pm: 49% & both: 45% of points are between 150-3000 lux (14-279 fc)

Solar Values (W/m2): 9/21 9am GHI: 513, DNI: 659, DHI: 90 & 9/21 3pm GHI: 447, DNI: 615, DHI: 87

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
						9am threshold results						3pm threshold results						Both threshold results	
				Include In Daylighting	Automated Shades	within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Level	Name	Number	Area			%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
L2	Room Name	100	105 m²	☑	☐	86	91 m²	6	7 m²	8	8 m²	81	86 m²	3	3 m²	16	17 m²	75	79 m²
L2	Room Name	101	40 m²	☑	☐	0	0 m²	0	0 m²	100	40 m²	0	0 m²	0	0 m²	100	40 m²	0	0 m²
Not Placed	Room Name	102	Not Placed	☑	☐	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²
Not Placed	Room Name	103	Not Placed	☑	☐	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²	-1	0 m²
L2	Room Name	104	45 m²	☑	☐	24	11 m²	3	1 m²	73	33 m²	16	7 m²	0	0 m²	84	38 m²	13	6 m²
L2	Room Name	105	73 m²	☑	☐	58	43 m²	0	0 m²	42	31 m²	61	45 m²	0	0 m²	39	29 m²	57	42 m²
L2	Room Name	106	79 m²	☑	☐	61	48 m²	0	0 m²	39	31 m²	63	50 m²	0	0 m²	37	29 m²	60	47 m²
L2	Room Name	107	66 m²	☑	☐	55	36 m²	0	0 m²	45	30 m²	56	37 m²	0	0 m²	44	29 m²	53	35 m²
L2	Room Name	108	82 m²	☑	☐	61	50 m²	0	0 m²	39	32 m²	62	50 m²	0	0 m²	38	31 m²	59	48 m²
L2	Room Name	109	77 m²	☑	☐	56	43 m²	0	0 m²	44	34 m²	56	43 m²	0	0 m²	44	34 m²	54	42 m²
L2	Room Name	110	76 m²	☑	☐	51	39 m²	0	0 m²	49	38 m²	56	42 m²	0	0 m²	44	34 m²	50	38 m²
L2	Room Name	111	71 m²	☑	☐	24	17 m²	0	0 m²	76	54 m²	43	30 m²	8	6 m²	49	35 m²	16	12 m²
L2	Room Name	112	251 m²	☑	☐	90	226 m²	10	24 m²	0	1 m²	93	233 m²	7	18 m²	0	0 m²	83	208 m²
L2	Room Name	113	63 m²	☑	☐	87	55 m²	13	8 m²	0	0 m²	98	62 m²	0	0 m²	2	1 m²	86	54 m²
L2	Room Name	114	121 m²	☑	☐	0	0 m²	0	0 m²	100	121 m²	0	0 m²	0	0 m²	100	121 m²	0	0 m²
L2	Room Name	115	121 m²	☑	☐	0	0 m²	0	0 m²	100	121 m²	0	0 m²	0	0 m²	100	121 m²	0	0 m²
L2	Room Name	116	75 m²	☑	☐	58	44 m²	0	0 m²	42	31 m²	61	45 m²	0	0 m²	39	30 m²	57	43 m²
L2	Room Name	117	74 m²	☑	☐	59	44 m²	0	0 m²	41	30 m²	61	45 m²	0	0 m²	39	29 m²	57	43 m²
L2	Room Name	118	74 m²	☑	☐	60	44 m²	0	0 m²	40	29 m²	61	45 m²	0	0 m²	39	29 m²	58	42 m²
L2	Room Name	119	47 m²	☑	☐	20	9 m²	2	1 m²	78	36 m²	17	8 m²	1	0 m²	82	38 m²	15	7 m²
L2	Room Name	120	74 m²	☑	☐	76	57 m²	6	4 m²	18	13 m²	73	54 m²	6	4 m²	21	16 m²	68	51 m²
