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Exploring the Impact of Window Configuration on Thermal and Visual Performance in Nepalese School Buildings during Winter

by
Srijana Goja Shrestha

A THESIS

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN

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DEPARTMENT OF ARCHITECTURE

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DECLARATION

I hereby declare that the thesis entitled, **"Exploring the Impact of Window Configuration on Thermal and Visual Performance in Nepalese School Buildings during Winter"** submitted to the Department of Architecture in the partial fulfillment of the requirement for the degree of Master of science in Energy Efficient Buildings, is a record of an original work done under the guidance of Associate Professor Dr. Sanjaya Uprety, Institute of Engineering, Pulchowk Campus. This thesis incorporates only work that I have accomplished with the exception for the consulted material which has been duly referenced and acknowledged.

Srijana Goja Shrestha

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ABSTRACT

Thermal and visual comfort play an important role in enhancing the health and performance of both students and teachers in classrooms. Most Nepalese school buildings are naturally ventilated with wooden shutters or open windows, whose performance depends on external weather conditions. Daylighting and thermal comfort are heavily influenced by these factors. Students spend about 20-30% of their daily time in school. A poor indoor environment can negatively affect the academic performance of students. Therefore, necessary actions must be taken to improve the thermal and visual performance of schools. Limited research has been conducted on indoor environmental quality related to thermal comfort in Nepalese school buildings.

A field investigation was carried out at Shree Balpremi Secondary School in Madhyapur Thimi, Bhaktapur, involving temperature and daylight illuminance measurements during January 2025, along with a student survey. From the field study, the mean indoor temperature (16.4–17.1°C) is below the thermal comfort range for Kathmandu's winter. From the data taken on March 7 at 4pm under an overcast sky, the average illumination level of classroom 7 is 353 lux.

Design Builder Software was used to carry out the thermal and visual simulation analysis and evaluate different window configurations of the base model. Results from simulation analysis revealed that an optimized window wall ratio of 20% with the use of insulation on walls and ceiling and changing window glazing can increase the indoor temperature by 50°C. The average indoor temperature is 22.60°C, which meets the threshold winter comfort temperature, i.e., 20.90°C(Shahi et al., 2021). Similarly average illumination is 590 lux under the overcast sky which meets the daylight standard. The study concludes that appropriate window configuration along with insulation measures can help to balance the thermal and visual performance in the classroom during the winter season. Further studies across different seasons should be carried out and need to implement passive design strategies such as thermal insulation and thermal mass along with window configuration that can help in thermal and visual comfort.

Keywords: Thermal Performance, Visual Performance, Daylighting, Window wall ratio

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CHAPTER 1: INTRODUCTION

1.1 Background

Thermal and visual comfort are important issues in school building design, as students spend significant amounts of time indoors. Poor indoor conditions can have a negative effect on the health and performance of both students and teachers. Occupants' satisfaction inside the building depends on the environment within the building. An appropriate indoor environment gives educational buildings a sense of space and attractiveness and generates an impression of vitality and a general feeling of satisfaction (Ashrafian & Moazzen, 2019). Building envelope is critical for energy efficiency, as its thermal properties directly affect heating and cooling loads. Windows, being weaker components of the envelope compared to walls, are more prone to heat loss or gain, thus receiving significant attention for energy optimization strategies(Lu et al., 2015).

Windows in schools play a key role in both thermal performance and visual comfort. The physical and dimensional attributes of the window are responsible for the control of solar radiation that enters the building, which directly affects the building's energy consumption and indoor thermal comfort through the heat transfer process. In the case of buildings, windows are designed primarily for functions like admittance of daylight, cross ventilation, and connection between the outside and inside environments. Among all the elements in façade design, the window-to-wall ratio (WWR) has a deep impact on introducing the amount of daylight inside any room (Sangraula & Uprety, n.d.). According to (Basnet & Uprety, n.d.) increasing the window wall area reduces the total energy consumption for lighting but after certain window wall ratio, no reduction is seen in lighting energy but the cooling energy of building is increased due to heat gain.

“Daylight in classrooms is a critical factor in school design in terms of its impact on students' health, learning, and visual performance. Among all the elements in façade design, the window-to-wall ratio (WWR) has a deep impact on introducing the amount of daylight inside any room (Sangraulaa & Uprety, 2020). Minimum and average daylight factors for classrooms have been defined as 2% and 5%, respectively (Baker & Steemers, 2014). Natural light is considered the primary source of light during the day, with an average day light factor of 4-5%, whereas in the common teaching areas of a school, a minimum illuminance of not less than 300 lx is required (Meresi, 2016).

In Nepal, most of the educational buildings have limited natural lighting, affecting the energy consumption and performance of students and teachers. After the 2015 earthquake, school buildings were design-based, meaning similar structures were implemented across the country, regardless of whether the building's climate, materials, and layout were appropriate (Gautam & Bajracharya, 2021). New building design generally does not consider climate-sensitive design strategies or apply any energy-efficient technology because the government has not formulated any energy-saving regulations (Bodach et al., 2016). Nepalese school buildings rely on natural ventilation through windows and doors for airflow, daylighting, and thermal comfort. Most windows have wooden shutters or are left open, with their performance largely dependent on outdoor climatic conditions(Shrestha & Rijal, 2023a). Only a small number of research has been undertaken on indoor environmental quality associated with thermal comfort in Nepalese school buildings (Shrestha & Rijal, 2023a).

The primary aim of this study is to present a method for selecting optimal window configurations for schools during the design stage, focusing on enhancing visual and thermal comfort while promoting energy efficiency in cold climates. This study will evaluate key design parameters, including window size, orientation, glazing type, and daylighting strategies, with the objective of proposing context-specific recommendations that balance thermal comfort, visual comfort, and energy efficiency. The findings will contribute to sustainable school design practices, offering practical solutions tailored to the needs of Nepal's cold climate.

1.2 Importance of Research

Students spend about 25–30% of their daily time in classrooms studying or engaging in different academic activities (Giuli, Da Pos, & Carli, 2012). Natural daylighting in classrooms plays a crucial role in school design, whose impact would be directly on student and teacher health, learning, and visual performance, as well as energy consumption. Moreover, effective use of daylight reduces the reliance on artificial lighting, helping to cut down energy consumption and operational costs in school facilities. In a global context, the educational building sector in developed countries in North America, Europe, and so on used advanced artificial lighting and mechanical ventilation for thermal comfort with the use of high energy consumption. However, developing countries such as Nepal are still relying on natural ventilation for daylighting and thermal performance (Lu et al., 2015b).In the case of Nepal, new building design generally does not consider climate-sensitive design strategies or apply any energy-efficient technology because the government has not formulated any energy-saving regulations (Gautam & Bajracharya, 2021).

This research aims to bridge this gap by analyzing how window design parameters, particularly the window-to-wall ratio (WWR), influence both daylighting effectiveness and thermal performance in classrooms. Through a combination of on-site data collection and simulation studies, the research intends to generate practical insights that can inform more climate-adaptive, energy-conscious school design. The findings are expected to benefit architects, engineers, educators, and policymakers, encouraging them to adopt passive design principles that enhance student well-being while reducing energy demands. Ultimately, the study contributes to shaping future educational infrastructure in Nepal that aligns with the goals of sustainability, comfort, and academic excellence.

1.3 Problem Statement

An effective infrastructure, such as building envelopes with insulation, has not been developed in most school buildings in Nepal that can maintain thermal comfort in classrooms (Shrestha et al., 2021). These community-constructed buildings are designed without engineering considerations, relying entirely on natural ventilation for indoor climate control (Shrestha & Rijal, 2023a). According to the school sector development plan 2016–2022 implemented by the Government of Nepal, the use of passive design strategies has not been mentioned or encouraged for improving the thermal environment and comfort of students in classrooms (Ministry of Education, 2016). So, school buildings in Nepal face significant challenges in maintaining indoor comfort during winter, with classrooms often experiencing low temperatures and insufficient daylight. According to (Gautam & Bajracharya, 2021) the opening of the prototype or historical institution is opaque and the direction is random, which generates insufficient light in the classroom and affects the physical and mental existence of students and teachers. Relying on artificial lighting and heating solution to the natural lighting can be uneconomical for developing countries like ours. Despite being important role of windows configuration in regulating indoor thermal and visual environments window design in Nepalese school buildings frequently lacks context-specific considerations. Key factors such as window size, orientation, glazing type, and daylighting strategies are often overlooked or inadequately addressed, resulting in suboptimal thermal regulation and daylight penetration. Climate responsive strategy or technology moving to energy efficiency aren’t employed in new building design in Nepal, because the government hasn’t formulated any energy-building design in Nepal, because the government hasn’t formulated any energy saving guidelines(Bodach et al., 2016). Various research studies, such as (Lu et al., 2015b), (Ashrafian & Moazzen, 2019), (Zomorodian, Korsavi, Tahsildoost, et al., 2016) are conducted on the impact of window configuration on the indoor learning environment, but in Nepal, only a few research studies are conducted on window wall ratio and daylighting such as (Basnet & Uprety, n.d.), (Shrestha & Rijal, 2023a), (Moktan & Uprety, 2023), (Gautam & Bajracharya, 2021) leaving a gap in understanding how optimized window designs can simultaneously reduce energy consumption and maintain comfort in thermal as well as visual comfort. These gaps highlight the need for comprehensive research to explore how window design strategies affect both thermal and visual performance in school buildings.

This research aims to address these gaps by assessing the impact of window size, orientation, glazing type, and daylighting strategies on thermal comfort and visual performance. By answering key questions such as how different window configurations affect indoor temperature and heating demand, how daylighting strategies can improve visual comfort while reducing reliance on artificial lighting, and the energy-saving potential of optimized window designs. The study will provide evidence-based design recommendations for enhancing indoor environmental quality. Ultimately, this research will offer practical solutions to reduce energy costs and create more sustainable, comfortable learning environments in Nepalese schools, aligning with the broader goal of improving educational infrastructure in energy-constrained regions.saving guidelines (Bodach et al., 2016). Various research studies, (Lu et al., 2015b), (Ashrafian & Moazzen, 2019), (Zomorodian, Korsavi, Tahsildoost, et al., 2016) are conducted on the impact of window configuration on the indoor learning environment, but in Nepal, only a few research studies are conducted on window wall ratio and daylighting such as (Basnet & Uprety, n.d.), (Shrestha & Rijal, 2023a), (Moktan & Uprety, 2023), (Gautam & Bajracharya, 2021) leaving a gap in understanding how optimized window designs can simultaneously reduce energy consumption and maintain comfort in thermal as well as visual comfort. These gaps highlight the need for comprehensive research to explore how window design strategies affect both thermal and visual performance in school buildings.

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1.4 Objectives

The primary objective of this research is to explore how window design configuration impacts indoor energy performance as well as visual comfort and daylighting.

Specific objective:

- To assess the impact of window configuration on thermal performance and daylighting
- To determine the energy-saving potential of optimized window design strategies in balancing thermal and visual performance.
- To assess the impact of window-wall ratio on thermal performance

1.5 Research Questions

How do window design strategies influence thermal and visual performance in Nepalese school buildings during winter?

Sub Questions:

- How do various window sizes and location affect indoor temperature and thermal comfort in winter?
- How can daylighting strategies be optimized to improve visual performance while maintaining thermal efficiency?

1.6 Topic Validity

A distinct research space exists regarding window design strategies that affect the thermal and visual performance of Nepalese schools during winter months. Research now emphasizes the essential position of windows because they drive energy efficiency along with daylight access and classroom comfort in current educational facilities worldwide.

The study in Iran (Zomorodian et al., 2016) indicated higher window head heights boost daylight intensity but result in lower average and minimum daylight factors, which affects uniformity performance. The windowsill height affects maximum DF ratings but reduces the distribution quality and lowers uniformity results. Windows with ratios between 35% and 50% fulfill BREEAM standards together with rooftop monitoring devices that achieve daylight quality and distribution needs of LEED. The threshold of 2000 lux represents the maximum level of illumination that results in glare occurrence. The performance evaluation process requires dynamic assessment methods because static metrics do not consider both occupancy schedules and climate conditions. Daylight distribution improved the most through roof monitors together with higher windows. Future research must test the proposed south-side-front windows with north-side-rear windows configuration through annual data collection to simultaneously prevent glare and too much sunlight exposure and visualize discomfort but maintain sufficient daylight entry.

The research by Ashrafian & Moazzen (2019) in Iran evaluated how window proportions (40-50%) and daylight control systems enhance classroom comfort and reduce energy use for lighting. The energy consumption can reach a reduction of 15-18% through heating savings of 8.5%. Early design choices matter because they lead to improved comfort and performance levels and require additional study about window arrangements and glass selection on energy efficiency and comfort levels in various climate zones.

Shrestha & Rijal (2023a) investigated Nepalese school buildings through their research and found that design strategies enhance thermal comfort in buildings with natural ventilation. The thermal preference of students showed a strong correlation with external climate because 63% of them wanted a cooler indoor environment. The implementation of passive strategies resulted in operative temperature levels reaching

28°C, but when combined with integrated methods, this reduced maximum summer temperatures by 3.3°C, keeping them below 27°C. Research suggests that these methods promote comfort together with energy savings for buildings with similar school designs, but additional studies across multiple climates and seasonal changes are advised.

A Nepal-based investigation by Moktan & Uprety (2023) discovered that passive design methods with thermal insulation and thermal mass among them could decrease Kathmandu classroom temperatures by 2-4°C to maintain an indoor environment within the suggested comfort area below 28°C. More than 80% of students reported feeling awkward with the heat, as they wanted the classroom temperature to be lower. These findings indicate that implementing these passive design strategies during new designs or retrofits can establish comfortable conditions for minimum financial investment. The research analyzed only indoor temperatures but excluded vital assessment elements such as humidity and air speed for complete thermal comfort determination.

Zahiri & Altan (2020) investigated the thermal behavior of a female secondary school in Tehran through simulated passive design application. Summer indoor temperatures exceeded comfort zones based on study findings. The application of double or triple glazing combined with thermal insulation and heavy thermal mass elements reduced indoor spaces by 2–4°C without significantly affecting energy usage for heating. South-facing classrooms containing thermal mass materials delivered the best performance outcomes. The study proves that passive strategies will enhance building comfort together with energy efficiency yet require careful monitoring against summer overheating concerns.

The findings in Basnet & Uprety (n.d.) show that a 30% window-to-wall ratio (WWR) provides optimal results to reach 500 lux of daylight in Kathmandu offices, while higher WWR values lead to greater energy use and glare issues. The illumination does not improve with further increases beyond a specific WWR since thermal discomfort sets in. Using WWR as a design parameter fails to yield comfortable visual conditions and might lead to increased energy consumption, so installing blinds becomes necessary to control reflected light.

The study by Gautam & Bajracharya (2021) on daylighting analysis focused on window position, WWR, WFR, and building orientation in several school buildings. It revealed that only the west-facing classroom at Durbar High School met the required 300 lux for reading, while other classrooms had inadequate daylight (56 to 140 lux). Suggestions for improvement included enlarging windows and replacing outdated ones. The study concluded that considering daylighting and thermal analysis early in the design process improves energy efficiency, comfort, and visual quality in classrooms.

The research conducted by Pourya & Alamdari (n.d.) about primary school building renovations in cold regions discovered that window orientation largely affects spring sunshine levels, where east and west orientations lead to a 20-25% decrease in thermal comfort compared to south orientations. Thermal comfort and energy efficiency, together with indoor air quality, reach their optimum in buildings when north- and south-facing windows are used. A building's energy efficiency obtains its maximum performance when WFR reaches 25%, while WFR between 15% and 30% provides the best optimal balance for cold climate environments. Window position does not affect comfort levels, but placing the windows in vertical or central positions leads to higher heating bills by 21% alongside better indoor air quality. During winter and autumn, it is advisable to utilize window openings with dimensions of 5-7.5% OFR, while multi-height windows serve to enhance indoor air quality and decrease energy costs. Building conditions that include short and regular window openings (G1) provide an 18% thermal comfort enhancement together with an 87% improvement in indoor air quality and energy savings of 6%.

According to the research conducted by Lu et al. (2015b), Nepalese educational facilities demonstrated acceptable CO_2 levels, which confirmed excellent air quality conditions. The researched approach for determining air changes per hour (ACH) verified the building's suitable ventilation since ACH values exceeded 25 h^{-1}. The renovation process, which involved replacing wooden window shutters with glass, did not pose a safety risk to CO_2 levels in the building. The research indicates that natural ventilation systems of schools in Nepal are successful at sustaining safe air quality and controlling airborne diseases.

The research by Kh et al. (2014) shows east- and south-oriented buildings raise energy usage by direct sunlight during school operation hours, which supports building designers to consider solar pathways. The limited space in Gaza requires 0.6 students/m² as maximum occupancy density, while vertical expansion represents an effective building solution. The combination of 25% WWR achieved successful daylighting control alongside HVAC energy efficiency, yet occupancy density had more significant influence on usage than both glazing and opaque parameters. Strategies focused on improvement achieved a 27% reduction of building energy usage, which started at 191 kWh/m², and energy distribution revealed that 37.5% came from the exterior walls. Giving buildings proper glazing and installing shading controls effectively controls excessive solar heat gain without compromising the view quality.

The study by Sayadi, Hayati, and Salmanzadeh (2021) highlights the importance of tailoring the window-to-wall ratio (WWR) based on specific climate conditions to improve thermal efficiency and reduce building energy use. Through simulations using IDA-ICE software, the researchers examined how different WWR values affected heating, cooling, and overall energy consumption in four Iranian cities with varying climates. They found that in colder regions like Tabriz, larger WWRs enhanced solar heat gain and lowered heating needs, while in hotter areas like Bandar Abbas, smaller WWRs helped limit heat gain, reducing the demand for cooling. The study also showed that window orientation and glazing type significantly influence energy performance. Ultimately, the research suggests that climate-sensitive window design, guided by simulation tools, is essential for achieving energy-efficient and comfortable indoor environments.

From the study by Saha et al. (2017), titled "North-South vs. East-West: The Impact of Orientation in Daylighting Design for Educational Buildings in Bangladesh," the authors found that north-south orientations with shading devices provided better daylight autonomy and visual comfort, while east-west orientations suffered from glare and over-illumination, leading to discomfort and inefficiency. The study also highlighted the ineffectiveness of horizontal shading for east-west facades and called for alternative shading strategies. Key research gaps identified include the need for more suitable shading solutions for east-west orientations, consideration of environmental factors, and further exploration across different building types.

The study by Ibrahim et al. (2012) explores how the placement and thickness of insulation impact building energy usage. It concludes that exterior insulation is more effective than interior insulation in minimizing heat loss and thermal bridging. While increasing insulation thickness enhances energy efficiency, the benefits plateau after reaching an optimal thickness, highlighting the importance of balancing cost and material use. Using high-performance materials can reduce the required insulation thickness while still maintaining efficiency. Climate also influences the best insulation approach, with colder climates needing thicker insulation. The research by Ibrahim et al. (2012) recommends combining insulation with other design elements for optimal energy savings, and energy simulations suggest potential reductions in energy consumption of 20-40% with optimized insulation strategies.

CHAPTER 2: LITERATURE REVIEW

2.1 Background of Public School in Nepal

Schools are categorized into public (government schools) and private schools. Or, in other words, the Ministry of Education of Nepal categorizes public schools into two types: i) aided community (public) schools, which receive regular government grants for teachers’ salaries and for other administrative purposes; ii) unaided community schools, which do not receive a regular government grant but are financed with support from the community, donations from other sources, and the school’s own resources (Thapa, 2013). Most community school buildings in our country are in poor condition, forcing some students to study outdoors or in waterlogged classrooms during the monsoon. These unfavorable conditions disrupt learning and reduce students' focus, leading to poor academic performance (Raj Parajuli & Das, 2013).

The school categorization is based on the number of students enrolled in schools. The width-to-length ratio for classrooms and learning spaces should have comfortable usage, which should be between 1:1 and 1:2, and have flexible use of the space. Attention should be paid to achieving good teacher – student interaction (Minister of Education, 2016). The standard window-to-wall ratio for daylighting is not clearly defined in the school design guidelines by the Ministry of Education (2016). The guideline merely states that natural daylight should be maximized in room designs to reduce reliance on artificial lighting while ensuring that glare is avoided.

2.2 Educational Buildings

According to NBC 206: 2015 Education buildings in Nepal includes school, college, training institutes with occupancy more than 25 students at a time which is divided into two categories:

Sub Group C1: Primary Schools (up to standard 5)

Sub Group C2: Secondary Schools (beyond standard 5)

Classroom with more than 50 students considered as an assembly unit and need to provide two doors.

2.3 School building design in Nepal

School building designs in Nepal are influenced by a mix of regional needs, resource availability, and local traditions. In rural and remote areas, traditional construction methods remain prevalent due to limited access to modern materials and technologies. In contrast, urban centers like Kathmandu and Pokhara are increasingly adopting contemporary and energy-efficient design principles that focus on sustainability and better environmental performance.