L2	Room Name	121	75 m²	☑	☐	68	51 m²	6	4 m²	26	19 m²	66	49 m²	6	4 m²	29	22 m²	61	45 m²
L2	Room Name	122	75 m²	☑	☐	57	43 m²	0	0 m²	43	32 m²	58	43 m²	0	0 m²	42	32 m²	55	41 m²
L2	Room Name	123	74 m²	☑	☐	19	14 m²	0	0 m²	81	60 m²	21	15 m²	0	0 m²	79	59 m²	19	14 m²
L2	Room Name	124	74 m²	☑	☐	69	51 m²	6	4 m²	25	19 m²	66	49 m²	6	4 m²	28	21 m²	61	45 m²
L2	Room Name	125	74 m²	☑	☐	68	51 m²	6	4 m²	26	19 m²	67	49 m²	6	4 m²	27	20 m²	62	46 m²
L2	Room Name	126	74 m²	☑	☐	82	60 m²	6	5 m²	12	9 m²	78	58 m²	6	4 m²	16	12 m²	72	53 m²
L2	Room Name	127	23 m²	☑	☐	0	0 m²	0	0 m²	100	23 m²	0	0 m²	0	0 m²	100	23 m²	0	0 m²
L2	Room Name	128	73 m²	☑	☐	51	37 m²	5	4 m²	44	32 m²	28	21 m²	0	0 m²	72	53 m²	23	17 m²
L2	Room Name	129	464 m²	☑	☐	89	414 m²	5	22 m²	6	28 m²	82	380 m²	7	32 m²	11	52 m²	77	358 m²
L2	Room Name	130	38 m²	☑	☐	95	36 m²	0	0 m²	5	2 m²	76	29 m²	24	9 m²	0	0 m²	71	27 m²
L2	Room Name	131	34 m²	☑	☐	71	24 m²	0	0 m²	29	10 m²	77	26 m²	23	8 m²	0	0 m²	48	16 m²
L2	Room Name	132	38 m²	☑	☐	100	38 m²	0	0 m²	0	0 m²	76	29 m²	24	9 m²	0	0 m²	76	29 m²
L2	Room Name	133	40 m²	☑	☐	100	40 m²	0	0 m²	0	0 m²	100	40 m²	0	0 m²	0	0 m²	100	40 m²
L2	Room Name	134	43 m²	☑	☐	84	36 m²	16	7 m²	0	0 m²	100	43 m²	0	0 m²	0	0 m²	84	36 m²
L2	Room Name	135	731 m²	☑	☐	23	167 m²	1	6 m²	76	557 m²	19	142 m²	1	4 m²	80	585 m²	18	128 m²
L2	Room Name	182	42 m²	☑	☐	53	22 m²	0	0 m²	47	20 m²	54	23 m²	0	0 m²	46	19 m²	52	22 m²
L2	Room Name	183	427 m²	☑	☐	20	87 m²	1	2 m²	79	338 m²	20	87 m²	1	2 m²	79	338 m²	20	84 m²
L2	Room Name	184	10 m²	☑	☐	0	0 m²	0	0 m²	100	10 m²	0	0 m²	0	0 m²	100	10 m²	0	0 m²
L2	Room Name	185	11 m²	☑	☐	32	3 m²	0	0 m²	68	7 m²	71	8 m²	0	0 m²	29	3 m²	32	3 m²
L2	Room Name	186	35 m²	☑	☐	29	10 m²	1	0 m²	70	24 m²	29	10 m²	2	1 m²	69	24 m²	27	9 m²
L2	Room Name	187	36 m²	☑	☐	23	9 m²	2	1 m²	75	27 m²	15	5 m²	1	0 m²	84	31 m²	13	5 m²
L2	Room Name	188	43 m²	☑	☐	100	43 m²	0	0 m²	0	0 m²	100	43 m²	0	0 m²	0	0 m²	100	43 m²
L2	Room Name	189	80 m²	☑	☐	58	46 m²	5	4 m²	38	30 m²	48	38 m²	2	1 m²	51	41 m²	42	33 m²
L2	Room Name	190	64 m²	☑	☐	64	41 m²	6	4 m²	30	19 m²	59	38 m²	2	2 m²	39	25 m²	54	34 m²
L2	Room Name	191	58 m²	☑	☐	17	10 m²	2	1 m²	81	47 m²	12	7 m²	0	0 m²	88	51 m²	10	6 m²
L2	Room Name	192	56 m²	☑	☐	16	9 m²	2	1 m²	82	46 m²	15	9 m²	0	0 m²	84	47 m²	13	7 m²
L2	Room Name	193	16 m²	☑	☐	100	16 m²	0	0 m²	0	0 m²	100	16 m²	0	0 m²	0	0 m²	100	16 m²
L2	Room Name	194	68 m²	☑	☐	100	68 m²	0	0 m²	0	0 m²	83	57 m²	17	12 m²	0	0 m²	83	57 m²