Traditional School Building Designs

In rural parts of Nepal, school buildings are typically constructed using locally available materials such as wood, brick, stone, and mud, which are cost-effective and culturally significant. These buildings are usually functional, with large multipurpose rooms serving as classrooms. The windows in these traditional schools are typically wooden with shutters to allow for ventilation and natural light. However, these large openings can also let in cold air, causing thermal discomfort during the winter. Without proper insulation, classrooms can become very cold, leading to the need for additional heating.

Modern School Building Designs

Urban areas, on the other hand, are moving toward modern, energy-efficient school designs that prioritize comfort, sustainability, and reduced energy consumption. In these schools, there is an emphasis on maximizing natural daylighting and reducing the reliance on artificial lighting. This is achieved through strategically placed windows and the use of energy-efficient glazing, such as double or triple glazing, to minimize heat loss. These schools also often include insulation in walls and ceilings, along with sealed windows to improve indoor air quality and thermal comfort. Passive solar design techniques, such as south-facing windows that capture sunlight in winter and shading devices that block excessive heat in summer, are also commonly used.

Importance of Window Configuration

The configuration of windows plays a critical role in balancing thermal comfort and visual performance in school buildings. In Nepal, particularly in colder regions, it is important to have windows that allow sufficient natural light while minimizing heat loss. South-facing windows are ideal for capturing solar energy in the winter. This is especially important in classrooms, where good natural lighting is essential for enhancing focus and productivity. However, large windows, although beneficial for daylighting, can cause thermal discomfort in cold weather if not properly insulated. As a result, more modern schools are incorporating energy-efficient window technologies, such as double-glazing, to improve insulation and reduce heating costs.

Challenges in School Building Design in Nepal

One of the main challenges in school building design in Nepal is the limited financial resources, particularly in rural areas. This often results in cost-saving measures that compromise comfort and safety. While urban schools can invest in advanced insulation and energy-efficient windows, rural schools often rely on traditional designs that fail to address issues like thermal discomfort and energy inefficiency.

Moreover, rural areas struggle with a lack of skilled labor and limited access to quality building materials, which makes it difficult to adopt modern construction techniques. However, there are efforts by the government and NGOs to improve the infrastructure of schools, focusing on energy-efficient and earthquake-resistant designs in both urban and rural settings.

2.4 Climate in Nepal

Nepal has diverse climatic due to its topographical variations, ranging from lower Terai plain to upper alpine region in North. According to (Bodach et al., 2016) Nepal is divided into four bioclimatic zone:

Warm temperate Climate (below 500m)

Temperate climate(500-1500m)

Cool Temperate Climate (1501-2500m)

Cold Climate (above 2500m)

Kathmandu lies in temperate climate and has mild climate most of the year. Kathmandu valley experiences four distinct seasons: pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and winter (December-February). The average maximum and lowest temperatures (1980-2010) are 23.8^0C and 11.4^0C, respectively.

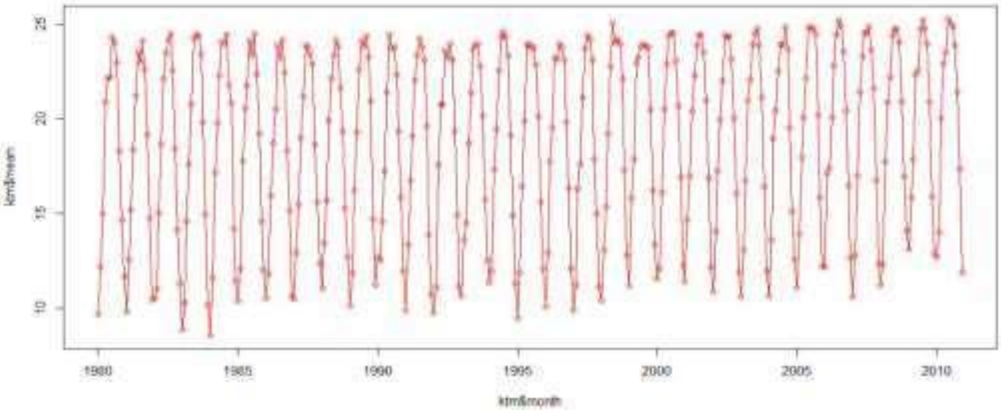


Figure 1: Monthly average temperature trend in Kathmandu valley (Data source: Department of Hydrology and Meteorology)

Nepal’s diverse climate directly affects its building design, particularly in educational structures. The country’s climate ranges from tropical and subtropical in the lowland Terai to cold, snowy winters in the mountainous regions. The central and northern parts of Nepal experience a temperate climate, while the higher altitudes endure harsh winter temperatures. These climate variations necessitate tailored architectural solutions for each region.

During the cold season, temperatures in Nepal often drop well below comfortable indoor levels, especially in areas like the Kathmandu Valley. As a result, there is an emphasis on using passive solar strategies and heating solutions, as well as optimizing window configurations to maximize daylight and solar heat. Schools, like other buildings, rely on natural ventilation and passive heating to reduce energy consumption while maintaining thermal comfort.

2.5 Climate and Its Impact on Building Design in Nepal

The cold winter months require buildings to provide insulation and be designed to capture solar heat effectively. In this season, it’s important for school buildings to allow sunlight to enter during the day and retain the warmth through the night. South-facing windows are particularly effective in winter, while shading techniques help prevent overheating in the warmer months. The focus is also on minimizing heat loss through walls and windows, ensuring that classrooms remain comfortable despite outdoor cold temperatures.

Windows are essential for maintaining thermal comfort and visual quality. Well-placed windows allow natural light to enter while minimizing heat loss. In addition, a carefully considered window configuration can reduce the reliance on artificial lighting, contributing to energy efficiency.

2.6 Thermal Performance of building

The building envelope consists of multiple components such as bricks, mortar, surface finishes, and external coatings. It functions as a boundary that separates the outdoor environment from the indoor space and plays a key role in maintaining thermal comfort inside the building by responding to external climate conditions. Building thermal performance is the process of transfer of energy between buildings and surroundings. Heat transfer in buildings through various building elements such as walls, roofs, ceilings, floors, etc., which is conduction. Such as heat transfer, it also takes from different surfaces by convection and radiation. Heat is also transferred in the building envelope due to occupant load and internal light and equipment.

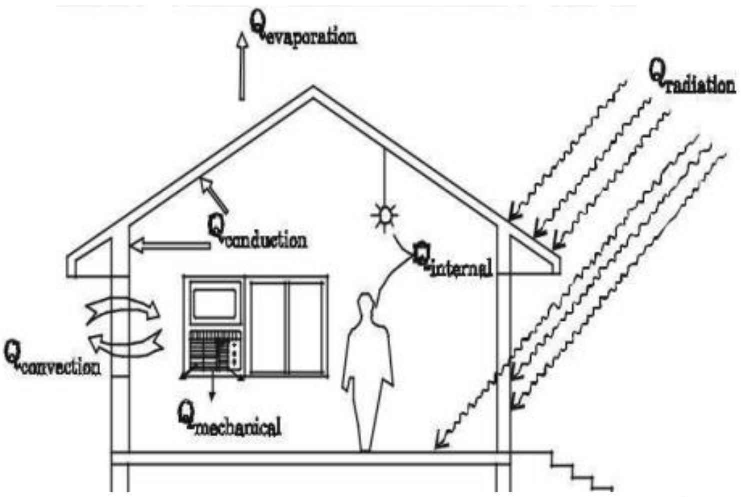


Figure 2: Thermal Performance of Buildings

2.7 Factors affecting thermal performance of buildings

- Thermal performance of a building can be affected by various factors, which are given below:
- Design parameters (geometric dimensions of building elements: walls, roofs, windows, orientation, shading devices, etc.).
- Material Properties (density, specific heat, thermal conductivity, transmissivity)
- Weather data (solar radiation, ambient temperature, wind speed, humidity, etc.)

- Building usage data (internal gains due to occupants, lighting and equipment, air exchanges, etc.)

2.8 Thermal measurements

Every building material used in building envelopes has its own physical properties that determine its energy performance, like conductance, reflectance, and thermal mass. For better thermal performance, you should use better material for heat flow.

1. Thermal conductivity (K) =$\frac{KA\Delta T}{L}$

Thermal conductivity describes how well a material can conduct or transfer heat. It is commonly represented by the symbol ‘k’, but may also be denoted by ‘λ’ or ‘κ’. The inverse of thermal conductivity is called thermal resistivity. Materials that have high thermal conductivity are typically used in applications like heat sinks to efficiently dissipate heat, while those with low thermal conductivity (low λ values) are used as thermal insulators to resist heat flow.

Where, K = thermal conductivity (W/mK), Q=Resultant heat flow (watts), A=surface area (m^2), ΔT=temp diff between warm and cold sides (K), L= thickness or length of material (m)

2. Thermal Conductance (W/m^2K)

Conductivity per unit area for specified thickness is known s thermal conductance. It is also known as heat flow per thickness.

3. U- factor (W/m^2K)

The U-value indicates how fast heat leaves building components, including walls and roofs as well as floors. The overall heat transfer coefficient describes the thermal conductance capabilities of a building element. The thermal performance of a structure becomes poorer as U-value rates increase, leading to greater heat losses, yet better insulation results from lower U-value measures. U-values provide substantial benefits through their capability to evaluate total thermal performance in building composition since they measure complete assembly behavior instead of material attributes in isolation. Overall coefficient of thermal transmittance. Lower U-factors mean less conduction, which means better insulation. (U=1/R)

Q= U x A x ΔT, U= Q /ΔTA = W/ Km2

Q = Heat transfer rate (in watts, W)

U = Overall heat transfer coefficient (U-value, in $W/m^2 \cdot K$)

A = Area of the surface (in m^2)

ΔT = Temperature difference across the material (in K or °C)

4. Thermal resistance (R- value=1/U) Unit (m^2K/W)

Thermal resistance refers to how well a material or building component resists the flow of heat. It is the inverse of thermal conductance, which represents a material’s capacity to allow heat to pass through it.

5. Thermal mass

Thermal mass refers to interior building materials that help regulate indoor temperatures by responding to daily temperature changes, thereby reducing the need for active heating and cooling. These materials absorb heat during periods of high solar radiation and gradually release it as the surrounding environment cools. By storing and releasing heat in this way, thermal mass plays a vital role in energy efficiency, especially when integrated into passive solar heating and cooling strategies. Thermal mass is the ability of a material to absorb and store heat energy. The four factors to understand are density, specific heat, and thermal capacity.

2.9 Thermal Comfort

“Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ANSI/ASHRAE 55:2017).

The primary standards of thermal comfort that were developed (such as the primary form of ASHRAE Standard 55) specifically concentrated on the heat balance models, which assume that thermal comfort is achieved if the body temperature can be held in a narrow range, skin moisture is low, and physiological effort of regulation is minimized (ASHRAE, 2017). Environmental factors (temperature, thermal radiation, humidity, and air velocity) and personal factors (activity and clothing) were taken into account as influential factors for thermal comfort in these models. Such divergence has led to observable differences between the subjective thermal comfort reported by students and the predictions of the Predicted Mean Vote-Percentage People Dissatisfied (PMV-PPD) model. More than 50 % of students evaluate their surrounding thermal environment within a typical thermal comfort range (i.e., slightly cool, neutral, and slightly warm).

2.10 Thermal Comfort from previous study

Table 1: ASHRAE-55 Standard recommendations

S.N.		**Operative Temperature**	**Acceptable range**
1	Summer	22^0C	20-23^0C
2	Winter	24.5^0C	23-26^0C

For naturally ventilated buildings, ASHRAE standard 55 proposes an adaptive thermal comfort model, which sets a 90% acceptable range for indoor temperature of 2.5K above and below the optimum comfort temperature.

From the study of Lamsal et al. (n.d.) to determine the comfort zone, the ASHRAE study was adopted and Szokley’s method was used to identify various potential control zones. The comfort temperature (Tc) was calculated based on the monthly mean outdoor temperature (Tout) using the following equation:

$Tc = 0.31Tout + 17.8$………………. equation 1

where Tc represents the indoor comfort temperature (°C) and Tout is the average outdoor temperature for the month (°C). Predicted comfort temperatures were calculated from this equation and comfort temperatures according to a field study of the Bhaktapur district for summer and winter climates.

Table 2: Thermal comfort for Bhaktapur during winter and summer

Places	Altitude (m)	Tout (°C)		Tc (°C)		Tcf (°C)	
		Summer	Winter	Summer	Winter	Summer	Winter
Bhaktapur	1350	22.4	10.1	24.7	20.9	25.6	15.2

Tout: Mean outdoor temperature (Rijal et al., 2010)

Tc: Predicted comfort indoor temperature by using equation 1 (de Dear & Schiller Brager, 2001)

Tcf: Comfort temperature according to field study (Rijal et al., 2010)

The mean comfort temperatures estimated using Griffiths' method were 17.2 ◦C, 20.9 ◦C, and 21.7 ◦C in the cold, temperate, and subtropical regions, respectively (Shahi et al., 2021).

2.11 Building material and thermal comfort

The building envelope serves not only as a barrier between the interior and the external environment but also as a shield against climatic factors that directly impact the building. The internal thermal comfort is dependent on the properties of the building materials used that are affected by the external temperature and humidity (Hyde, 2013). Heat and cold can enter the building through transparent and translucent materials and windows, and the indoor conditions are influenced by the thermophysical properties of materials (Latha et al., 2015). Materials with lower thermal conductivity, thermal diffusivity, and absorptivity tend to experience smaller temperature fluctuations on the interior surface of the walls compared to materials with higher thermal conductivity. Ventilation also plays an important role in maintaining thermal comfort. The building envelope serves not only as a barrier between the interior and the external environment but also as a shield against climatic factors that directly impact the building. The internal thermal comfort is dependent on the properties of the building materials used that are affected by the external temperature and humidity (Hyde, 2013). Heat and cold can enter the building through transparent and translucent materials and windows, and the indoor conditions are influenced by the thermophysical properties of materials (Latha et al., 2015). Materials with lower thermal conductivity, thermal diffusivity, and absorptivity tend to experience smaller temperature fluctuations on the interior surface of the walls compared to materials with higher thermal conductivity. Ventilation also plays an important role in maintaining thermal comfort apart from building materials. Building envelopes without proper ventilation can trap heat inside, further degrading the thermal comfort of occupants. Recent advancements and technological innovations in building materials offer considerable potential for enhancing thermal comfort and energy efficiency in tropical regions (Latha et al., 2015).

The study by Zahiri & Altan (2020) suggests that passive strategies, such as building materials, glazing, and orientation, significantly improve comfort and efficiency during winter. The study by Shrestha & Rijal (2023) and Moktan & Uprety (2023) shows that operative temperature can be reduced by 2–4°C through the use of thermal improvement strategies, including passive design strategies such as natural ventilation, wall insulation, ceiling insulation, roof insulation, and thermal insulation. Contemporary research reports several types of advanced materials, such as gas-filled panels, polymer skins, aerogels, and vacuum insulation panels, that have the potential to provide better thermal insulation depending on the locations and the thickness of the material (Ibrahim et al., 2012).

2.12 Window Configuration

Windows characterize energy use and visual comfort patterns in buildings (Ochoa et al., 2012). Configuration of openings can modify the intensity and distribution of daylight to create appropriate luminous environments (Zomorodian et al., 2016). Configuration of windows can be dealt with on the basis of side lighting, window location, and WWR. In a classroom that does not use mechanical ventilation, the window is expected to ventilate the room for significant thermal comfort. Many factors regarding windows, such as window opening type, size, and position, that possibly affect the indoor airflow, indoor air distribution, and air exchange rate could contribute to obtaining the thermal condition in the classroom (Talarosha & Marisa, 2018).

Saha et al. (2017) analyze how window orientation affects daylighting in educational buildings. They conclude that shaded windows are more effective in north and south orientations, while unshaded windows perform better in east and west. Proper window design can enhance lighting, reduce glare, and improve energy efficiency in classrooms.

2.13 Visual Performance

Building occupants are exposed simultaneously to different kinds of stimuli. However, it has been noted that discomfort due to visual effects (glare, headaches, deregulation of the circadian rhythm leading to depression) is more frequently reported than discomfort from thermal effects due to the time delay in experiencing the latter and thus being important in building design due to the possible rejection by users of the built environment because of its influence on their overall health (Achard et al., n.d.). Visual performance and comfort criteria will be divided into illuminance-based and glare-based criteria as they need separate consideration when measuring visual satisfaction in the work environment(Ochoa et al., 2012). The Illuminating Engineering Society of North America (IESNA) defined glare as “the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance and visibility.”

(Osterhaus, 2005) argued that glare is an essential factor to consider when designing educational facilities. Exposure to discomfort glare may degrade task performance due to fatigue and reduced concentration. Therefore, it is very important to plan for a minimum of discomfort glare in interior spaces. From the study of (Lee & Lee, 2019) conclude that discomfort glare in classrooms often exceeds acceptable limits (DGP > 0.35) on sunny days. Adding shading devices and optimizing window designs effectively reduced glare, highlighting the need for advanced glare metrics like DGP in design standards to improve visual comfort in schools.

2.14 Metrics used to assess Daylight Performance:

a) Daylight factor

According to Norwegian Green Building Council and BRE Global “The average daylight factor is the average indoor illuminance (from daylight) on the working plane within a room, expressed as a percentage of the simultaneous outdoor illuminance on a horizontal plane under an unobstructed International Commission on Illumination (CIE) Standard Overcast Sky”. Minimum and average daylight factor for classrooms have been defined as 2% and 5%, respectively(Baker, 2014).

b) Illuminance:

Illuminance is the amount of light falling on a surface per unit area, measured in lux (Council, 2012). Othman & Mazli (2012) have recommended average values of 750, 500, 500 and 300-600 and lux for visual tasks in classrooms, including reading and writing respectively. According to the Chartered Institution of Building Services Engineer (2011), the average-maintained illuminance in a classroom should be kept above 300 lux, whereas in laboratories and rooms -as well as on whiteboards- the minimum required illuminance is 500 lux.

c) Useful Daylight Illuminance (UDI):

UDI refers to the fraction of time throughout the year when the indoor horizontal daylight illuminance at a specific location falls within a defined range of acceptable illuminance levels. According to the original UDI definition by Nabil and Mardaljevic (2006), the lower and upper thresholds are set respectively to 100 lx and 2000 lx.

d) Discomfort Glare Probability (DGP):

The Daylight Glare Probability (DGP) metric measures the likelihood of glare disturbance based on factors like vertical eye illuminance, luminance, and the source's solid angle. It is considered the most effective metric for assessing glare due to its strong correlation with user perception. Wienold (2007) proposed a simplified formulation that significantly reduces computational effort:

$$DGP = 6.22 \times 10^{-5} \times E_v + 0.184$$

E_v = Vertical eye illuminance produced by the light source (E_v)

- Imperceptible glare: $DGP \leq 0.35$ for 95% of time (Wienold, 2007).
- Perceptible glare: $DGP \leq 0.40$ for 95% of time (Wienold, 2007).

2.15 Thermal Performance

The comfort of a room's occupants can be negatively impacted by large hot or cold surfaces, particularly windows and skylights. The surface temperatures of windows tend to fluctuate more than those of other surfaces in a room. Even if the room air temperature is kept comfortable, occupants may still experience considerable discomfort due to radiant heat exchange with the window surfaces. Ochoa et al. (2012) studied a hypothetical office room with varying WWRs (10–100%) and evaluated four orientations using EnergyPlus. They recommend 30% WWR for North and 20% for South, East, and West for minimal energy use, while 50–70% (North) and 50–60% (others) ensure visual comfort.

The study by (Kh et al., 2014) examined how occupancy, window-to-wall ratio (WWR), and building orientation affect energy use in school buildings in Gaza. It found that higher occupancy increased energy consumption, while building orientation (east and south-facing) influenced solar exposure. Increasing WWR improved daylighting but raised cooling loads. The study suggested an optimal occupancy density of 0.6 students/m² and a WWR of 25% to reduce overall energy consumption.

2.16 Thermal and Visual Performance Criteria

Thermal performance criteria evaluate energy consumption for functions like heating, cooling, lighting, and ventilation. These values can be measured on-site post-commissioning to compare with projected estimates. They are generally represented in units of energy, such as kWh or GJ, per unit area over a given time frame. Energy performance can also be assessed through user comfort by utilizing various indices and predictive approaches. Some are given below:

Table 3: Different criteria used for thermal and visual comfort and performance evaluations (Ochoa et al., 2012).