- **Yellow rows:** highlights classrooms with a low percentage of daylight with different orientations. these classrooms suffer from poor illumination, necessitating a greater dependence on artificial lighting. As an illustration, when a space exhibits a 60% value below the established threshold, it signifies that a substantial proportion of the room is not being adequately illuminated by natural light. This insufficiency might be attributed to inadequate positioning of windows, insufficient room depth, or obstacles.

- **Red rows:** highlights the classroom with the highest percentage of natural light, **(room 113)**recording the highest percentage among the other classrooms. As shown in Figure 9, Excessive exposure to direct sunlight in certain spaces may result in over-illumination or glare, necessitating the implementation of supplementary shade or design modifications.

- No rooms in this set exhibit a moderate percentage. these rooms possess a significant fraction of their surface area that is exposed to ideal daylight levels. This suggests that they are adequately illuminated by natural light throughout the designated periods of 9 am and 3 pm. As an illustration, a room exhibiting an 85% occupancy rate would display a majority of its surface area being sufficiently illuminated.

5.2. Simulation of Selected Classroom (Room 113)

Room 113 is a medium-sized as shown in Figure 9, rectangular classroom with a capacity of approximately **25** students. Desks are arranged in traditional rows and columns. Natural light enters through two large windows on the left wall, the facades are missing sun blockers, and the classrooms depend solely on curtains for controlling light. as shown in Figure 10

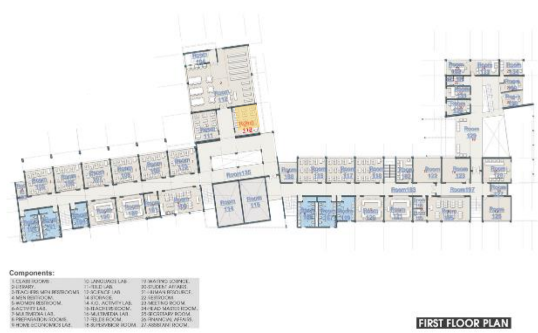


Figure (9): room numbering
Source: (Ibrahim and Abdul Rahman 2018)

Figure (10): classroom real shot
Source: researchers site visit

5.2.1. Window-to-Wall Ratio of Selected Classroom

Window-to-Wall Ratio represents 80% of the total wall area as shown in (Figure 11 -12), Which will directly affect the amount of natural lighting and thermal and visual comfort inside the classroom.

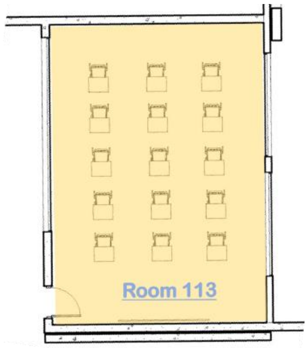


Figure (11): Floor Plan of Classroom 113
Source: Revit

Figure (12): classroom interior shot
Source: Revit

5.2.2. Day-light Analysis of Selected Classroom

The simulation demonstrated that Long-term exposure to direct sunlight in specific areas leads to over-illumination and glare, hence requiring the incorporation of additional shading or modification of windows design. as shown in According to the figure, the room is well-lit, particularly in the areas closest to the windows, and the light intensity steadily decreases with distance from the light source. (Figure 13)

Figure (13): daylight and glare simulation of Room 113
Source: Revit simulation

6. Results And Discussion

6.1 Analysis The daylight in the classroom

In the Table (4) illustrates the impact of different window-to-wall ratios (WWR) on overall daylight entry in the classroom. The research demonstrates the effect of horizontal and vertical window locations on the distribution and intensity of daylight. Each column in the table represents a different WWR percentage (from 30% to 90%), and the colour gradient inside each cell signifies the intensity of daylight, with blue denoting low light levels and red indicating greater light levels.

The window ratios applied differently in horizontal and vertical forms are shown in this table (3); a higher percentage denotes a bigger proportion of windows and provides a visual comparison of window-wall ratio in both horizontal and vertical orientations, ranging from 30% to 90 .

Table (3): The different window-wall ratio applied in the case study in horizontal and vertical forms