	Energy aspects	Visual aspects
Performance	Consumption Degree days Adaptive comfort	Illuminance
Comfort	Predictive mean vote (different indexes) Predicted temperature and RH	Uniformity Contrast
		Daylight glare index Daylight glare probability Other glare indexes (artificial lighting)
Thermal and visual dynamic evaluations	Time condition is met Averages (yearly, monthly, etc.) Usable range (maximum–minimum)	

2.17 Role of Windows Configuration on Thermal Performance

Building envelope is critical for energy efficiency, as its thermal properties directly affect heating and cooling loads. Windows, being weaker, have emphasized the importance of window glazing as an important technological innovation to achieve indoor thermal comfort in enclosed spaces since after the Renaissance period. Manandhar et al. (2015) found that modifying building orientation, size, thermal mass, or window design in Nepal's hot, humid region could significantly reduce indoor temperatures and enhance thermal comfort. This study shows that in the hot, humid climate of Nepal, changing window orientation, orienting buildings along the N-S axis (longer side), providing glazed windows on the north side, or using simple overhang shades can reduce cooling load demand by more than 10-15% (Manandhar & Yoon, 2015). Thermal performance analysis on residential buildings in Butwal by Kafley et al. (n.d.) observed that as the window-to-wall ratio (WWR) increases, annual thermal energy consumption also rises. Specifically, with a WWR of 0.9, energy consumption went up by 5.24% for south-facing orientations and 7.16% for northeast-facing orientations. Zahiri and Altan (2020) found that passive design strategies, such as improved insulation, optimized glazing, and building orientation, significantly enhance thermal comfort and energy efficiency in school buildings during winter.

Zahiri and Altan (2020) found that optimizing window configurations, glazing types, and building orientation improves thermal comfort, visual comfort, and energy efficiency. Key findings include that more windows reduce daylight quality, zoning cuts lighting energy use by 48%, and triple-glazed windows enhance thermal comfort. The window-to-wall ratio, orientation, and wall inclination are crucial for energy performance and daylight.

The study by M. Al-Tamimi et al. (2011) examines how window orientation, WWR, and natural ventilation affect indoor thermal comfort. It finds that east-facing rooms tend to be hotter than west-facing ones, especially without ventilation. Reducing WWR to 25% improves comfort, keeping temperatures below 28.6°C for most of the day. Opaque walls (WWR = 0%) also help maintain stable indoor temperatures. Natural ventilation, particularly with airflow over 0.7 m/s, further enhances thermal comfort.

2.18 Role of WWR on Thermal Comfort

ASHRAE 55 defines thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment” Thermally comfortable and well-designed learning spaces enhance students' academic performance, concentration, and productivity. Thermal comfort is often one of the most overlooked design parameters while constructing educational buildings in Nepal (Moktan & Uprety, 2023). Teli et al. (2014) found that children are more sensitive to higher temperatures than adults are and prefer a cooler environment. From three different scenario of glazing ratio and window configuration on occupant comfort and energy demand of one school Turkey, Teli et al. (2014) found that the best performance is obtained with a 50% glazing ratio, but performance is similar with a 40% glazing ratio. A continuous horizontal window offers better visual performance than separate windows that yield the same overall transparency ratio. Under a clear sky, PPD values varied by about 10% depending on the glazing design, and occupant comfort has huge impact by the window configuration.

Sayadi, Hayati, and Salmanzadeh (2021) examine the ideal window-to-wall ratio (WWR) for buildings in seven different climate zones through IDA-ICE simulations. Their findings suggest that the optimal WWR depends on factors like climate, building orientation, window type, and thermal comfort needs. The study emphasizes that elements such as overhangs, automated blinds, and window characteristics play a crucial role in enhancing energy efficiency and ensuring occupant comfort.

2.19 Relation between Window Wall Ratio (WWR) and Daylighting

Daylighting is the controlled admission of natural light, direct sunlight, and diffused skylight into a building to reduce electric lighting and save energy (Ander & FAIA, 2016). According to the UK Department for Education & Employment (1999), appropriate illumination is also crucial to the quality of an indoor environment. Especially in schools, it is necessary to provide a well-lit environment that enables students and staff to carry out their tasks comfortably and adequately in attractive and stimulating surroundings. According to Essay (2015), a study has indicated that students studying in windowless classrooms tend to be less interested in their work, complain more, and are more hostile, hesitant, and maladjusted.

The International Building Code and British Standard BS 8206 have also recommended minimum window areas, with the former requiring a minimum net glazed area of not less than 8% of the floor area of the room and the latter recommending a minimum window area of 20% of the external window wall for a room measuring less than 8 m in depth and 35% of the external wall for rooms deeper than 14 m (Zomorodian, Z. S., & M., 2016). Zomorodian et al. (2016) analysed the impact of window configurations on daylight performance in a southeast-facing classroom using validated simulations. The study found that increasing the WWR to 35–50% and adding a roof monitor could help meet LEED and BREEAM daylight credits. However, no single strategy met both standards, suggesting that combining higher WWR, roof monitors, and light shelves may enhance daylighting performance.

A study in Malaysia examined daylighting in small classrooms using two models (72 m² each, with depths of 6 m and 12 m) and simulated north-facing windows. It concluded that a window-to-floor area ratio of 18% to 45% is sufficient for adequate natural lighting (Mirrahimi et al., 2013).

From the study of Basnet and Uprety (2022), neglecting WWR as a design parameter will result in visual discomfort, high consumption of energy for lighting and thermal balance, and will demand. Other strategies to maintain visual comfort, such as the use of blinds and other strategies to block unwanted sun and glare, which disconnect people from nature and the architects, cause them to lose their long-term control over the building and find that 30 percent WWR is optimum for lighting the office building with the illumination level of 500 lux from the study.

From the study of the window-to-wall ratio for daylighting in the context of apartment buildings in the Kathmandu Valley by Sangraula and Uprety (2020), it was found that a WWR of 24% and higher is required for providing sufficient daylight inside the bedroom of the apartment building in the Kathmandu Valley.

2.20 Energy Efficiency in School

Schools are important parts of education systems and use a lot of energy. Like other buildings, they often waste energy. The reasons for this are complex, involving many different and changing factors. Energy efficiency in educational institutions is an important area of academic research, policy, and practice (Rospi et al., 2017). Similarly, the impact of the physical school environment on energy efficiency involves the complexity of energy infrastructure and its management, as well as its intricate interactions with the outside environment and other system elements (Brychkov et al., 2023). Energy efficiency in schools involves strategies and technologies aimed at reducing energy use while maintaining a comfortable and effective learning environment. This can be achieved through several key methods.

Building design plays a significant role. Proper insulation in the walls, windows, and doors helps prevent heat loss during winter and heat gain in summer, reducing the need for extra heating or cooling. Additionally, positioning the building to make the most of natural light can minimize the need for artificial lighting. For example, south-facing windows capture sunlight, which can provide warmth during cold months. Passive solar design techniques, such as using thermal mass and strategically placed windows, also help regulate indoor temperatures without relying heavily on mechanical heating or cooling systems.

Lighting efficiency is another important factor. Maximizing the use of natural light through windows and skylights can reduce the need for electric lighting, creating well-lit spaces that save energy. Switching to LED lights and incorporating features like motion sensors or timers ensures that lights are only on when needed, further cutting down on energy consumption.

Heating, ventilation, and air conditioning (HVAC) systems are key energy users in schools. Using modern, energy-efficient systems helps maintain comfortable temperatures while using less energy. Additionally, zoning allows heating or cooling in specific areas only when needed, and proper ventilation systems help ensure fresh air circulation without wasting energy.

Insulation and windows also play a crucial role in energy efficiency. High-quality insulation helps stabilize indoor temperatures, reducing the reliance on heating and cooling systems. Energy-efficient windows, such as double-glazed models, prevent heat loss and contribute to better thermal comfort.

Incorporating renewable energy sources, like solar panels, helps schools reduce reliance on traditional electricity, cutting costs and lowering their carbon footprint. In some areas, schools may also explore wind or geothermal energy as additional sources of sustainable power.

Smart technologies are increasingly being used to manage energy use in schools. Smart meters track energy consumption in real-time, providing insights that help schools identify areas for improvement. Building automation systems can also manage heating, cooling, and lighting based on real-time data, optimizing energy consumption.

Replacing outdated appliances with modern, energy-efficient equipment is another way to reduce energy consumption. Encouraging staff and students to adopt energy-saving behaviors, such as turning off lights and appliances when not in use, further reduces waste.

Finally, maintaining energy-efficient systems and educating the school community about energy-saving practices are crucial for ensuring ongoing energy efficiency. Regular maintenance of HVAC systems, insulation, and lighting helps ensure that they continue to perform efficiently, while promoting energy-conscious behaviors among students and staff creates a culture of sustainability. The benefits of energy efficiency in schools are significant. Reduced energy consumption leads to lower utility bills, freeing up resources for educational needs. Improved indoor air quality and temperature control create a healthier and more comfortable environment for students and staff. Additionally, energy-efficient practices contribute to environmental sustainability by reducing the school's carbon footprint. Lastly, schools can use their energy-efficient buildings as teaching tools, helping students learn about sustainability, renewable energy, and conservation. By integrating these strategies, schools can reduce their energy use, improve the learning environment, and make a positive impact on both the local and global environment.

2.21 Glazing type and thermal performance

According to Aguilar-Santana et al. (2020), windows in buildings play crucial roles by providing ventilation, daylighting, solar heat gain, and enhanced aesthetics. Generally, the thermal and optical characteristics of a window can be described using key parameters such as U-value, Solar Heat Gain Coefficient (SHGC), and visible transmittance. The assessment of these parameters is influenced by the three primary heat transfer mechanisms: conduction, convection, and radiation.

Table 4: Glass configuration

Glass configuration	U-value (w/m2k)
Uncoated single glass 6 mm	5.70
Uncoated double glass 12 mm cavity	2.80
Uncoated double glass 15 mm air cavity	1.40
Uncoated double glass 15 mm argon cavity	1.20
Uncoated triple glass 16 mm with argon	0.79
Uncoated double glass 22 mm monolithic aerogel	0.65

Types of glazing

Single Glazing: Traditionally used in older buildings, single glazing provides minimal insulation and can lead to heat loss, making it less energy-efficient for school buildings, especially in cold climates like Nepal. It allows higher heat transfer, leading to higher energy consumption for heating.

Double Glazing: This involves two panes of glass with an insulating gap between them, which significantly improves thermal insulation compared to single glazing. It helps maintain a comfortable indoor temperature by reducing heat loss during cold weather.

Triple Glazing: Similar to double glazing, but with three panes of glass, offering even better thermal insulation. This is especially useful in colder climates, contributing to energy savings by minimizing heat loss and reducing the need for artificial heating.

Low-Emissivity (Low-E) Glass: A coating applied to the glass that reflects infrared heat while allowing visible light to pass through. This technology helps in improving thermal insulation without compromising natural daylighting. Low-E glass can be a good choice for Nepalese schools during the winter, as it improves energy efficiency by reducing heat loss while maximizing daylighting.

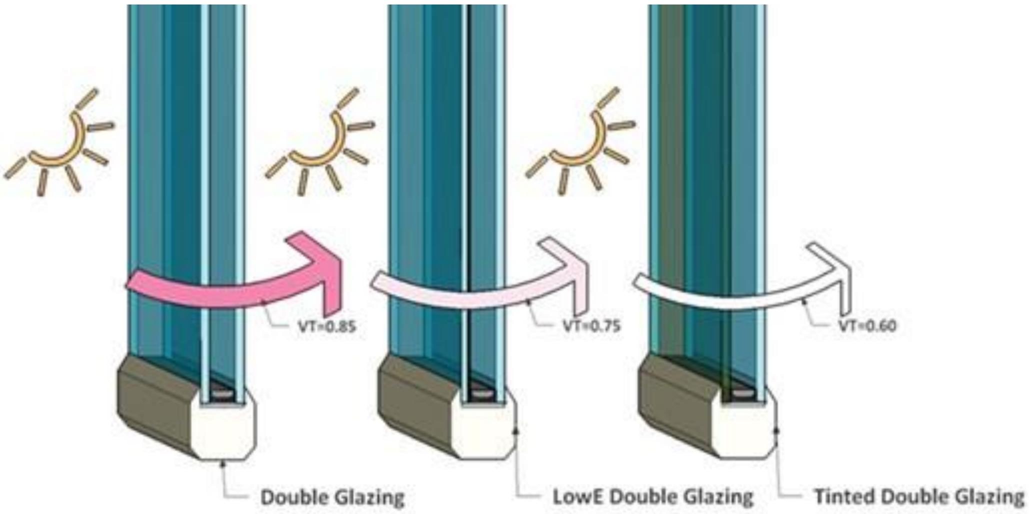


Figure 3: Visible transmittance for different coatings in double-glazing units.

2.22 Policies on Windows at School Classroom

Only there are few standards on windows for school classrooms. The Ministry of Health guidelines on implementing the school health environment in 2019 suggest that the ratio of window area to floor area should be 15% to ensure adequate daylight and ventilation, while 5 to 10% of this should consist of permanent openings for ventilation (Talarosha & Marisa, 2018). 2.1.3.

The International Building Code and British Standard BS 8206 have also recommended minimum window areas, with the former requiring minimum net glazed area not less than 8% of the floor area of the room and the latter recommending minimum window area of 20% of the external window wall for a room measuring less than 8m in depth and 35% of the external wall for rooms deeper than 14 m

Credits of Green building rating tools

- LEED NC-v.2.2 EQ 8.1: requirement for LEED 2.2 EQ addresses a minimum daylight illumination of 25 footcandles to be achieved in at least 75% of all regularly occupied areas.
- BREEAM HEA1: The BREEAM Health and Wellbeing Credit, HEA1, pass requires that both the following conditions are met: 1. For pre-schools, schools and further education colleges, at least 80% of floor area in occupied spaces should be day lit, having an average daylight factor of 2.25 at the height of 0.8 meters for a multi-story building in a city with latitude less than 40. 2. A uniformity ratio of at least 0.4 (spaces with glazed roofs, such as atria, must achieve a uniformity ratio of at least 0.7 or a minimum point daylight factor of at least 1.4%)
- Adaptive thermal comfort and acceptable temperature range for free running buildings (from BS EN 15251:2007, prEN 16789-1: 2015)

Category	Explanation	Suggested acceptable range ^{o}C
I	High level of expectation. Also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young	+ 2 / - 3 ^{o}C

	children and elderly persons, to increase accessibility.	
II	Normal expectation	+ 3/-4 ^{o}C
III	An acceptable moderate level of expectation	+4/-5 ^{o}C
IV	Low level of expectation. This category should only be accepted for a limited part of the year	>+4/ <-5 ^{o}C

- Adaptive thermal comfort for learning and teaching lies in category II

Daylight study performance from previous studies

Table 5: Daylight performance (Saha et al., 2017)

	Criteria	Description
Daylight autonomy (DA)		The percentage of the occupied period (Hours) of the year that the minimum daylight requirement is exceeded through the year
	>80%	Excellent daylight designs
	60-80%	Good daylight designs
Continuous daylight Autonomy	40-60%	Adequate daylight designs
	>5%	Not acceptable. A high probability that this will lead to a situation with a direct sunlight patch and hence glare
Daylight autonomy Max (DAmax)	<5%	Acceptable

Useful daylight illuminance (UDI)	<100 lux	Gloomy room with insufficient daylight.
	100-2000 lux	The room is with useful daylight levels for the occupants
	>2000 lux	The room is too bright and exceeds the upper threshold of the useful range. Higher levels glare or discomfort maybe delivered together with overheating issues

2.23 LEED BD+C: New Constructionv4.1 - LEED v4.1 Daylighting Credit

(LEED v4.1 BUILDING DESIGN AND CONSTRUCTION, 2025)

Projects must select one of the following three compliance options:

a) **Option 1. Simulation: Spatial Daylight Autonomy and Annual Sunlight Exposure (1–3 points, 1-2 points Healthcare)**

Use annual daylight simulations based on IES LM-83-12 to calculate:

- sDA300/50% (Spatial Daylight Autonomy): Percentage of floor area receiving at least 300 lux for 50% of annual occupied hours.
- ASE1000,250 (Annual Sunlight Exposure): Percentage of floor area receiving over 1000 lux for at least 250 occupied hours annually.

For healthcare projects, evaluate only perimeter regularly occupied spaces (as defined by the EQ Credit: Quality Views). Report the average sDA300/50% across all regularly occupied areas. Spaces with ASE1000,250 over 10% must explain how glare is mitigated through design.

Simulation details:

- Use a grid of ≤600 mm (2 ft) at 760 mm (30 in) above the finished floor.
- Include permanent interior obstructions, but movable furniture and partitions may be excluded.
- Use hourly simulations based on a Typical Meteorological Year (TMY) for the nearest weather station.

Table 6: Points for Option 1 (LEED v4.1 BUILDING DESIGN AND CONSTRUCTION, 2025)

	New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality	Healthcare
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least 40%	1 point	1 point
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least 55%	2 points	2 points
The average $sDA_{300/50\%}$ value for the regularly occupied floor area is at least 75%	3 points	Exemplary performance
Each regularly occupied space achieves $sDA_{300/50\%}$ value of at least 55%	Exemplary performance or 1 additional point if 2 points achieved above.	Exemplary performance

b) Option 2. Simulation: Illuminance Calculations (1–3 points, 1-2 points Healthcare)

Use computer simulations to assess daylight levels at 9 a.m. and 3 p.m. on a clear-sky day during the equinox for all regularly occupied spaces. In healthcare facilities, the analysis should focus on perimeter regularly occupied areas as defined by EQ Credit Quality Views. Confirm that illuminance levels in these spaces fall between 300 lux and 3,000 lux at both times. If the spaces have view-preserving automatic glare-control systems with manual override, it's sufficient to demonstrate that the minimum illuminance level of 300 lux is achieved.

Points are awarded according following table.

Table 7: Points for Option 2 (LEED v4.1 BUILDING DESIGN AND CONSTRUCTION, 2025)

New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of regularly occupied floor area within perimeter area	Points
55%	1	55%	1
75%	2	75%	2
90%	3	90%	Exemplary performance

Calculate illuminance intensity for sun (direct component) and sky (diffuse component) for clear-sky conditions as follows:

- Use typical meteorological year data, or an equivalent, for the nearest available weather station.
- Select one day within 15 days of September 21 and one day within 15 days of March 21 that represent the clearest sky condition.
- Use the average of the hourly value for the two selected days.

Exclude blinds or shades from the model. Include any permanent interior obstructions. Moveable furniture and partitions may be excluded.

c) Option 3. Measurement (1-3 points, 1-2 points Healthcare)

Measure actual daylight levels in each regularly occupied space. For healthcare, assess perimeter occupied zones. Ensure measured illuminance falls within 300–3,000 lux. If glare-control systems with manual override are installed, meeting the 300-lux minimum is sufficient.

Measurement Details:

- Take measurements at work plane height (30 inches above floor), between 9 a.m. and 3 p.m.
- 1 Point: Take measurements once during any regularly occupied month.
- 2 Points: Take two measurements – one in any occupied month, the second based on Table 4 (seasonal timing).
- Use grids of:

10 ft (3 m) spacing for areas >150 sq. ft, 3 ft (900 mm) spacing for areas ≤150 sq. ft.

- Measurements should include furniture, fixtures, and equipment.

Table 8: Points for Option 3 (LEED v4.1 BUILDING DESIGN AND CONSTRUCTION, 2025)

New Construction, Core and Schools, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of regularly occupied floor area within perimeter area	
55% at one time in the year	1	55% at one time in the year	1
75% at two times in the year	2	75% at two times in the year	2
90% at two times in the year	3	90% at two times in the year	exemplary performance

Table 9: Timing of measurements for illuminance (LEED v4.1 BUILDING DESIGN AND CONSTRUCTION, 2025)

If first measurement is taken in …	take second measurement in …
January	May-September

February	June-October
March	June-July, November-December
April	August-December
May	September-January
June	October-February
July	November-March
August	December-April
September	December-January, May-June
October	February-June
November	March-July
December	April-August

2.24 Literature Review Summary

Table 10: Literature Review Summary

Reference	Country	Climate	Simulation Method	Thermal Improvement Strategy	Major Findings
Shrestha & Rijal, 2023b	Nepal	Kathmandu (Summer)	PMV, Design Builder	Passive design strategies (natural ventilation, wall insulation, ceiling insulation, roof insulation,	Comfort temperature: 26.6°C in summer; Integrated model reduces operative temperature by

				thermal insulation)	3.3°C for comfort.
Moktan & Uprety, 2023	Nepal	Kathmandu (Summer)	Not mentioned	Passive design strategies (thermal insulation, thermal mass, glazing)	Classroom operative temperature: 27–32°C; Integrated model reduces temperature by 2–4°C.
Bakmohammadi & Noorzai, 2020	Iran	Tehran	Parametric model using Rhino (Grasshopper, Honeybee, Ladybug)	Building parameters (orientation, wall inclination, WWR, glazing material)	WWR significantly influences thermal demand, daylight metrics (UDI & DA), and electric lighting energy.
Zahiri & Altan, 2020	Iran	Teheran winter climate	Design builder	Passive design strategies (wall insulation, orientation, glazing, roof insulation, thermal insulation)	Passive strategies like building materials, glazing, and orientation significantly enhance comfort and efficiency during winter.