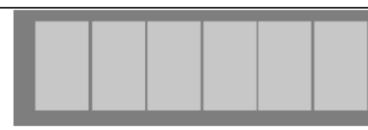
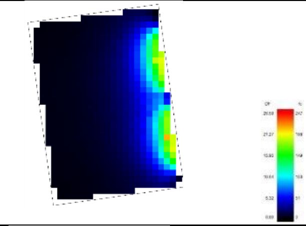
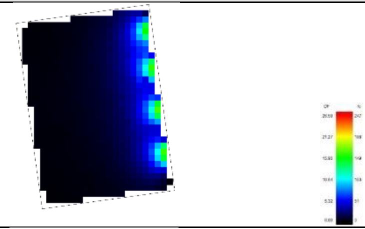
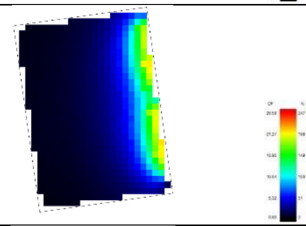
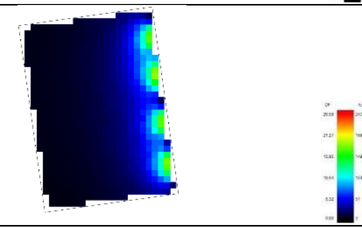
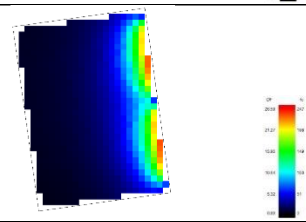
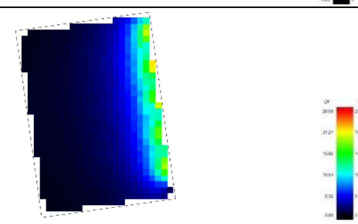
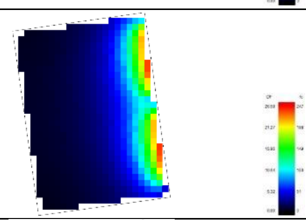
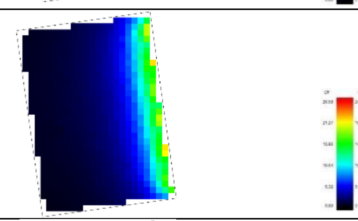
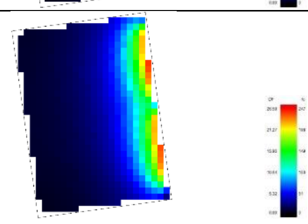
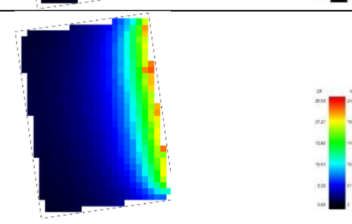
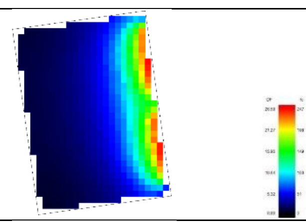
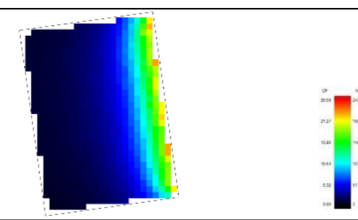
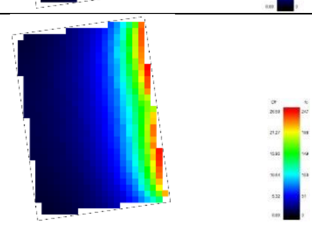
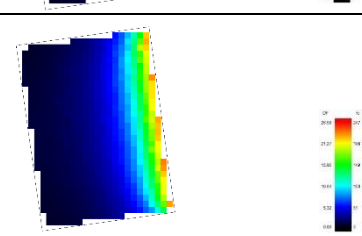
WINDOW –WALL RATIOS		Horizontal	Vertical
	30%		
	40%		
	50%		
	60%		
	70%		
	80%		
	90%		

Table (4): Daylight simulation of different window-wall ratio applied in the case study

		Horizontal	Vertical
TOTAL DAYLIGHT	30%		
	40%		
	50%		
	60%		
	70%		
	80%		
	90%		

30% window-wall ratio

The classroom has limited light penetration, since just 30% of the wall is horizontally windowed, leading to a dim atmosphere, with most areas remaining in low vertical light levels.

40% window-wall ratio

The horizontal light distribution in the space enhances, allowing more sunshine to penetrate neighboring sections, but yet preserving substantial blue zones.

50% window-wall ratio

The ratios of horizontal and vertical light enhance light dispersion, diminishing dark blue regions and augmenting green areas, while both central and remote zones get more sunshine.

60% window-wall ratio

Horizontal light dispersion enhances green zones and diminishes dark blue areas, whereas central and distant regions receive more sunshine than those with lower ratios.

70% window-wall ratio

The classroom is well-lit horizontally, with green and yellow areas dominating, indicating a balance of natural light. Vertically, the room becomes brighter with an even distribution of light, enhancing the daylight environment.

80% window-wall ratio

The classroom is well-lit with abundant daylight; nevertheless, the intensity near the window may induce glare or overheating, and the vertical orientation may lead to discomfort

90% window-wall ratio

The classroom's horizontal configuration, characterized by predominantly windowed walls, offers abundant sunshine and a broad spectrum of green, yellow, and red zones, albeit it may be too luminous adjacent to the window.

Lower Ratios (30-50%) provide limited daylight penetration, middle Ratios (60-70%) offer balanced illumination, and higher Ratios (80-90%) offer very bright rooms with wide distribution but the potential for excessive brightness, glare, and heat gain.

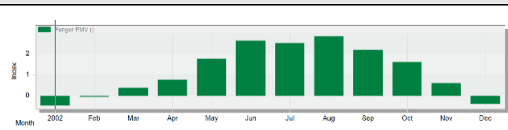
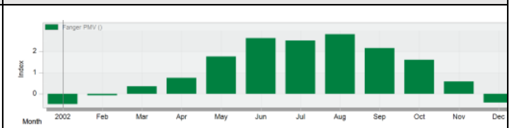
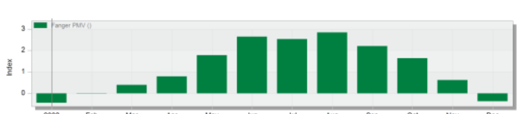
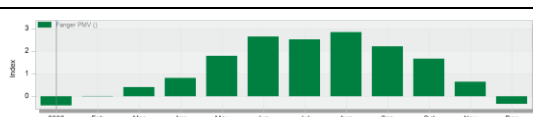
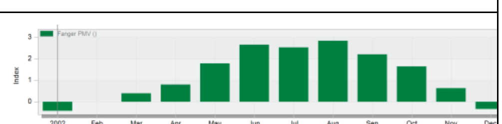
6.2. Thermal Comfort Analysis of Selected Classroom

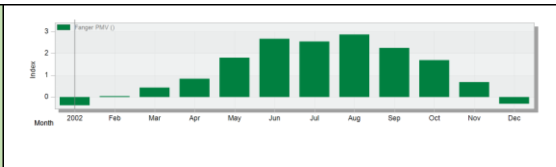
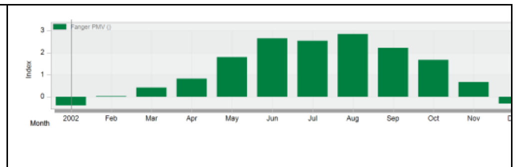
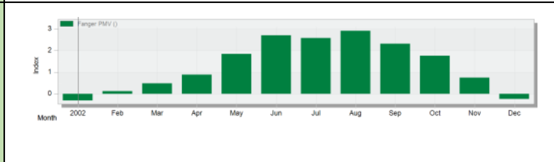
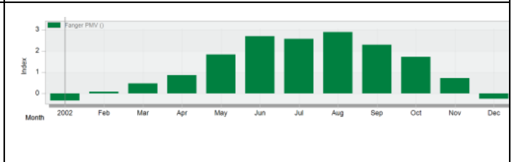
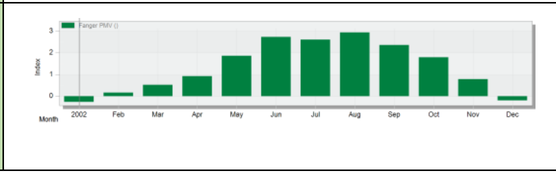
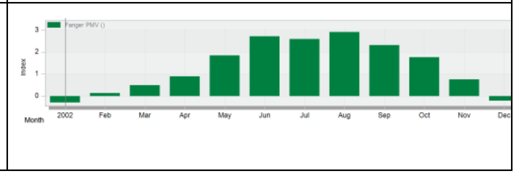
By Comparing the thermal comfort inside the selected Classroom Figure 11 uses different window-wall ratio as follows in Table(5-6)

Table 5: the PMV values for the corresponding months of the year across different window-wall ratio

PMV		WINDOW RATIOS													
		30%		40%		50%		60%		70%		80%		90%	
		H	V	H	V	H	V	H	V	H	V	H	V	H	V
	JAN	-0.46	-0.48	-0.44	-0.45	-0.41	-0.42	-0.37	-0.39	-0.33	-0.33	-0.30	-0.33	-0.26	-0.30
	FEB	-0.05	-0.06	-0.03	-0.03	0.01	-0.00	0.05	0.03	0.09	0.09	0.12	0.09	0.17	0.13
	MAR	0.37	0.36	0.39	0.38	0.41	0.40	0.44	0.42	0.47	0.47	0.49	0.47	0.53	0.50
	APR	0.77	0.76	0.79	0.78	0.81	0.80	0.84	0.82	0.87	0.87	0.89	0.87	0.93	0.90
	MAY	1.76	1.76	1.77	1.77	1.79	1.79	1.81	1.80	1.83	1.83	1.85	1.84	1.87	1.86
	JUNE	2.62	2.62	2.63	2.63	2.65	2.65	2.67	2.67	2.69	2.70	2.70	2.70	2.73	2.72
	JULY	2.50	2.50	2.52	2.52	2.53	2.53	2.55	2.55	2.57	2.58	2.58	2.58	2.61	2.59
	AUG	2.81	2.80	2.83	2.82	2.85	2.84	2.87	2.86	2.89	2.89	2.91	2.89	2.94	2.91
	SEPT	2.17	2.15	2.19	2.18	2.22	2.20	2.26	2.23	2.29	2.29	2.32	2.29	2.36	2.32
	OCT	1.62	1.60	1.64	1.62	1.67	1.65	1.70	1.68	1.73	1.73	1.76	1.73	1.80	1.76
	NOV	0.60	0.58	0.62	0.61	0.65	0.64	0.68	0.67	0.72	0.73	0.75	0.73	0.80	0.76
	DEC	-0.39	-0.40	-0.37	-0.37	-0.33	-0.34	-0.30	-0.31	-0.26	-0.25	-0.23	-0.25	-0.18	-0.22

Table 6: The thermal comfort of window-wall ratio applied differently in horizontal and vertical forms