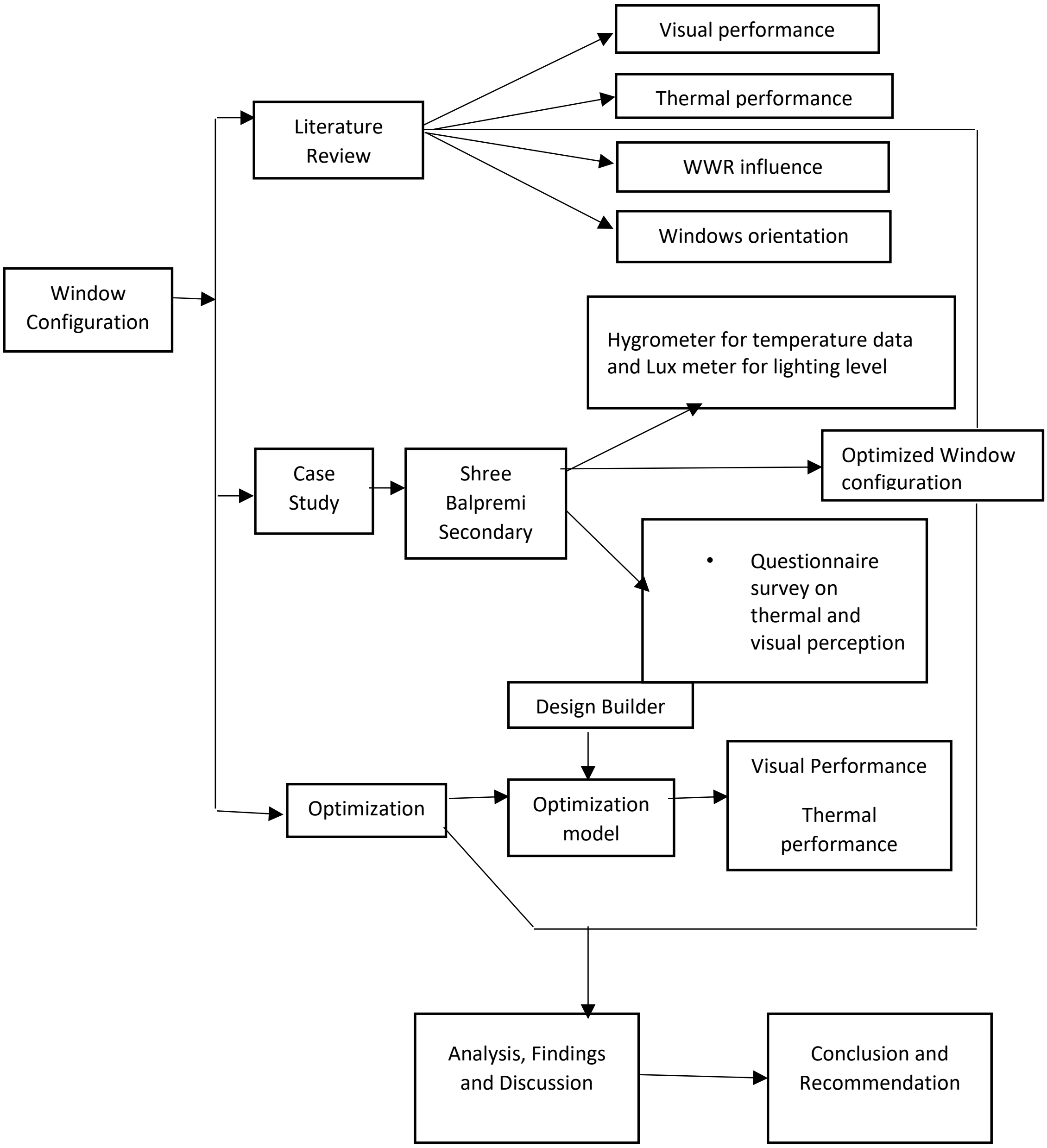
Ochoa et al., 2012	Netherlands	Amsterdam	Energy plus	Optimization of window sizes for low energy consumption and high visual comfort	Found contradictions in optimizing window size for energy efficiency vs. visual comfort. Explored multi-objective optimization techniques.
Moktan & Uprety, 2023	Nepal	Kathmandu Summer	Design Builder	Passive design strategies (insulation, thermal mass, and window glazing reduced)	Simulation results showed that insulation, thermal mass, and window glazing reduced temperatures by 2-4°C. passive design strategies significantly lower indoor temperature during the summer and maintain thermal comfort in the classrooms

Zomorodian et al., 2016	Iran	Kashan (67% clear, 23% partly-cloudy and 10% cloudy during a year)	Design Builder	wall ratio, incorporating light shelves and roof monitors	Increasing WWR to 35%, 40%, and 50%, along with a roof monitor, allows compliance with BREEAM and LEED daylight credits.
Kh et al., 2014	Gaza	Palestine	Design builder	Orientation, WWR, occupancy density, shading devices	East & south-facing orientations increase energy use. 25% WWR balances daylighting & HVAC demand. Occupancy density (0.6 students/m²) has a greater impact on energy use than glazing or opaque materials. Optimized strategies reduced energy use by 27%.
Pourya & Alamdari, n.d	Canada	Québec	Energy plus	Window orientation, window-to-	East & west-facing windows reduce thermal

				floor ratio (WFR), window opening strategy	comfort by 20-25% in spring. North & south-facing windows optimize IAQ & energy efficiency. A 25% WFR is ideal. Vertical & central windows increase heating energy by 21% but improve IAQ
(Basnet & Uprety, n.d.)	Nepal	Kathmandu	Velux Daylight visualizer	Daylight analysis Window-to-Wall Ratio (WWR) optimization	30% WWR is optimal for achieving 500 lux in offices. Higher WWR increases energy use & glare without improving lighting.
Saha et al., 2017	Bangladesh		ECOTECT and Radiance software	Different direction of window with shading and with out shading	North-South oriented classrooms receive more uniform daylight. East-West orientations face glare and overheating issues. Proper orientation

(M. Al-Tamimi et al., 2011)	Malaysia		Monitoring indoor and outdoor temperatures	Minimizing solar radiation, while thermal insulation, shading, and low U-value glass	East-facing windows have higher solar heat gain, raising indoor temperatures compared to west-facing ones. Reducing WWR to 25%
(Shahi et al., 2021)	Nepal	Kalikot, Kathmandu, Chitwan	Thermal comfort survey, Monitoring indoor and outdoor temperatures	Improving thermal insulation and reducing infiltration in the cold region increased indoor temperatures by 1.1–1.8°	The estimated mean comfort temperatures were 17.2°C in the cold region, 20.9°C in the temperate region, and 21.7°C in the subtropical region.

CHAPTER 3: CONCEPTUAL RESEARCH FRAMEWORK



A conceptual framework acts as a foundational structure for a research study, illustrating the logical connections between the main variables involved. It typically starts with the independent variable (IV), which is believed to have an effect on the dependent variable (DV)—the primary outcome being investigated. In many cases, a mediating variable (MV) is introduced to explain the process through which the IV influences the DV, providing deeper insight into the underlying mechanisms. Additionally, a moderating variable (ModV) may be included to indicate conditions that could alter the strength or direction of this relationship. This entire framework helps organize the research, develop focused questions or hypotheses, and guide the methodology.

To effectively apply this framework, researchers use various methods to collect and examine data. Case studies offer detailed, contextual understanding of the variables by closely examining real-world examples. Field visits enhance this by providing direct observation of the environment, allowing researchers to gather firsthand information and validate the relevance of their theoretical model. For studies that require controlled experimentation or forecasting, simulations can replicate conditions and test assumptions in a virtual or experimental setup.

After collecting the necessary data, the next step involves data analysis, where information is systematically evaluated to assess the relationships proposed in the framework. Quantitative analysis might involve statistical techniques to test variable interactions, while qualitative analysis focuses on interpreting patterns, meanings, or experiences reflected in the data. Together, the conceptual framework and these research methods form a comprehensive strategy for conducting a meaningful and well-structured study.

CHAPTER 4: METHODOLOGY

This study adopts a quantitative approach that combines field measurements, simulations, and analytical methods to assess the impact of window design on thermal and visual comfort, as well as energy efficiency, in school buildings during winter. The research focuses on key design parameters, including window size, orientation, window-to-wall ratio (WWR), thermal performance, and visual performance, with the goal of developing context-specific recommendations for Nepalese school buildings. The methodology includes a field survey, on-site measurements, and simulation analysis. The survey collected data on environmental conditions and students' thermal and visual perceptions to evaluate indoor thermal comfort. A structured questionnaire survey will be carried out to get a general idea of the thermal and visual sensation as experienced by occupants. On further process, a case study of school buildings selected under categories of commonly found building typologies for educational buildings around Nepal. On-site measurements included indoor temperature and humidity readings using a digital hygrometer in the classroom, as well as illuminance measurements using a lux meter.

The weather file was processed and converted into an "EPW" format for use in Design Builder software. Thermal and non-thermal zones were defined based on field data, and the comfort band for the study area was determined using the neutral temperature. The selected building was then simulated in natural ventilation and daylighting operation across all thermal zones. Input data on occupant activities and building usage were gathered from field observations, while the thermal properties of materials were sourced from the software's built-in database. The building model was developed, and various simulation scenarios were created and analyzed to assess the impact of different window configurations on thermal and visual performance. Following this, the effect of various window configurations on thermal and visual performance will be studied. Based on a literature review, it was observed that some studies used simulations incorporating individual optimal technologies in isolation (Shrestha & Rijal, 2023a).

4.1 Paradigm

This research employs a pragmatic paradigm that aligns with the study’s objective of creating practical, context-specific recommendations for optimum window design in school buildings. By integrating data-driven analysis with user feedback, the research seeks to balance energy efficiency, thermal comfort, and visual comfort, providing effective solutions to enhance learning environments in Nepal and similar settings.

Ontology (Nature of Reality): Reality is seen as fluid and context-specific, shaped by various factors like climate, window design, and occupant behavior, all of which affect indoor comfort and energy performance.

Epistemology (Nature of Knowledge): Knowledge is derived from a combination of objective, quantifiable data and subjective user experiences, providing a comprehensive understanding of the research issue.

Methodology (Approach to Inquiry): A mixed-methods approach is employed, blending data-driven analysis with user-focused insights to offer practical, solution-oriented outcomes.

4.2 Questionnaire

Based on the literature review, various variables affecting thermal and visual performance due to window configuration in schools have been identified:

a) **Geographic Location**

b) **Demographic Information**

- Respondent name (optional)
- Age group

c) **Classroom Details**

- Size of the classroom
- Orientation of the classroom
- Number and size of openings (windows, doors)
- Type of building materials used
- Total number of students

d) **Thermal Perception**

- Is room heating or cooling required during the summer and winter seasons?
- Which are the extremely hot and cold months of the year?
- Is the classroom comfortable during hot and cold days?
- If not, what are the reasons?

e) **Energy Consumption**

- How often do you need to use active heating or cooling systems during school hours?
- How often do you need to use artificial lighting during school hours?

f) Visual Perception

- At what time of day does the classroom receive the most daylight?
- Do you experience glare issues in the classroom?
- What measures, if any, are taken to reduce glare in the classroom?
- Do the indoor climatic conditions of the classroom affect your mood, concentration, or well-being during lesson hours?
- Overall, how do you find the visual appearance of the classroom?
- How do you perceive any glare caused by the lamps?

g) Surveyor Checklist

- Is there a provision of overhangs or other shading devices for rain protection?

h) Surveyor Observations

- Sky condition during the survey (e.g., clear, cloudy, overcast).
- Approximate temperature and humidity during the survey.
- Approximate lux level in the classroom.
- Thermal sensation of the room (e.g., warm, neutral, cool).
- Visual sensation of the room (e.g., bright, dim, glaring).

CHAPTER 5: CASE STUDY

5.1 Description of Case Study Building

Figure 4: Google site image

The study area for this study is located in Madhyapur Thimi, Bhaktapur, inside the Kathmandu Valley. Kathmandu Valley is located in the central part of the country, lying between 27°36' and 27°50' north latitude and 85°07' and 85°37' east longitude, with a mean elevation of about 1300 meters (4265 feet) above sea level (Upadhyay, Yoshida, & Rijal, 2006). The Kathmandu Valley records up to 35.6°C as the maximum ambient temperature in summer. The temperature in winter ranges between 2°C and 20°C. The average annual rainfall in the Kathmandu Valley is found to be 1400mm (Baniya, Techato, Ghimire, & Shrestha, 2018). The coldest months are January and December, whereas the hottest months are June, July, and August.

The case study chosen for this research is a school building named Shree Balpremi Secondary School located at Madhyapur Thimi-4, Bhaktapur. Block 4-C-8 is a 4-story building with 2 classrooms on each floor. The building is elongated in the south-north direction, oriented towards the east. The building is rectangular in plan with a floor area of 118.30 sq. m. The classroom is designed for 25 students. The building is a frame-structured construction with 230 mm-thick brick masonry walls, maintaining uniform thickness for both exterior and partition walls. Rebuilt after the 2072 earthquake, the structure complies with government-issued school design guidelines and is classified as a disaster-resilient school building.

Classrooms were naturally ventilated with a sill height of 3’ -0” and typical windows (6’-0” X 4’-0”) and doors (3’-6” X 7’-0”). It features powder-coated metal doors and windows with openings with 50% glazed shutters. Artificial lighting is installed in classrooms to improve illuminance during class hours, while ceiling fans are provided for cooling in the summer to help maintain thermal comfort.

Figure 5 : East orientation

Figure 7: Classroom 6 interior

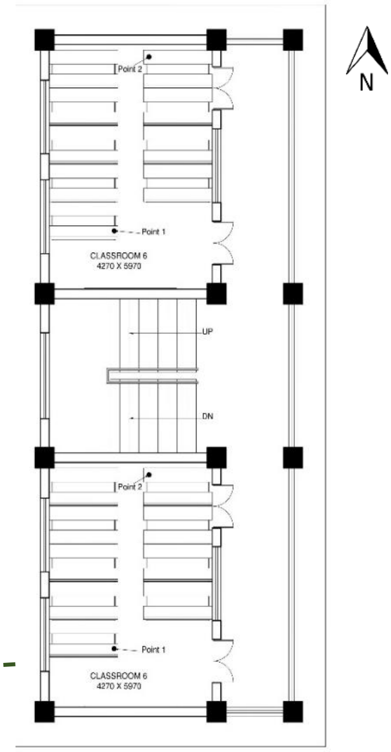


Figure 6: Selected classroom floorplan

5.2 Field Measurement

The field study was conducted over five days in January 2025, measuring indoor air temperature and daylight illuminance in a classroom. The table below presents the specifications of the instruments used.

Table 11: Instruments Used

Specification	Details
1. Digital Hygrometer	HTC-2
Temperature and measurement range	50 ~ +70 degree (-58 ~ +158°F)
Accuracy	±1°C (1.8°F)
2. Digital lux meter	HTC LX-101
Ranges	0-50,000 lux
Sampling Time	0.4 sec

Operating Temperature	0^0 to 50^0 C(32^0-122^0F)
Operating Humidity	Less than 80% R.H

The instruments were placed at a desk height of 800 mm from the floor, and readings were taken at 10:00 AM, 1:30 PM, and 4:00 PM. This time frame was chosen based on references from previous research studies. From the field study the mean indoor temperature of classroom 6 was 16.9^0C.

5.2.1 Indoor Temperature

In naturally ventilated classrooms, the indoor environment is highly influenced by outdoor conditions. During the survey, classroom windows were kept closed, with partially glazed openings. The mean indoor temperature recorded in the classroom was 16.9°C, which falls below the thermal comfort range from the study of (Shahi et al., 2021) mean comfort temperature estimated using Griffiths' method is 20.9^0C for Kathmandu during winter season.

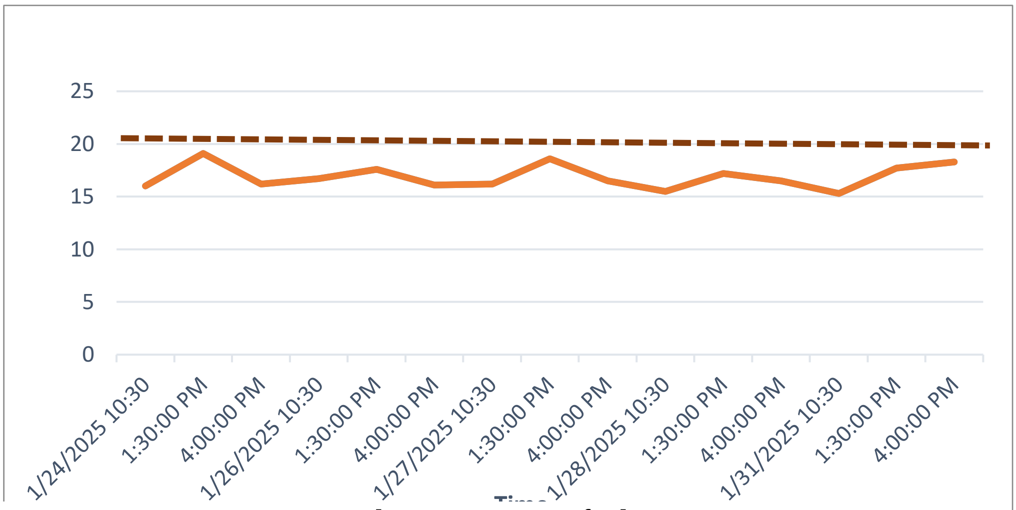


Figure 8: Internal Temperature of Classroom 6

Figure 8 chart illustrates temperature trends recorded from January 24 to January 31, 2025, showing a steady pattern with slight daily variations. Throughout the period, all temperature readings stay below the set threshold of 20^0C, marked by the bold brown dashed line. The orange line, which represents the actual temperature measurements, fluctuates modestly between 15 and 19 units at different times of the day—specifically at 10:30 AM, 1:30 PM, and 4:00 PM. Above figure shows the need of internal heating to meet the thermal comfort during winter season inside the classroom.

5.2.2 Visual Performance

To study natural lighting in Grade 6 and 7 classrooms, illuminance levels were measured on five different days: January 24, 26, 27, 28, and 31. Among these, data from January 28 and 31 were selected for detailed comparison, as they best represented variations in daylight conditions.

To study natural lighting in Grade 6 and 7 classrooms, illuminance levels were measured on five different days: January 24, 26, 27, 28, and 31. Among these, data from January 28 and 31 were selected for detailed comparison, as they best represented variations in daylight conditions.

Measurements were taken with artificial lights switched off, at a height of 2’-6” (762 mm), which corresponds to the average eye level of a seated student.

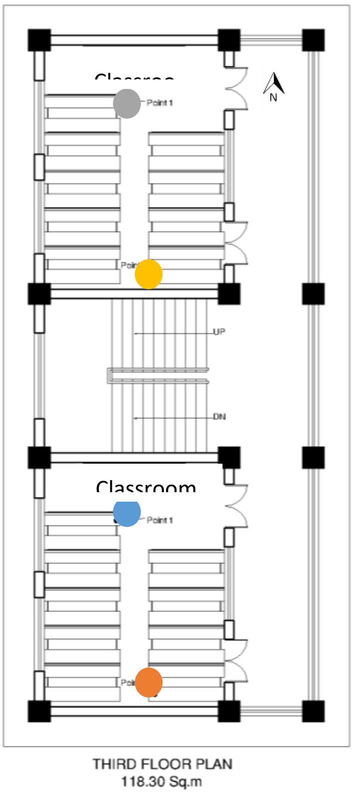


Figure 10: Floor plan showing

illuminance point

As shown in Figure 9, two measurement points were chosen inside each classroom: Point 1 near the window and Point 2 farther inside the room. These points helped capture how daylight levels change across the classroom space. The classrooms, each measuring 4270 mm × 5970 mm, are located

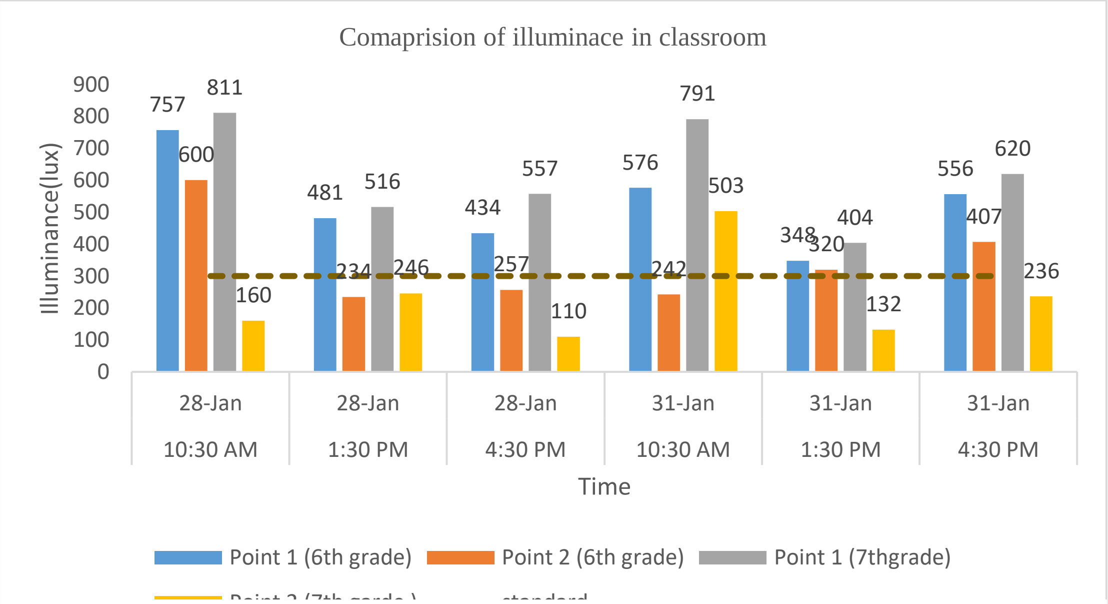


Figure 9: Comparison of Illuminance in Classroom

on the third floor and share a similar layout and orientation, making them suitable for comparison.