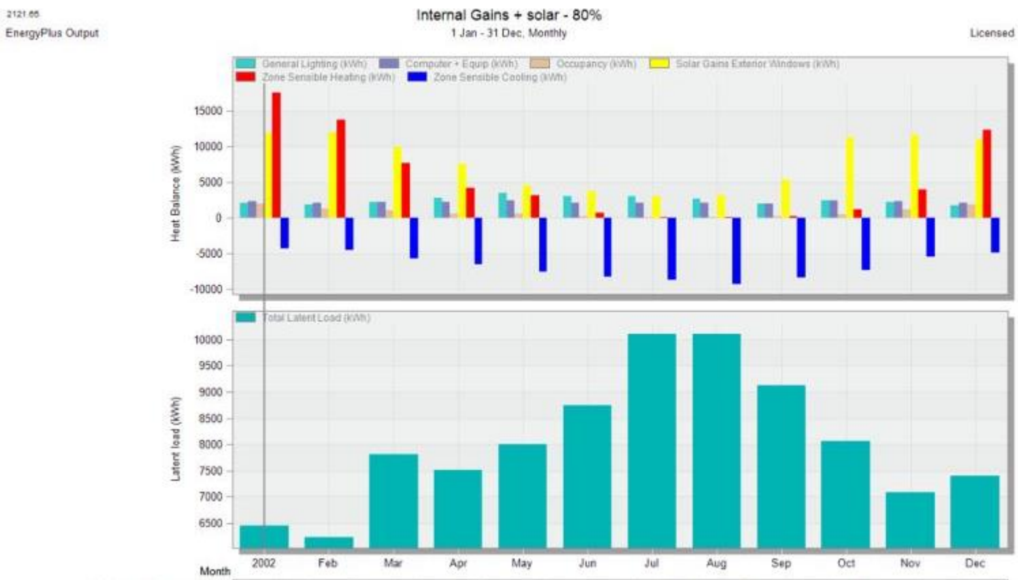
window-wall ratio		Horizontal (PMV)	Vertical (PMV)
	30%		
	40%		
	50%		

	60%		
	70%		
	80%		
	90%		

- Thermal neutrality is shown by a PMV value that is near to 0, and discomfort is indicated by values that are farther from 0. High summertime PMV readings in this table, particularly for larger window-wall ratio (e.g., 70% and above), suggest possible discomfort from the heat.In contrast, wintertime PMV readings (-0.48 to almost 0) suggest a more neutral or slightly cold thermal comfort that might be either pleasant or slightly uncomfortable.
- In all months, the PMV values usually rise with increasing window-wall ratio (from 30% to 90%), suggesting higher interior temperatures or greater thermal comfort. Both horizontal and vertical orientations will have the same effect.
- June shows a peak in the PMV of 2.72–2.73 at a 90% window-wall ratio, up from 2.62 for both H and V at a 30% window-wall ratio. Larger window spaces may boost indoor temperature, according to this trend, perhaps because they let in more sunlight.
- Consistent with the seasonal variations in outside temperatures, the PMV reaches its lowest point in January, February, and December and reaches its highest point in June, July, and August during the summer months.
- August is when PMV increases the highest, rising from moderate levels of 0.77–0.84 in April to high levels of 2.85–2.94 in August. This indicates the influence of window ratios and summertime solar exposure.
- Spring and Fall Months (March, April, May, September, October): A 50–60% window-wall ratio provides a balance with PMV values around 0.3 to 1.8, which aligns well with moderate thermal comfort

6.3. Energy Consumption Analysis of Selected Classroom

Four stages of evaluation were used for the analysis of the following simulations. The analyses were conducted using the design-builder software. a simulation of energy consumption. To find the cases that created the best energy consumption performed for the different parameters, the classroom was evaluated with 80%. Horizontal window-wall ratio as shown in Figure (14)



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lighting (kWh)	2121.65	1836.60	2286.46	2800.39	3501.12	3041.11	3014.18	2689.77	1973.08	2451.70	2241.20	1734.73
Computer + Equip (kWh)	2366.39	2162.72	2264.57	2262.14	2475.48	2094.87	2104.58	2104.58	2029.41	2475.48	2371.23	2126.39
Occupancy (kWh)	2011.89	1244.35	1068.56	578.88	595.66	212.40	184.66	192.44	301.23	519.61	1128.56	1853.84
Solar Gains Exterior Windows (kWh)	11897.27	12010.74	9856.87	7543.66	4574.40	3690.33	3030.95	3149.57	5375.07	11345.96	11611.70	10932.63
Zone Sensible Heating (kWh)	17583.07	13744.14	7730.34	4231.96	3195.62	702.25	105.97	85.61	288.10	1185.98	4035.11	12349.51
Zone Sensible Cooling (kWh)	-4280.56	-4517.74	-5665.72	-6449.15	-7498.64	-8287.19	-8668.13	-9278.63	-8351.40	-7254.97	-5439.80	-4857.39
Total Latent Load (kWh)	6457.02	6228.21	7815.49	7516.40	7997.79	8754.68	10110.88	10103.09	9122.51	8073.84	7091.27	7403.84

Figure (14): energy consumption simulation of Room 113
Source: Design builder simulation

According to the results, the summer months are when the overall amount of energy used peaks, especially in July and August. January and December had the lowest energy usage.