Figure 10 shows a detailed comparison of daylight illuminance levels in two classrooms, one for the 6th grade (south-facing) and the other for the 7th grade (north-facing), recorded at three intervals (10:30 AM, 1:30 PM, and 4:30 PM) on January 28 and 31. Measurements were taken at two points within each classroom: Point 1 near the window (perimeter zone) and Point 2 further inside (deeper zone), with all values compared against the recommended standard of 300 lux, shown by a dashed brown line. The 7th-grade classroom displays more stable and evenly distributed lighting throughout the day due to the presence of both eastern and western openings, which help diffuse natural light effectively. This results in relatively higher illuminance levels, especially at Point 1, where the peak value of 811 lux was recorded at 10:30 AM on January 28. However, like the 6th-grade classroom, point 2 in the 7th-grade room consistently shows lower illuminance, indicating limited daylight reach into the interior.

In contrast, the 6th-grade classroom exhibits more extreme fluctuations in illuminance. It receives strong direct sunlight from east-facing openings in the morning, such as 757 lux at Point 1 at 10:30 AM on January 28, but the levels drop sharply in the afternoon due to ineffective west-facing windows, falling to 434 lux at 4:30 PM. Throughout both days, point 2 in the 6th-grade room remains below the 300-lux standard, highlighting poor daylight access deeper into the room—similar to the 7th-grade classroom. On January 31, this trend continues, with the 7th-grade room maintaining stronger and more balanced afternoon light (620 lux at Point 1 at 4:30 PM), while the 6th-grade classroom again shows a more noticeable decline.

5.3 Questionnaire Survey

Based on the literature review, various variables affecting thermal and visual performance due to window configuration in schools have been identified, and a structured questionnaire was prepared. A structured questionnaire survey was carried out among students in the classroom to gather insights on their thermal sensation, preferences, and acceptability. The survey also aimed to understand their visual sensations, preferences, and the impact of these factors on their learning experience.

The survey was conducted on January 31st between 1:30 – 2:00 PM. The thermal perception of the students was collected using the modified 7-point ASHRAE scale (ASHRAE, 2020).

Table 12: Scales used for questionnaire survey

Scale Assigned	Thermal Sensation	Thermal Preference	Visual Preference
1	Cold	A Bit Warmer	Very Insufficient
2	Slightly Cold	No Change	Insufficient
3	Neutral	A Bit Cooler	Adequate
4	Slightly Warm		Excessive
5	Warm		

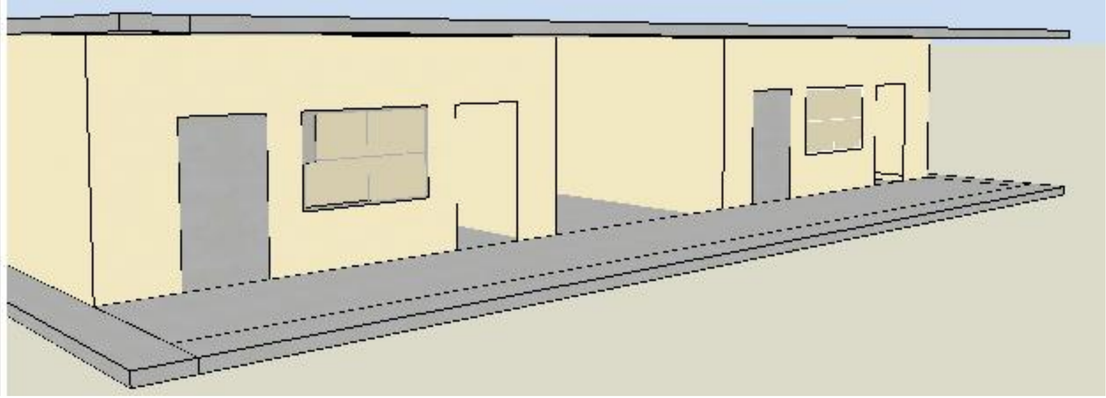


Figure 11: Design Builder model

5.4 Simulation

Nowadays, there are many software tools to carry out simulations. For this research, DesignBuilder 6.1 was used for the thermal and visual performance of classrooms. DesignBuilder is user-friendly 3D modeling simulation software based on the EnergyPlus engine developed by the US Department, used to analyze energy use, thermal comfort, daylighting, and ventilation for energy-efficient design, and has been extensively tested, validated, and used around the world.

To carry out the simulation, a base model of the school building was created based on its actual architectural design. A local weather file (.epw) representing Kathmandu's climate was applied to the model. Since the school is located near Tribhuvan International Airport, the Kathmandu weather data, downloaded from the EnergyPlus website, was considered appropriate for simulating local environmental conditions.

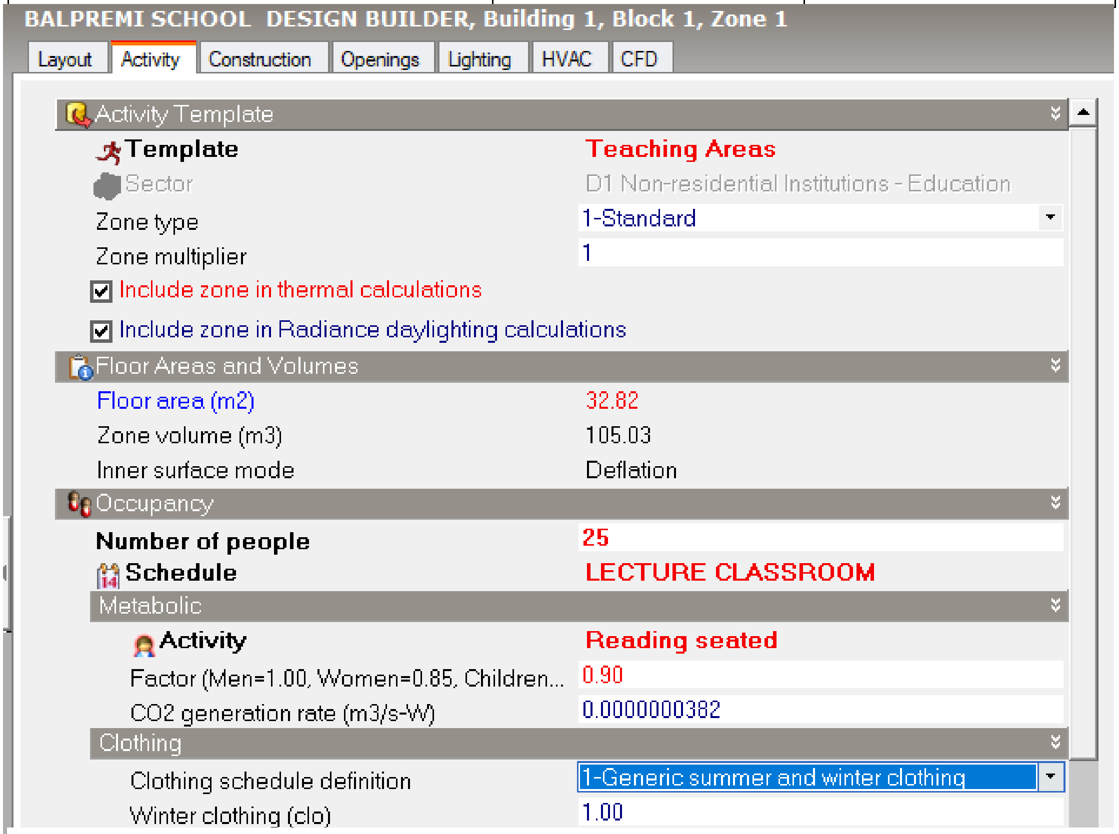
The simulation focused on the second floor of the building, which is more exposed to sunlight and external climate conditions. Initially, the model was simulated using the existing window-to-wall ratio (WWR) to establish baseline results. Following this, the WWR was systematically varied in a series of simulations to examine its impact on both daylight distribution and thermal comfort in the classrooms.

5.4.1 Parameter

Base model parameter

Table 13: Base model parameter

Windows	WWR	Occupancy
Class 6	10%	25
Class 7	10%	25


BALPREMI SCHOOL DESIGN BUILDER, Building 1, Block 1, Zone 1

Activity Template

Template	**Teaching Areas**
Sector	D1 Non-residential Institutions - Education
Zone type	1-Standard
Zone multiplier	1

☑ Include zone in thermal calculations

☑ Include zone in Radiance daylighting calculations

Floor Areas and Volumes

Floor area (m2)	32.82
Zone volume (m3)	105.03
Inner surface mode	Deflation

Occupancy

Number of people	**25**
Schedule	**LECTURE CLASSROOM**

Metabolic

Activity	**Reading seated**
Factor (Men=1.00, Women=0.85, Children...	0.90
CO2 generation rate (m3/s-W)	0.0000000382

Clothing

Clothing schedule definition	1-Generic summer and winter clothing
Winter clothing (clo)	1.00

Figure 12: Activity parameters for Design Builder

Figure 12 shows the simulation settings used in DesignBuilder for modeling a classroom zone within a school building. The zone is defined under the "Teaching Areas" template, aligned with the D1 category for non-residential educational institutions. It is set as a standard single zone (multiplier: 1) and is included in both thermal and daylighting analyses, allowing for comprehensive evaluation of its environmental performance. The room has a total floor area of 32.82 square meters and a volume of 105.03 cubic meters.

The occupancy settings indicate that the space accommodates 25 individuals, following a 10am to 4pm schedule that outlines typical classroom usage hours. The occupants' activity is set to "reading seated," which represents low physical activity and has a metabolic factor of 0.90—slightly below the standard adult male reference. This affects internal heat gains and contributes to the overall energy performance modeling. For thermal comfort analysis, a predefined clothing schedule is applied, representing seasonal variations in clothing insulation: 1.00 clo for winter (indicating heavier clothing) and 0.50 clo for summer (indicating lighter clothing). These parameters are essential for producing accurate simulations of both indoor thermal comfort and daylight conditions within the classroom environment.

CHAPTER 6: ANALYSIS AND FINDINGS

6.1 Thermal Sensation and Preference

From the survey, 56.7% of students reported feeling comfortable, while 33.3% found the classroom slightly cold as shown in figure 6. 23% of student responded comfortable during winter season shown in figure 14. According to the ASHRAE standard, classroom need 80% of acceptability level to satisfy (ASHRAE, 2020). The classroom in this study is unable to meet these criteria.

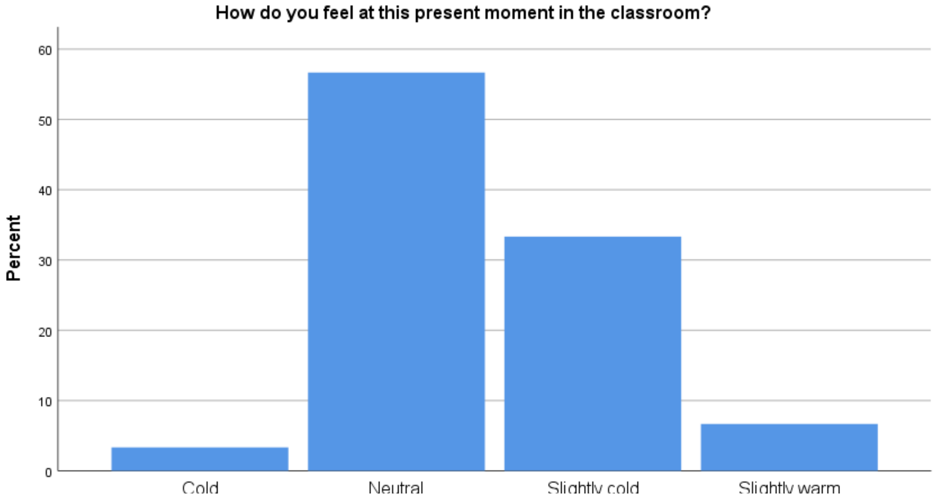


Figure 13: Thermal Preference

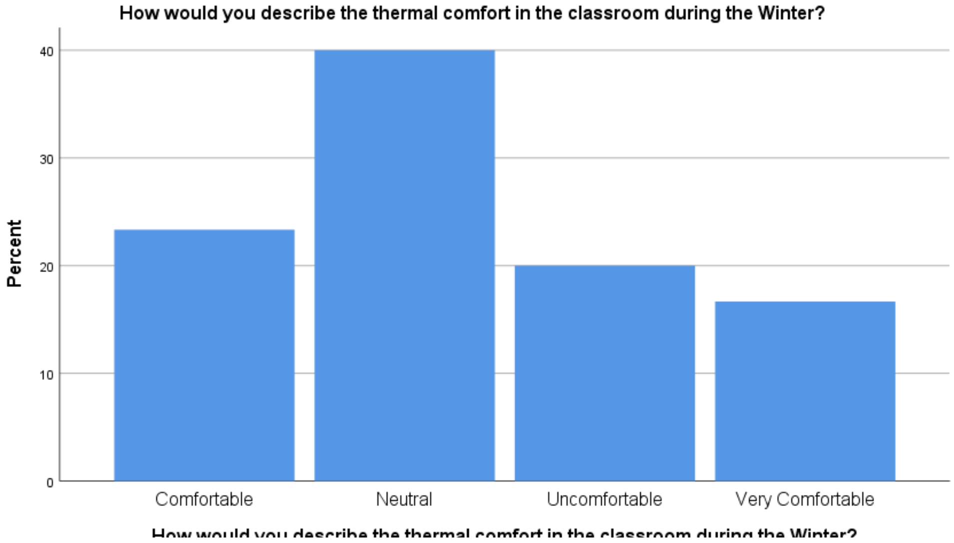


Figure 14: Thermal comfort survey

6.2 Visual Preference

50% of students voted insufficient daylight in the classroom, with most perceiving the highest daylight levels around noon. Furthermore, 73% of students occasionally felt the need for artificial lighting, while 46.7% rarely experienced glare issues. However, no measures such as curtains were implemented to reduce glare.

Interestingly, most students were uncertain about the impact of window size on thermal and visual comfort in the classroom. Additionally, 96.7% of students preferred to keep the window size unchanged.

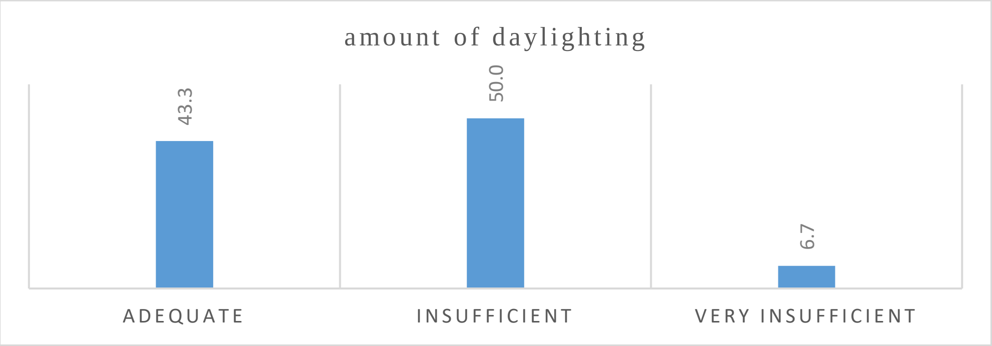


Figure 15: Amount of Daylighting

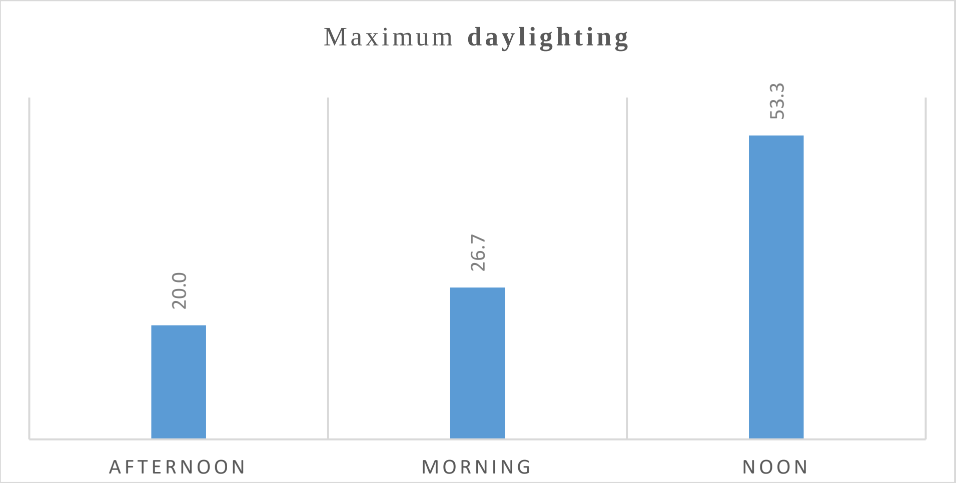


Figure 16 : Maximum Daylighting

From survey on daylighting, 53.3% students responded maximum daylighting during afternoon time shown as figure15. 50% of student responded insufficient daylighting during class hours shown as figure 14.

6.3 Energy Performance

From conducted the survey, 73.3% of student responded occasionally and 26.7% responded for rarely for the use of artificial lighting during school hour. Similarly, 76.7 % of student responded on need of heating or cooling during summer/winter season and 23.3% of student responded not required for heating and cooling during summer/ winter.

6.4 Validation

Visual performance

To verify the reliability of the simulation results, illuminance readings taken on March 7, 2025, at 4:00 PM under an overcast sky were chosen for analysis. This particular time and date were selected due to the stable overcast sky, which provided evenly distributed daylight. Such conditions are ideal for evaluating daylight simulations, as they eliminate the variability caused by direct sunlight and ensure consistent lighting throughout the room.

The field measurements were conducted in Classroom 6 using a grid layout with intervals of approximately 1.06 meters. This spacing was intentionally selected because indoor lighting levels can vary noticeably over small distances, especially near windows, walls, or furniture. A finer grid allowed for more accurate detection of variations in light levels across the space. The complete layout of the observation grid used for data collection is included in the Annex.

The on-site illuminance data were then compared with simulated results generated using the same environmental settings, including identical room geometry, materials, and sky condition. The following table presents a detailed comparison of the observed and simulated values at each measurement point, along with the calculated differences (errors).

Table 14:Comparison of observed and simulation data for the day of March 7, 2025 at 4:00 PM

Points	Observed data	Simulated data	Error
A	278	354	-76
B	170	237	-67
C	115	249	-134
D	302	266	36
E	273	267	6
F	441	414	27
G	264	261	3
H	314	266	48
I	700	633	67
J	258	207	51
K	330	238	92
L	879	820	59
M	153	103	50
N	296	300	-4
O	523	529	-6
Average	353.0667	342.9333	-10.1333

As shown in the table, some points (e.g., E, G, N) show a close match between observed and simulated illuminance values, with minimal differences. However, several locations—such as Points C, K, and B—display more noticeable discrepancies. The largest negative error of -134 lux was recorded at Point C, indicating a significant overestimation by the simulation. On the other hand, Point D had a positive difference of 36 lux, where the simulated value was slightly lower than the measured one.

The overall average observed illuminance was 353.07 lux, while the average simulated illuminance was 342.93 lux, resulting in a small mean difference of -10.13 lux. This relatively minor variation indicates that the simulation results align closely with real-world conditions under overcast skies. Despite a few localized inconsistencies, the general accuracy of the simulation model is validated.

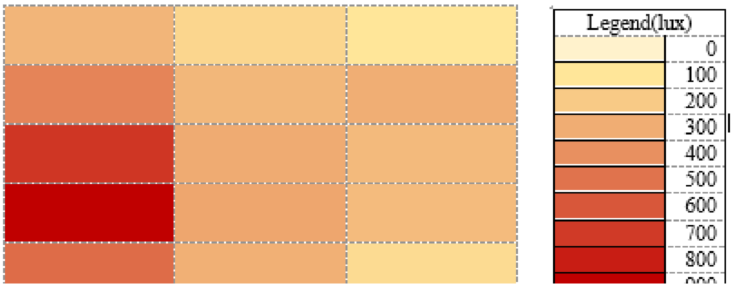


Figure 17 Classroom 7 daylighting field data heatmap

Above figure 17 shows the classroom illuminance level measured through digital lux meter. From the image higher illuminance can be seen towards west side of classroom where large window opening ranges form 441-879 lux, with eastern side of classroom ranges form 115-302 lux and at center grid ranges with 170-330 lux.