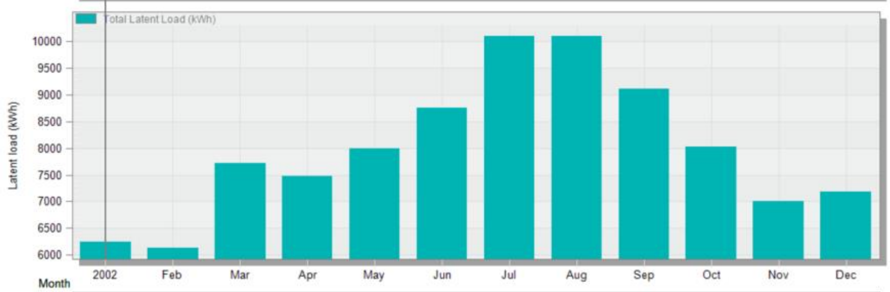
The maximum consumption in the class room by using 80% Horizontal window-wall ratio in July in summer is about ١٠١١0.88 kWh

According to previous results for lighting and thermal comfort within the classroom the 60%-70% vertical window-wall ratio optimal for maximizing daylight while maintaining a balanced and comfortable thermal inside classroom, the energy consumption was compared with this window-wall ratio to prove the best energy consumption as shown in Table 7.

Table 7: The energy consumtion of window-wall ratio (60-70-80) applied differently vertical forms

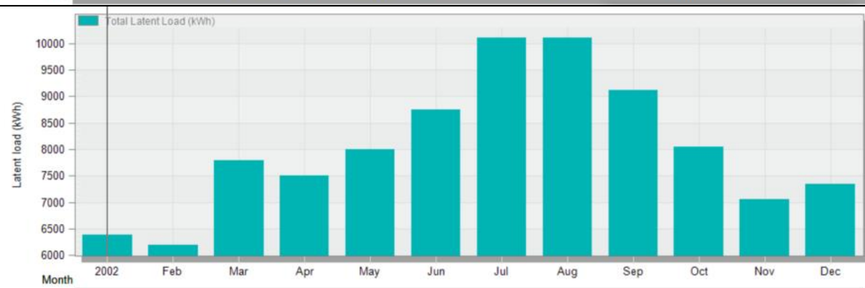
Energy Consumption

60%



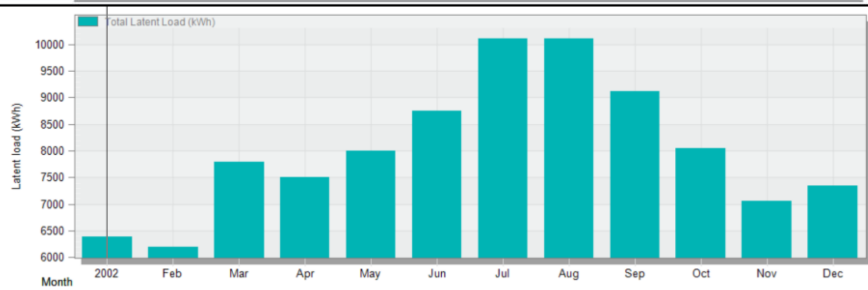
	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lighting (kWh)	2697.56	2393.07	2867.47	3190.49	3782.27	3285.89	3309.70	3094.08	2554.63	3052.77	2803.06	2279.20
Computer + Equip (kWh)	2366.39	2162.72	2264.57	2262.14	2475.48	2094.87	2104.58	2104.58	2029.41	2475.48	2371.23	2126.39
Occupancy (kWh)	2224.71	1345.57	1163.59	610.70	602.67	214.28	186.77	195.63	314.83	565.87	1217.70	2072.02
Solar Gains Exterior Windows (kWh)	8506.38	8644.30	7066.25	5424.37	3301.94	2680.84	2207.47	2284.66	3864.88	8126.48	8369.04	7909.56
Zone Sensible Heating (kWh)	17788.22	13849.05	7793.39	4202.62	3192.63	697.95	99.49	78.64	273.60	1194.40	4044.04	12493.20
Zone Sensible Cooling (kWh)	-4057.29	-4297.47	-5495.49	-6341.08	-7445.61	-8247.01	-8620.24	-9206.25	-8210.00	-7037.89	-5216.90	-4597.85
Total Latent Load (kWh)	6244.20	6127.00	7720.46	7484.58	7990.78	8752.79	10108.76	10099.91	9108.90	8027.58	7002.12	7185.65