From the analysis the error percentage is 2.8%. Above table demonstrates some difference between site data and simulated data, due to several reasons listed below:

- The surface reflectivity of site and that of one used to model may also vary resulting in difference in calculation.
- The light meter is very sensitive device and the reading can be affected by with slight change in position and other unintended disturbance.

Since the observed data and simulated data are not 100%. So, simulation results need to be referred vary need to be referred for major decisions.

6.5 Simulation Result

The render for studying illuminance level was done using overcast sky condition for the month of January for worst case scenario, with higher resolution and render quality. Similarly thermal performance also studied along with it at 1:00 pm.

6.5.1 Base case model

Table 15: Base model building material Thermal properties

Components	Materials	Thickness(mm)	U value (W/m K)
Wall	Brick with 12mm plaster on both side	230	2.04
Ceiling	RCC with screeding	150	2.53
Floor	RCC with 50mm screeding	150	2.53
Windows	Single glazed & powder coated metal shutter with 40% glazed	40	5
Doors	Powder coated metal	40	5

Table 15 shows building material and their thermal properties for the base model of a classroom. The walls are made of brick with 12 mm plaster applied on both sides, having a thickness of 230 mm and a U-value of 2.04 W/m²·K, without insulation. The ceiling and floor are both constructed using reinforced cement concrete (RCC) with screeding, each 150 mm thick, and have a U-value of 2.53 W/m²·K, suggesting a slightly higher rate of heat transmission than the walls. The windows consist of single glazing with powder-coated metal frames, featuring 40% glass coverage and a thickness of 40 mm. They have a high U-value of 5 W/m²·K, showing that they offer minimal resistance to heat flow. The doors, also 40 mm thick and made of powder-coated metal, share the same U-value of 5 W/m²·K.

Thermal Performance

From the simulation, 10% WWR base model shows that thermal comfort is not achieved average temperature from 10:00 am- 4:00 pm is 15.3^{0}C which is below thermal comfort temperature i.e. 20.9^{0}C. While solar gains through windows increase steadily, reaching 2.11 kW by 16:00 pm, they are insufficient to offset significant heat losses, particularly through the external floor and walls. The building shows thermal lag, with indoor temperatures rising slowly despite increasing outdoor temperatures. Overall, the 10% WWR provides limited passive heating, indicating the need for better insulation and potentially higher WWR or optimized window placement to improve winter thermal performance.

Visual Performance

Table 16: Window configuration

Base model		
Location	**size**	**Average lux**
West	1.8 x 1.2 (2nos)	342.93
East	1.8 x 1.2 (2nos)	
South		

The base model used for simulation uses the typical windows of size 1.8 m width and 1.2 m height. The west façade consists of two windows, and the east façade has a single window and is windowless in the southern façade, resulting in a greater impact on daylight assessment inside the classroom.

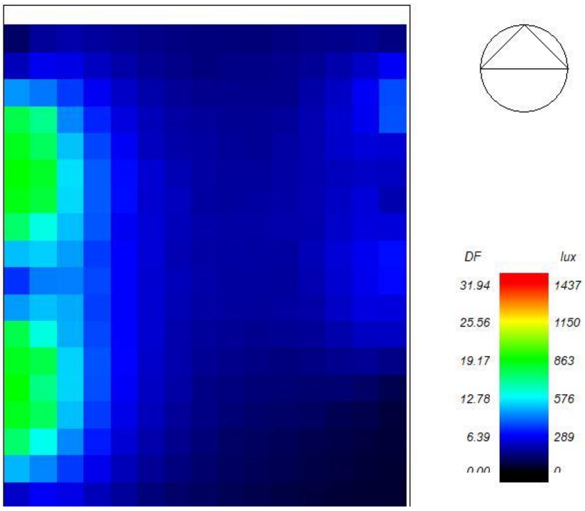


Figure 18 Base model illuminance

The daylight assessment evaluation for this classroom occurs under overcast sky conditions according to Figure 18. The highest amount of daylight reaches the western area of the classroom because it contains a greater number of openings compared to the other regions. The rear region of the classroom experiences minimum illumination of 103 lux while the overall average daylight factor (DF) amounts to 9.15% and average illuminance remains at 342.93 lux. The study reveals through Figure 18 that the existing window placement leads to lighting inequality inside the classroom space. The classroom needs improved lighting which requires a higher and optimally designed window-to-wall ratio (WWR) system.

6.5.2 WWR 12%

In this model, input parameter is same as base model except windows are changed to fully glazed of 6mm clear glass and with aluminum frame.

Thermal performance

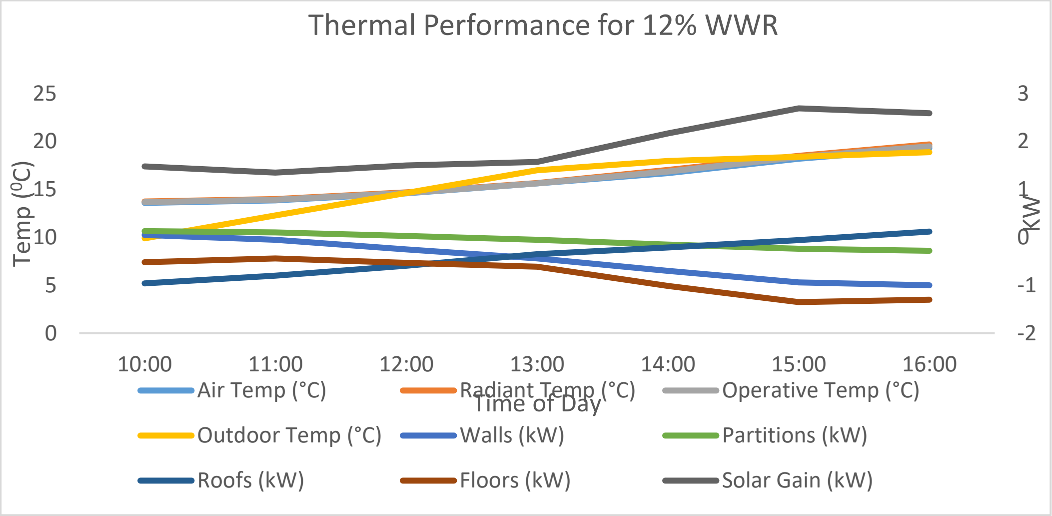
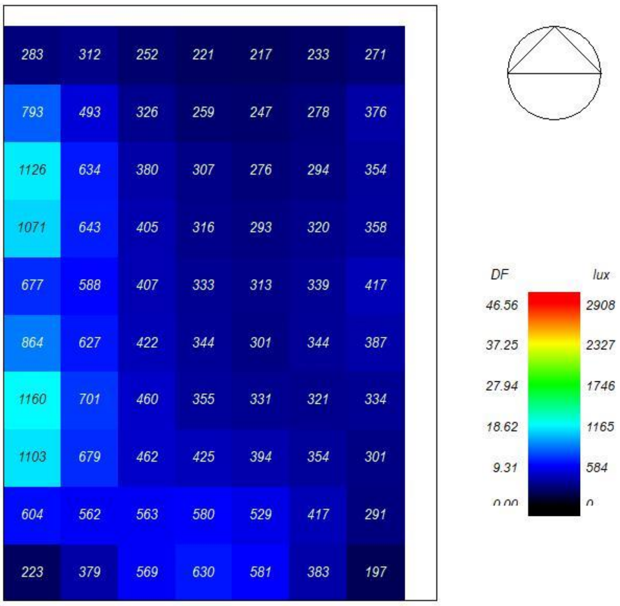


Figure 19:Thermal performance for 12% WWR

Figure 19, shows the thermal performance with improved window wall ratio of 12% and window configuration of base model with adding window in southern external wall and adjusting size of the windows shows improved thermal conditions throughout day on January 28, 2025, mainly due to solar gains. The operative temperature grows from its starting point of 13.67°C at 10:00 until it reaches 19.49°C at 15:00. The passive solar contribution through window gain shows a direct correlation with the rising solar heat gains from 1.48kW to over 2.59 kW while also demonstrating the importance of heat from sunlight even with small change of window size can increases solar gain than base model. Radiant temperature changes 13.7^{0}C at 10:00 and its peak temperature 19.69^{0}C during 16:00. Thermal comfort depends on surface heat effects to a higher extent than it depends on air temperature levels. The floor loses most energy throughout the day because it generates maximum heat loss of -1.35 kW from floor during early afternoon which exceeds both roof and wall losses. The transfer of heat through interior walls between rooms proves to be ineffective. The examination results indicate that windows of minimal size effectively increase interior warmth through solar heat gain yet major thermal losses through floors and roofs hinder total energy efficiency.

Visual performance

Under overcast sky conditions, increasing the Window-to-Wall Ratio (WWR) from 10% to 12% leads to an improvement in the classroom’s overall illuminance. However, the evaluation shows that daylight distribution remains uneven across the interior due to the orientation and positioning of 12% WWR openings on the south, east, and west walls.



283	312	252	221	217	233	271
793	493	326	259	247	278	376
1126	634	380	307	276	294	354
1071	643	405	316	293	320	358
677	588	407	333	313	339	417
864	627	422	344	301	344	387
1160	701	460	355	331	321	334
1103	679	462	425	394	354	301
604	562	563	580	529	417	291
223	379	569	630	581	383	197

Figure 20: WWR 12% illuminance

The peak illuminance is recorded at 1160 lux along the western façade, where sunlight enters more directly compared to other sides. In contrast, the minimum illuminance is observed at 197 lux in the southeast corner of the classroom. The Daylight Factor (DF) reaches 7.51%, and the average daylight level is measured at 468 lux. Despite these values, daylight performance is dissatisfactory in areas further from the windows. Illuminance significantly diminishes towards the rear and central zones of the classroom, where values range between 301 lux and 422 lux. Light entering from the east and west façades contributes to overall brightness but is insufficient to prevent the natural attenuation of light in deeper areas of the room. As a result, the illuminance level at the center of the classroom decreases with distance from the windows. Notably, 21% of the classroom floor area receives less than 300 lux, which falls below the recommended standard for adequate visual comfort and learning environments.

6.5.3 WWR 16%

In this model, input parameter is same as base model except windows are changed to fully glazed of 6mm clear glass and with aluminum frame. Using Tabel 16 window configuration thermal and visual performance is analyzed.

Table 17 shows the window configuration for WWR16% with the use of a typical window size of 2.1m width and 1.5 m height. The southern façade is provided with a typical window of 2.1m width and 0.6m height, which acts as a critical factor for classroom thermal and visual performance.

Table 17: Window configuration

16% WWR optimized model		
Location	size	Average lux
West	2.1 x 1.5 (2nos)	582
East	2.1 x 1.5(1nos)	
South	2.1 x .6 (1nos)	

Thermal Performance

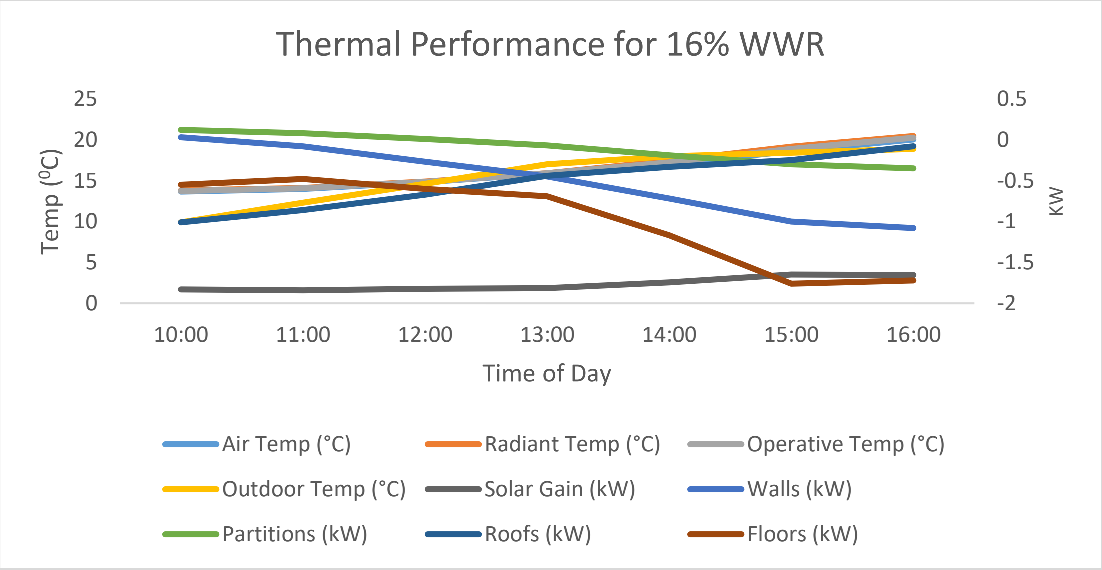


Figure 21: Thermal performance for 16%WWR

Figure 21 illustrates the thermal performance of a classroom with an improved 16% Window-to-Wall Ratio (WWR), achieved by adjusting the window sizes on external walls. This modification results in improved thermal conditions throughout the day on January 28, 2025, primarily due to increased solar gains. Enlarging the windows on the west, east, and south façades raises solar gains from 1.69 kW to a peak of 3.52 kW at 15:00, which subsequently increases the indoor air temperature—reaching a maximum of 20.24°C at 16:00 and 13.73°C at 10:00. The mean radiant temperature follows a similar trend, rising to 13.8°C at 10:00 and peaking at 20.45°C at 16:00. Thermal comfort is influenced more significantly by surface heat exchange (such as radiant temperature) than by air temperature alone.

Among all surfaces, the floor contributes the most to heat loss, with a maximum thermal loss of -1.72 kW during early afternoon, surpassing losses from both the roof and walls. Additionally, heat transfer through interior walls proves to be minimal and ineffective.

Overall, while minimally sized windows effectively enhance indoor warmth through passive solar heat gain, substantial thermal losses through the floor and roof continue to limit the classroom's overall energy efficiency.

Visual Performance

Under the overcast sky condition, the maximum illuminance for classroom 6 is 1360 lux and minimum is 146 lux with average DF 9.37% and average daylight 582 lux which meets standard average 500 lux for classroom. Providing windows in southern wall help in balance illuminance inside the classroom shown as figure 22.

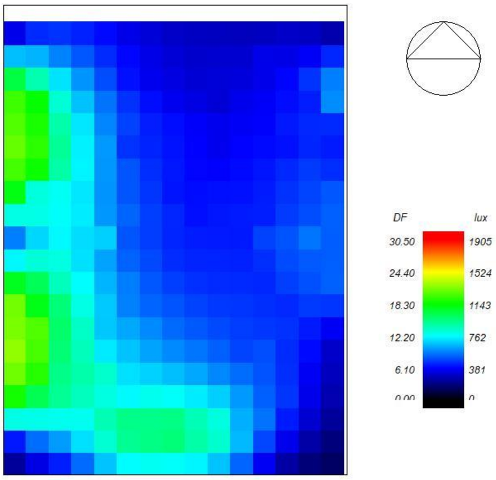


Figure 22:16% WWR illuminance

Since WWR 16% meets Visual requirement but not meet thermal performance need of improved optimized WWR.

6.5.4 WWR 18%

In this model, input parameter is same as base model except windows are changed to fully glazed of 6mm clear glass and with aluminum frame. Table 13 shows window configuration of window used in the scenario.

Table 18: Window configuration in 18% WWR

18% WWR optimized model		
Location	size	Average lux
West	2.1 x 1.5 (2nos)	655
East	2.1 x 1.5(1nos)	
South	2.4 x 1.05(1nos)	

Table 18 shows the window configuration for WWR18% with the use of a typical window size of 2.1m width and 1.5 m height. The southern façade is provided with a typical window of 2.4m width and 1.05m height, which acts as a critical factor for classroom thermal and visual performance. The size of the windows is changed for the improvement of the thermal and visual performance of the classroom.

Thermal Performance

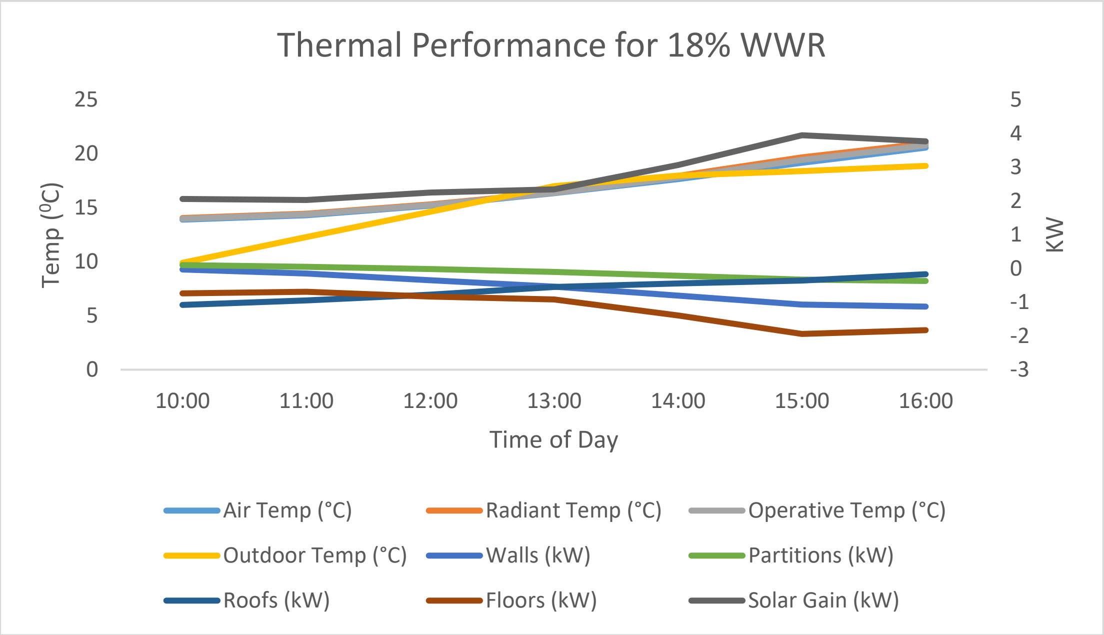


Figure 23: Thermal performance for 18% WWR

With improved 18% WWR with adjusting the size of windows in external wall shows improved thermal conditions throughout day on January 28, 2025, mainly due to solar gains. Maximum temperature 20.77°C during 16:00 pm. Average indoor temperature during the school hour is 16.85^{0}C which is below thermal comfort temperature i.e.

20.9^0C. During 15:00 pm solar gain from windows reach to maximum 3.95 KW and slightly dropping to 3.77 kW by 4:00 PM whereas walls, roofs, floors and partition are related for heat loss. So, windows area can relate to thermal performance.

Visual Performance

Under the overcast sky condition, the maximum illuminance for classroom 6 is 1370 lux and minimum is 148 lux with average DF 9.37% and average daylight 611 lux which meets standard average 500 lux for classroom.

Since WWR 18% meets Visual requirement but not meet thermal performance need of improved optimized WWR.

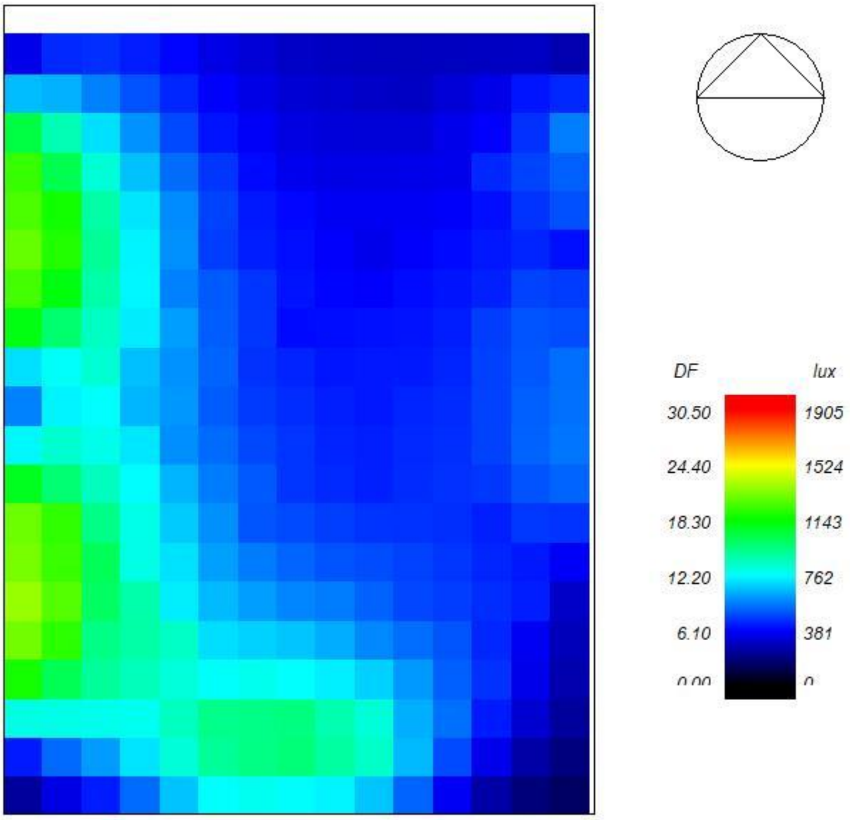


Figure 24: 18% WWR illuminance

6.5.5 WWR 20%

In this model, input parameter is same as base model except windows are changed to fully glazed of 6mm clear glass and with aluminum frame. Table 14 shows window configuration of window used in this scenario

Table 19: Window configuration in 20% WWR

20% WWR		
Location	size	Average lux
WEST	2.25 X 1.5 (2nos)	611
East	2.25 X 1.5(1nos)	
South	2.4 X 1.2(1nos)	

Table 19 shows the window configuration for WWR 20% with the use of a typical window size of 2.25m width and 1.5 m height. The southern façade is provided with a typical window of 2.4m width and 1.2m height, which acts as a critical factor for classroom thermal and visual performance.

Thermal Performance

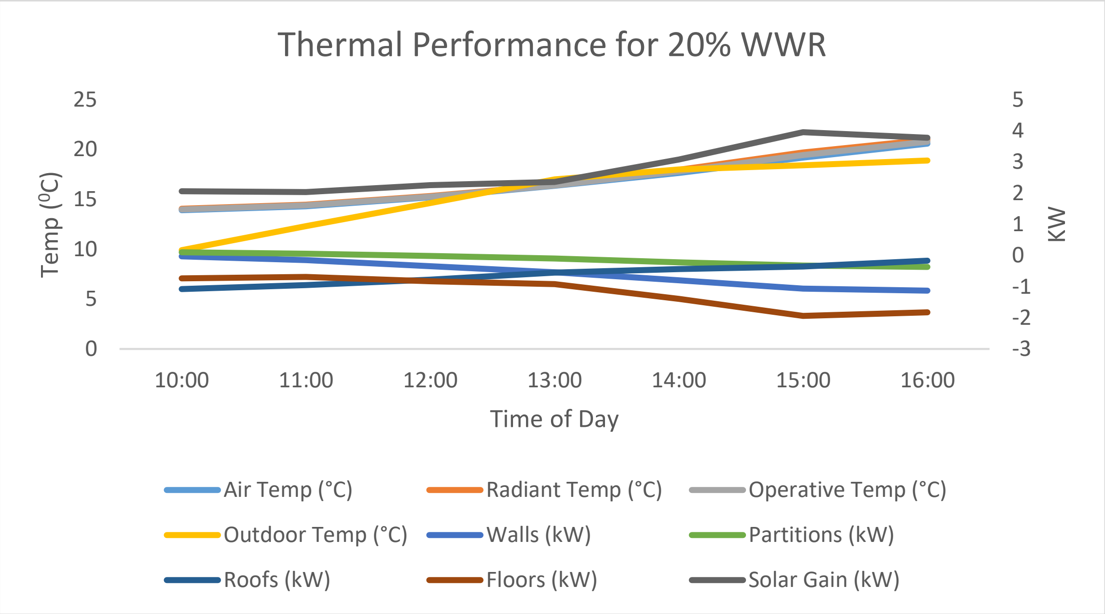


Figure 25: Thermal performance for 20% WWR:

With improved 20% WWR with adjusting the size of windows in external wall shows improved thermal conditions throughout day on January 28, 2025, mainly due to solar gains. Maximum temperature **21.13°C** during 16:00 pm. Average indoor temperature during the school hour is 17.1^{0}C which is below thermal comfort temperature i.e. 20.9^{0}C. During 15:00 pm solar gain from windows reach to maximum 4.29 KW and slightly dropping to 4.08 kW by 4:00 PM whereas walls, roofs, floors and partition are related for heat loss. So, windows area can relate to thermal performance.

Visual Performance

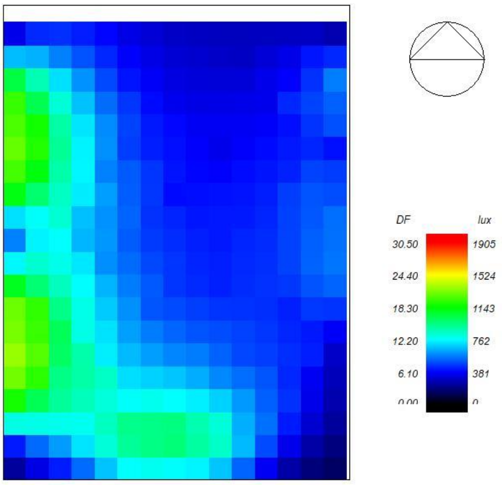


Figure 26: 20% WWR illuminance

Under the overcast sky condition, the maximum illuminance for classroom 6 is 1414 lux and minimum is 164 lux with average DF 10.08% and average daylight 611 lux which meets standard average 500 lux for classroom.

Since WWR 20% meets Visual requirement and nearly meets thermal comfort. With the increase WWR to 20% due to increase of size of windows in western and easter walls, increase in glare. So, to optimized both thermal and visual performance, passive strategy scenario optimized scenario is created. Mahoney table suggest 20-40% WWR inside Kathmandu valley. Hence this scenario meets Mahoney Tabel and amount of glare was analyzed.

Glazing Analysis

With the increase in WWR ratio, there also increase glare inside the classroom crating visual imbalance. Illuminance of classroom 6 is analyzed under sunny intermediate for glare effect. Result shows average illuminance is 1597 lux, around 45% of area of classroom shows glare around 2pm. During 1pm average illuminance is 728.34 lux and 30% of area shows glare

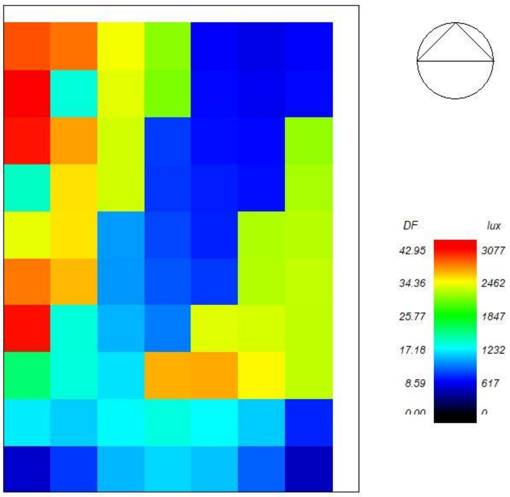


Figure 28: Illuminance of room with

WWR 20% during 2pm

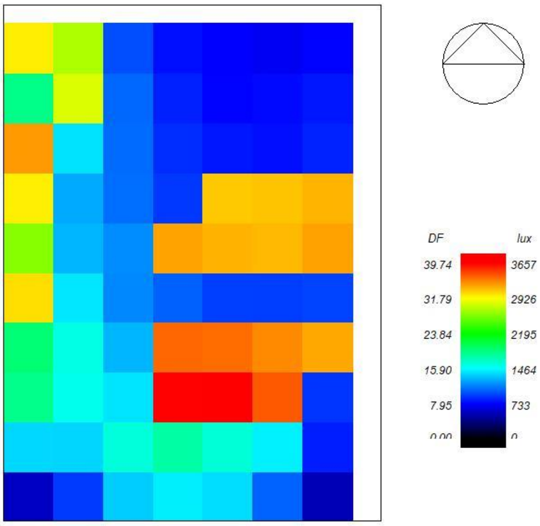


Figure 27: Illuminance of room with

WWR 20% during pm

The figure 29 shows average illuminance data and glare percentage measurements that change during classroom hours in a building with 20% window-to-wall ratio (WWR). Illuminance rates stay stable between 1400 lux and 1800 lux from 10 AM until 2 PM when reaching its peak at 1 PM. The illuminance levels decrease swiftly from 800 lux to 250 lux between 3 PM and 4 PM. The percentage of glare experienced by occupants shows a gentle decline from 30% at 10 AM until 11 AM reaches its minimum point at 25% before it starts increasing again through the afternoon until reaching a peak at 45% at 2 PM.

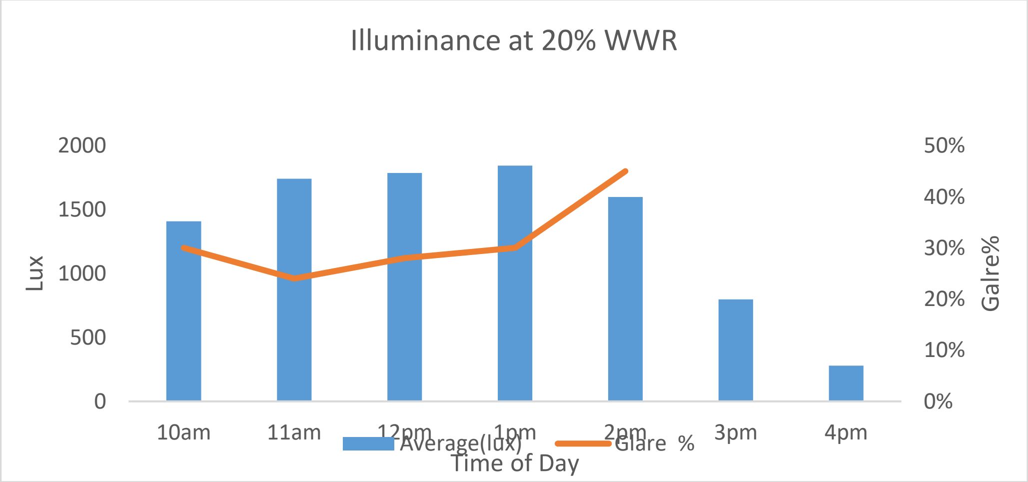
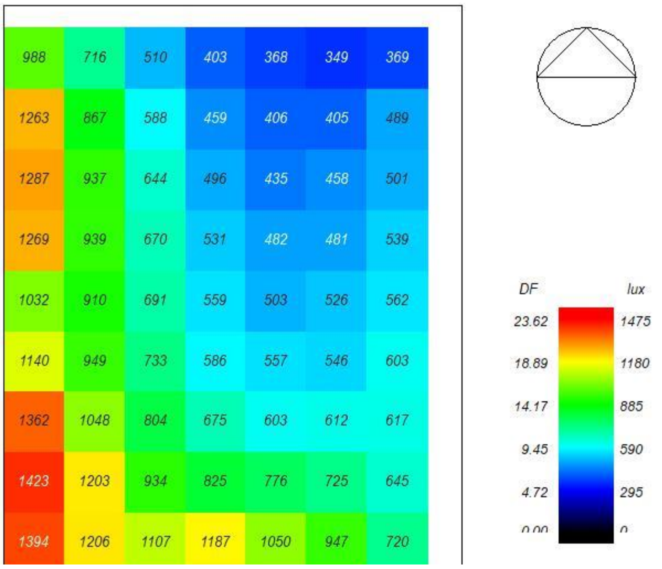


Figure 29: Illuminance and Glare at 20% WWR

The intensifying glare during early afternoon creates lighting complications after sufficient daylight exposure during late morning and early afternoon periods has been achieved. Daylight conditions between 2 PM and other hours will become insufficient without artificial lighting sources to supplement the reduced available light. The figure shows why it matters to maximize daylight access through glare control to achieve visual comfort within spaces having a 20% WWR.

6.5.6 WWR 25%

Visual Performance



988	716	510	403	368	349	369
1263	867	588	459	406	405	489
1287	937	644	496	435	458	501
1269	939	670	531	482	481	539
1032	910	691	559	503	526	562
1140	949	733	586	557	546	603
1362	1048	804	675	603	612	617
1423	1203	934	825	776	725	645
1394	1206	1107	1187	1050	947	720

Figure 30: Illuminance (WWR25%)

Figure 30 shows the daylight illuminance inside classroom with 25% window wall ratio under the overcast sky condition. Evaluation of the classroom reveals how daytime lighting illuminates unevenly through the interior because it extends to 25% Window-to-Wall Ratio (WWR) openings across south, east, and west walls. The peaks of illuminance reach 1475 lux along the southern façade because sunlight enters this area most strongly. Similarly, minimum 349 lux in northern side of classroom with no windows. The observed Daylight Factor (DF) values in these spots exceed 2% which meets requirements for visual activities. Daylight illumination dissatisfying diminishes substantially in the remote distances from windows especially affecting the rear sections and central space of the classroom where lighting amounts fall range of 559 lux- 670 lux. lux along with acceptable DF metrics. Light entering from east and west windows affects daylight distribution throughout the space yet fails to prevent the light attenuation happening deeper inside the room. The implemented daylighting design accomplishes LEED v4.1

basic illumination requirements because all measured lighting levels exist between 300 to 3000 lux.

Thermal Performance

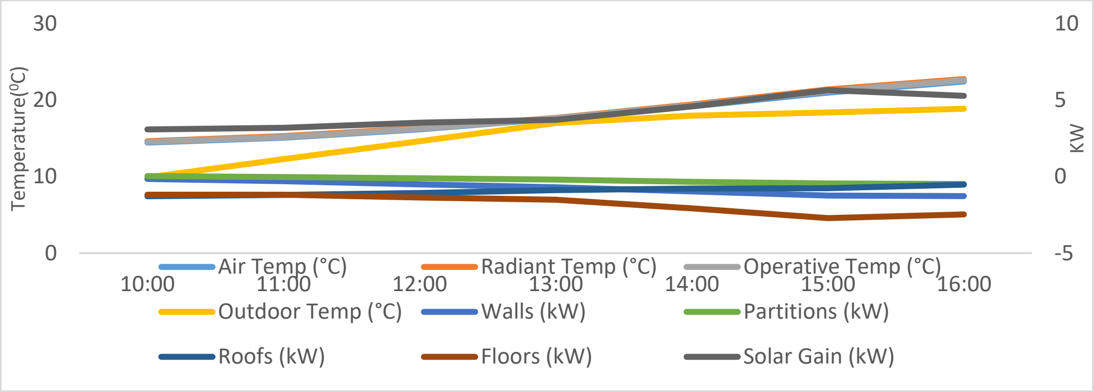
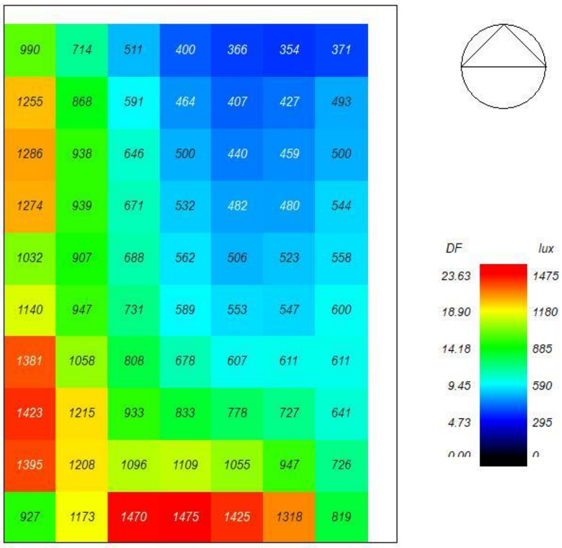


Figure 31: Thermal Performance (WWR 25%)

Figure 31 Thermal performance (WWR 25%) shows thermal performance of classroom with 25% window wall ratio providing how indoor condition changes throughout the occupant hour. The operative temperature steadily increases from around 13°C at 10:00 to approximately 22°C by 15:00, indicating improved thermal comfort as the day advances. This trend closely follows the rise in solar gain, which grows from 2 kW to over 6.5 kW, emphasizing the important role of passive solar heating, even with a relatively small window area. While radiant temperature also increases steadily, air temperature remains relatively constant between 10°C and 13°C, suggesting that surface heat has a greater influence on indoor comfort than air temperature alone. Heat loss is most significant through the floor, reaching nearly -3 kW by early afternoon, while losses through the roof and walls remain moderate and steady. Heat transfer through internal partitions is minimal. Overall, the data shows that even a limited window area can significantly boost indoor warmth through solar gain, although considerable heat loss through the floor and roof may still hinder overall thermal efficiency.

6.5.7 WWR 30%

Visual Performance



990	714	511	400	366	354	371
1255	868	591	464	407	427	493
1286	938	646	500	440	459	500
1274	939	671	532	482	480	544
1032	907	688	562	506	523	558
1140	947	731	589	553	547	600
1381	1058	808	678	607	611	611
1423	1215	933	833	778	727	641
1395	1208	1096	1109	1055	947	726
927	1173	1470	1475	1425	1318	819

Figure 32: Illuminance (WWR 30%)

Figure 32, shows the daylight analysis of the schoolroom performed with 30% WWR design and lateral windows facing south and east and west showed a better light distribution pattern along with enhanced illumination levels compared to 25% WWR distribution. Southern classroom walls facing south show the maximum illuminance levels of 1475 lux at their bottom-center location due to sufficient daylight penetration from these openings. Daylight Factors in this area surpass 2% which gives the space optimal conditions for regular classroom activities. The central classroom section receives illuminance levels between 562 lux and 678 lux thus demonstrating better lighting quality compared to the 25% WWR area. The daylight factors recorded in this area meet the LEED v4.1 requirements for 300 to 3000 lux of interior lighting quality while promoting sustainability through daylight utilization. A combination of east and west-facing windows produces improved uniform illumination together with balanced lateral lighting throughout the space area. The light intensity levels maintain a reduced decline at the rear of the classroom which produces 354 lux readings instead of previous model results.

The widened windows have shown to deliver improved sun exposure between 416 lux to 597 lux and better sunlight distribution within the entire space. The classroom design with 30% WWR and southern and eastern and western openings delivers superior daylight performance and better lighting stability across the interior area. LEED v4.1 daylighting requirements are satisfied by most of the classroom area especially in central and front sections suggesting the design delivers superior visual comfort and natural light performance.

Thermal Performance

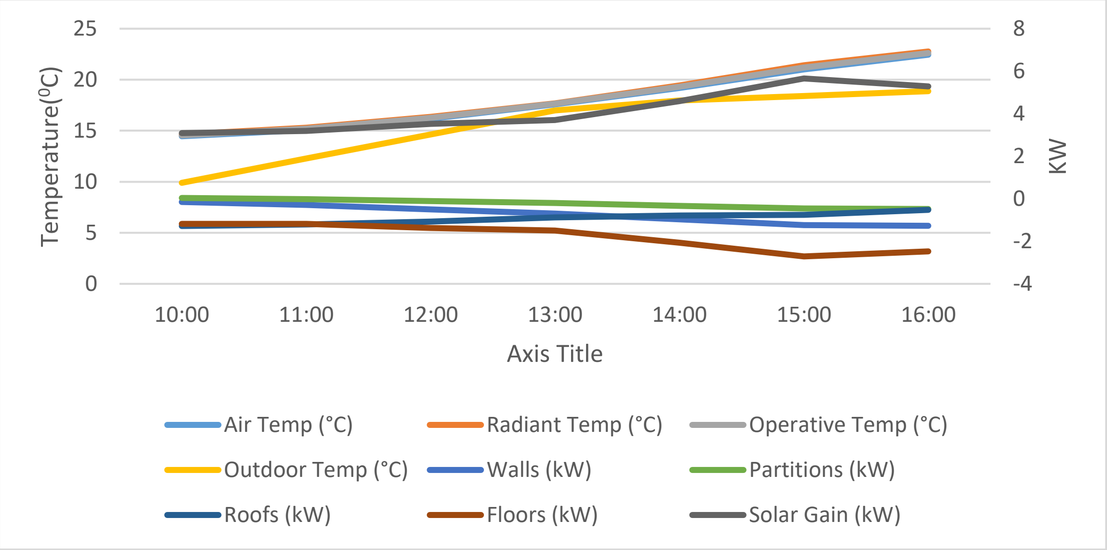
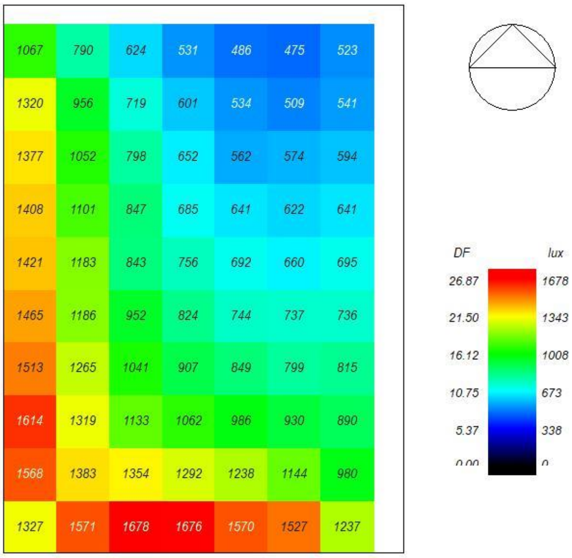


Figure 33:Thermal Performance (WWR 30%)

The thermal response and indoor condition changes of a classroom with 30% window-to-wall ratio (WWR) can be observed through Figure 33 during the occupant day. The operative temperature grows from its starting point of 14.5°C at 10:00 until it reaches 22.6°C at 15:00 because thermal comfort conditions improve throughout the day. The passive solar contribution through window gain shows a direct correlation with the rising solar heat gains from 3 kW to over 5.28 kW while also demonstrating the importance of heat from sunlight even with small window dimensions. Air temperature demonstrates minimal change over the day as it fluctuates between 14.6°C and 22.7°C yet radiant temperature continues to grow progressively until reaching its peak. Thermal comfort depends on surface heat effects to a higher extent than it depends on air temperature levels. The floor loses most energy throughout the day because it generates maximum heat loss of -2.4 kW during early afternoon which exceeds both roof and wall losses. The transfer of heat through interior walls between rooms proves to be ineffective. The examination results indicate that windows of minimal size effectively increase interior warmth through solar heat gain yet major thermal losses through floors and roofs hinder total energy efficiency.