70%



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lighting (kWh)	2226.85	1924.24	2425.91	2897.59	3575.50	3106.18	3091.01	2790.67	2112.60	2580.46	2346.07	1823.45
Computer + Equip (kWh)	2366.39	2162.72	2264.57	2262.14	2475.48	2094.87	2104.58	2104.58	2029.41	2475.48	2371.23	2126.39
Occupancy (kWh)	2079.97	1281.89	1099.61	592.16	596.40	211.80	184.10	192.40	303.86	546.17	1159.36	1916.00
Solar Gains Exterior Windows (kWh)	11191.98	11368.96	9274.96	7098.08	4304.48	3472.95	2852.54	2963.97	5057.58	10680.16	11008.87	10411.68
Zone Sensible Heating (kWh)	17660.78	13741.25	7740.72	4179.32	3177.10	695.01	99.32	78.37	271.60	1183.52	4006.53	12321.00
Zone Sensible Cooling (kWh)	-4204.16	-4439.38	-5610.09	-6408.17	-7486.46	-8282.94	-8669.25	-9274.46	-8322.09	-7174.17	-5367.83	-4777.42
Total Latent Load (kWh)	6388.93	6190.67	7784.44	7503.12	7997.05	8755.27	10111.44	10103.13	9119.87	8047.28	7060.46	7341.68

80%



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lighting (kWh)	2328.00	2015.75	2539.91	2977.76	3638.75	3161.45	3155.52	2873.75	2225.27	2695.12	2451.35	1913.71
Computer + Equip (kWh)	2366.39	2162.72	2264.57	2262.14	2475.48	2094.87	2104.58	2104.58	2029.41	2475.48	2371.23	2126.39
Occupancy (kWh)	2073.21	1278.30	1095.76	590.75	595.70	211.77	184.22	192.47	303.65	545.01	1156.25	1910.15
Solar Gains Exterior Windows (kWh)	11177.77	11352.66	9254.92	7074.81	4284.43	3448.77	2830.02	2944.89	5041.06	10662.03	10993.85	10401.01
Zone Sensible Heating (kWh)	17658.92	13739.79	7741.35	4180.25	3177.50	695.14	99.40	78.43	271.71	1183.73	4006.24	12322.04
Zone Sensible Cooling (kWh)	-4210.35	-4445.23	-5617.12	-6412.84	-7489.99	-8285.77	-8672.53	-9279.03	-8328.72	-7181.82	-5374.65	-4782.92
Total Latent Load (kWh)	6395.69	6194.26	7788.29	7504.53	7997.75	8755.31	10111.32	10103.06	9120.08	8048.44	7063.57	7347.52

- According to the results The total energy load remains high in the summer months (July and August) for all window-to-wall ratios
- January consistently has the lowest energy consumption across all different window-to-wall ratios.
- ٧0% vertical window-wall ratio and ٨0% vertical window-wall ratio have nearly identical energy loads throughout the year, with slightly lower peaks in July and August compared to ٦0% vertical window-wall ratio
- The maximum energy consumption in the class room by using٧0% vertical window-wall ratio in July in summer is about ١٠١١١,٤٤ kWh,

- the lowest energy consumption in the class room by using 60% vertical window-wall ratio in January is about 62٤٤.02 kWh

7. Conclusion

- Throughout the year, a 50% window-wall ratio emerges as the most equitable choice. It sustains modest PMV levels across all seasons:
During winter, temperatures remain at acceptable levels without becoming excessively chilly.
During summer, it mitigates overheating relative to elevated window ratios.
During transitional months (spring and autumn), it offers optimal comfort.
- Winter Months (January, February, November, December): The PMV values are around -0.4 to 0.6, indicating relatively comfortable conditions for most window ratios for a more balanced comfort in these months, a 70% window-wall ratio appears optimal as the PMV stays close to 0.0–0.1, providing a slightly warm comfort without feeling too cold
- The 50% window-wall ratio is considered to be the most effective option for attaining maximum thermal comfort throughout the year in both horizontal and vertical orientations.
- A window-to-wall ratio (WWR) of 60-70% is excellent for both horizontal and vertical orientations since it optimizes sunshine while minimizing glare and preventing substantial regions of high intensity (red zones).
- A 60% window-wall ratio strikes a good balance between bringing in sufficient daylight and distributing it evenly throughout the room.
- The horizontal orientation at this ratio shows better daylight penetration and more uniform distribution across the room compared to the vertical orientation, which tends to concentrate light near the window.
- Therefore, the 60% vertical and 70% vertical window-wall ratio is optimal for maximizing daylight while maintaining a balanced and comfortable interior light level.
- The window-to-wall ratio (WWR) of 80%, which was adopted in the design of the separation, is not good in horizontal orientation, but in the separate vertical orientation, it improves the brightness of the sun while reducing glare and preventing large areas of high density (red zones). The ratio can be adopted in the vertical case but with the addition of solar breakers.
- The research concluded that the classroom with the best thermal performance in all study samples and the lowest energy consumption is the room and daylight while maintaining a balanced with a 60% window-wall ratio

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