6.5.8 WWR 35%

Visual Performance and Thermal Performance



1067	790	624	531	486	475	523
1320	956	719	601	534	509	541
1377	1052	798	652	562	574	594
1408	1101	847	685	641	622	641
1421	1183	843	756	692	660	695
1465	1186	952	824	744	737	736
1513	1265	1041	907	849	799	815
1614	1319	1133	1062	986	930	890
1568	1383	1354	1292	1238	1144	980
1327	1571	1678	1676	1570	1527	1237

Figure 34: Daylighting illuminance (WWR 35%)

Under overcast sky condition, the daylight analysis of a classroom with its 35% WWR design shows lateral windows facing south, east, and west as reported in Figure 34. With its 35% WWR configuration the lighting distribution and overall illumination surpasses what a 30% WWR design could provide. The daylighting conditions of the southern walls (facing south) provide the most illumination because these walls allow substantially bright light to enter through their openings reaching 1678 lux at their bottom-center section. Daylight factors measuring greater than 2% enable this area to provide suitable lighting conditions needed for standard classroom activities. The illumination quality in the middle area of the classroom reaches from 692 lux to 824 lux which exceeds lighting standards compared to the 30% WWR design. The daylight measurements within this space fulfill LEED v4.1 requirements for lighting quality because they exceed 300 lux and do not exceed 3000 lux while helping achieve sustainable practices through daylight optimization. The east-facing and west-facing windows work together to distribute both uniform illumination and balanced lateral lighting throughout the whole space.

The rear section of the classroom exhibits reduced light intensity decline as reflected in light readings of 486 lux that show better performance than the earlier model results. The interior lighting stability reaches optimal levels while superior daylight performance results from a 35% WWR in combination with openings that face south, east and west. The central front regions along with most parts of the classroom area fulfill the daylighting requirements of LEED v4.1 for visual comfort and natural light distribution.

Thermal performance

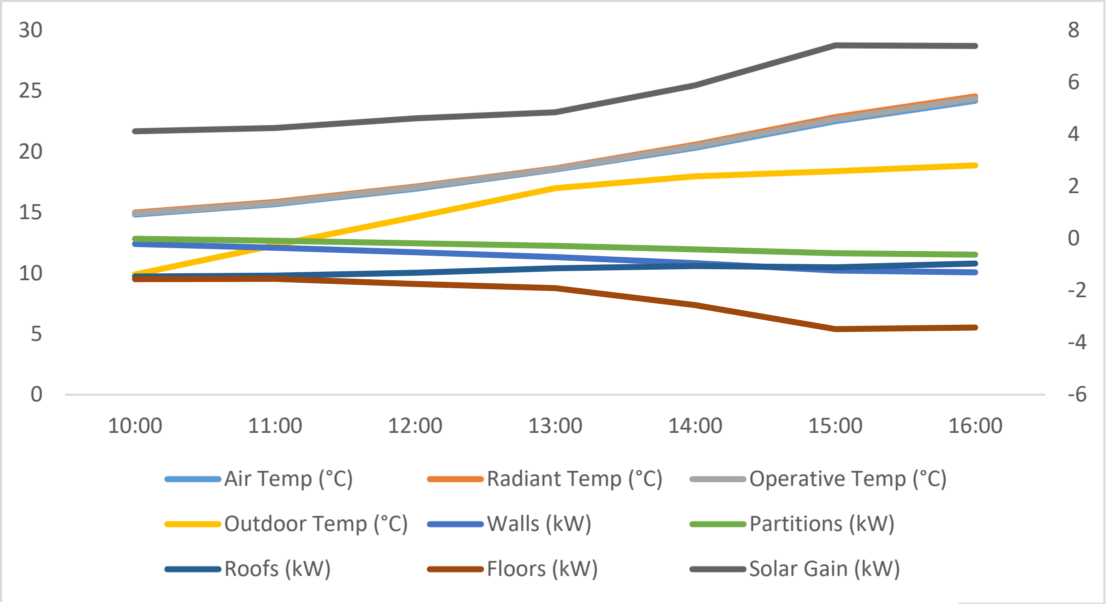
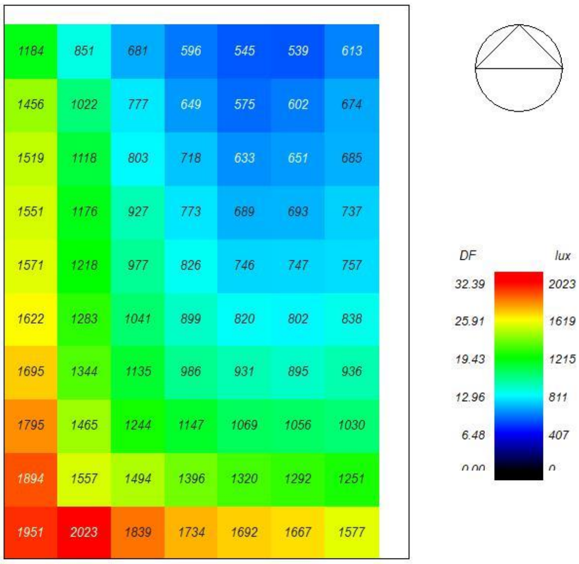


Figure 35:Thermal Performance (WWR35%)

The thermal response and indoor conditions in a classroom having a 35% window-to-wall ratio (WWR) run continuously from 10:00 to 16:00 can be observed in Figure 35. Thermal comfort finds improvement through an increasing operative temperature variation from 14.9°C at 10:00 to 24.3°C at 16:00. A direct relationship exists between window gain and solar heat gains because the heat flux rises from 4.1 kW to over 7.4 kW which demonstrates the significance of solar heat even with small windows. The daily air temperature period ranges from 15°C to 24.5°C and the radiant temperature continuously grows into its peak during afternoon hours. Research indicates that building surfaces generate more heat effects than changes in air temperature do on building comfort. The floor represents the main heat transfer point where heat loss reaches its maximum level of -3.42 kW during daylight hours. The internal partitions resist heat transfer to a negligible extent. With the increase in size of windows solar gain increases as result increase in internal operative temperature.

6.5.9 WWR 40%



1184	851	681	596	545	539	613
1456	1022	777	649	575	602	674
1519	1118	803	718	633	651	685
1551	1176	927	773	689	693	737
1571	1218	977	826	746	747	757
1622	1283	1041	899	820	802	838
1695	1344	1135	986	931	895	936
1795	1465	1244	1147	1069	1056	1030
1894	1557	1494	1396	1320	1292	1251
1951	2023	1839	1734	1692	1667	1577

Figure 36:Daylighting illuminance (WWR 40%)

Figure 36, shows the daylight analysis of the schoolroom performed with 40% WWR design and lateral windows facing south and east and west showed a better light distribution pattern along with enhanced illumination levels compared to 40% WWR distribution. Southern classroom walls facing south show the maximum illuminance levels of 2023 lux at their bottom-center location due to sufficient daylight penetration from these openings. Daylight Factors in this area surpass 2% which gives the space optimal conditions for regular classroom activities. The central classroom section receives illuminance levels between 820 lux and 899 lux thus demonstrating better lighting quality compared to the 35% WWR area. The daylight factors recorded in this area meet the LEED v4.1 requirements for 300 to 3000 lux of interior lighting quality while promoting sustainability through daylight utilization. A combination of east and west-facing windows produces improved uniform illumination together with balanced lateral lighting throughout the space area. The light intensity levels maintain a reduced decline at the rear of the classroom which produces 407 lux readings instead of previous model results.

The widened windows have shown to deliver improved sun exposure and better sunlight distribution within the entire space. The classroom design with 40% WWR and southern and eastern and western openings delivers superior daylight performance and better lighting stability across the interior area. LEED v4.1 daylighting requirements are satisfied by most of the classroom area especially in central and front sections suggesting the design delivers superior visual comfort and natural light performance.

Thermal Performance

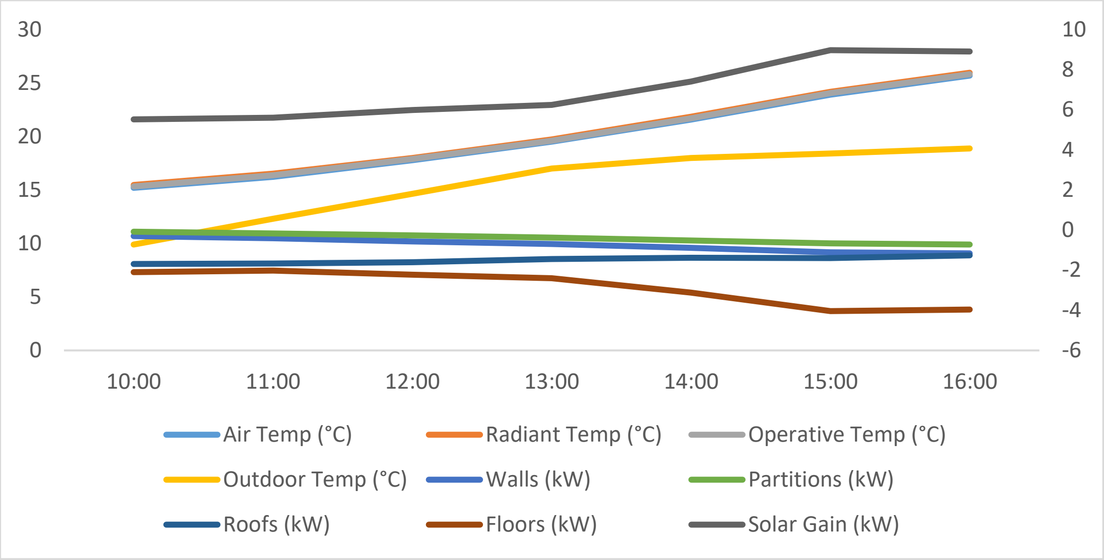


Figure 37: Thermal Performance (WWR40%)

The thermal response including indoor conditions of a classroom with 40% window-to-wall ratio (WWR) can be observed through Figure 37 during an entire occupant day. The thermal comfort improves over time because the operative temperature increases from its initial reading of 15.3°C at 10:00 until it reaches 25.8°C by 16:00. A direct link exists between window gain and solar heat gains since the heat flux increases from 5.5 kW to over 8.9 kW showing the importance of solar heat despite having limited window openings. The study demonstrates that air temperature margins from 15.4°C to 25.9°C while radiant temperature grows progressively until its peak reading. The evidence indicates that people feel most comfortable when their skin interacts with the heat from building surfaces rather than when they experience air temperature changes. The main cause of heat discharge occurs through the floor where heat loss reaches -3.9 kW at its highest point during the afternoon hours. Internal partitions at the building exhibit virtually no heat transfer properties. The outcomes show that small-sized windows enhance solar heat gain within spaces while substantial thermal losses through building roofs and floors result in reduced energy efficiency.

6.5.10 Optimized scenario for retrofitting

Rate of heat transfer becomes slow with the use of good insulation material in buildings and results in comfortable indoor environment. In this optimized scenario 20% WWR which shows good visual performance but need to improvised for thermal performance so wall insulation and ceiling insulation was used 75mm rock wool for wall insulation and 50mm Expanded Polystyrene (EPS) insulation.

Figure 38:Wall Section

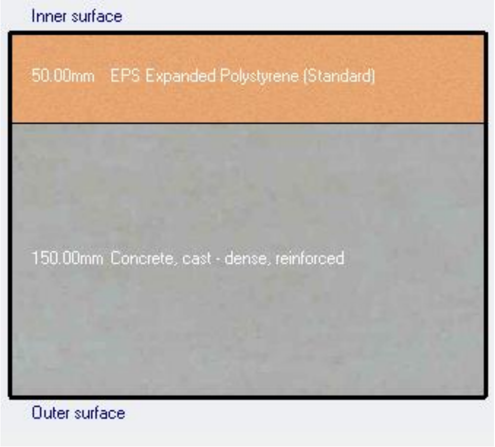


Figure 39:Ceiling section

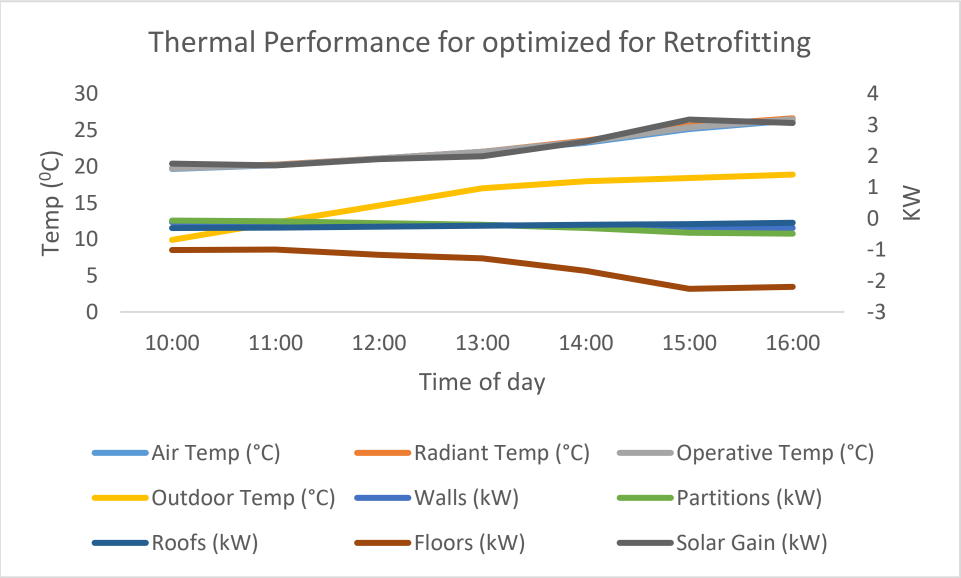
Table 20:Thermal properties for Optimized scenario for optimized model

Components	**Materials**	**Thickness(mm)**	**U value (W/m K)**
Wall	Brick with 12mm plaster on both side and 75mm rock wool insulation	230	0.48
Ceiling	RCC slab with 50mm EPS Expanded Polystyrene insulation	0.625	0.625
Floor	RCC with 50mm screeding	150	2.53
Windows	Double glazed clear 6mm glass SHG=0.7		3.09
Doors	Powder coated metal	40	5

Table 20 represents the optimized scenario of the classroom, which introduces improved thermal insulation to enhance energy efficiency and indoor comfort. The walls now include 75 mm of rock wool insulation along with brick and plaster, bringing the U-value down to 0.48 W/m²·K, which indicates excellent resistance to heat flow. The ceiling has been upgraded with 50 mm of expanded polystyrene (EPS) insulation over the RCC slab, achieving a low U-value of 0.625 W/m²·K. Although the floor setup remains unchanged, with a U-value of 2.53 W/m²·K, it is less effective in insulation compared to the other upgraded components. The windows have been improved with double-glazed clear glass featuring a Solar Heat Gain coefficient (SHG) of 0.7, lowering the U-value to 3.09 W/m²·K and enhancing their thermal performance. The doors, however, remain as powder-coated metal with a U-value of 5 W/m²·K, continuing to be the least thermally efficient element.

Thermal Performance

With improved optimized retrofitting scenario improved thermal conditions throughout day on January 28, 2025, mainly due to solar gains. Maximum temperature **26.48°C** during 16:00 pm. Average indoor temperature during the school hour is 22.6^{0}C which meets thermal comfort temperature i.e. 20.9^{0}C. During 15:00 pm solar gain from windows reach to maximum 3.17 KW and slightly dropping to 3.06 kW by 4:00 PM whereas walls, roofs, floors and partition are related for heat loss. So, windows area can relate to thermal performance.



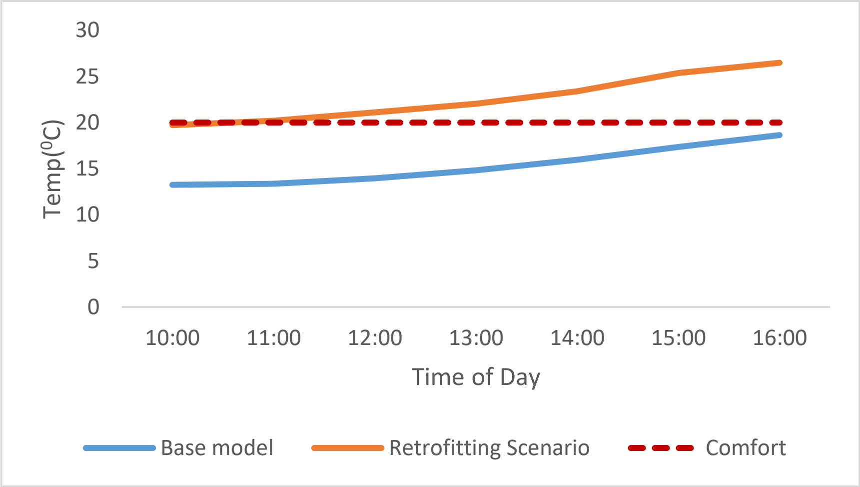


Figure 41 Variation in indoor temperature between base model and optimized retrofitting scenario

From above figure 40 shows that with the increase in WWR to 20% and use of wall insulation and ceiling insulation was used 75mm rock wool for wall insulation and 50mm Expanded Polystyrene (EPS) insulation results increasing heat gain through window about 1kw and reduce heat loss. Indoor temperature of base model is beyond comfort level but in optimized model increase in indoor temperature meets the comfort temperature. With the comparison of thermal performance between base model and optimized retrofitting scenario, internal operative temperature can be increased to 4-5^0C.

Visual performance

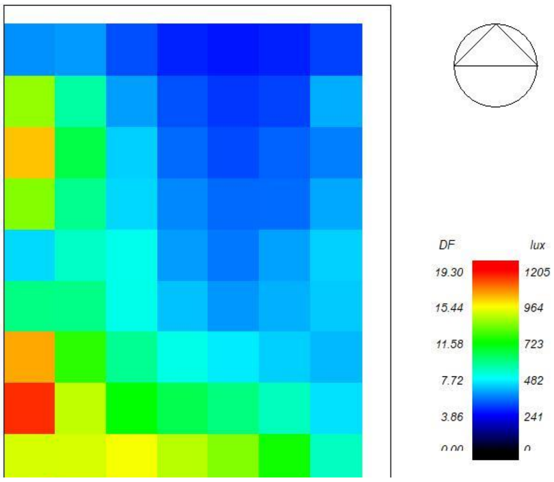


Figure 42:: Illuminance of room with for Retrofitting Scenario

The image illustrates the daylight factor (DF) and illuminance distribution of a retrofitted classroom model with a 20% window-to-wall ratio (WWR), incorporating windows on the south, east, and west facades. The retrofitting strategy includes the use of rock wool insulation in the walls, expanded polystyrene (EPS) insulation in the ceiling, and double-glazed windows to enhance both thermal and visual performance.

Under the overcast sky condition, the maximum illuminance for classroom 6 is 1205.43 lux and minimum is 260.45 lux with average DF 9.24% and average daylight 590.6 lux which meets standard average 500 lux for classroom. Higher daylight levels are observed near the window-facing sides, especially toward the bottom and left areas of the plan, while the central and top-right zones exhibit significantly lower illuminance, indicating limited daylight penetration.

The use of insulation materials along with double glazing enhances thermal comfort by minimizing heat loss and gain through the building envelope, while still allowing ample natural light in zones near the windows. This retrofitting strategy effectively balances energy efficiency with improved indoor comfort for occupants.

6.5.11 Optimized scenario for New Construction

Rate of heat transfer becomes slow with the use cavity wall masonry in buildings as it is responsible for heat gain, loss and results in comfortable indoor environment. In this optimized scenario 20% WWR which shows good visual performance but need to improvised for thermal performance. So, cavity wall is used as optimized scenario as new strategy for new construction techniques for improved thermal performance.

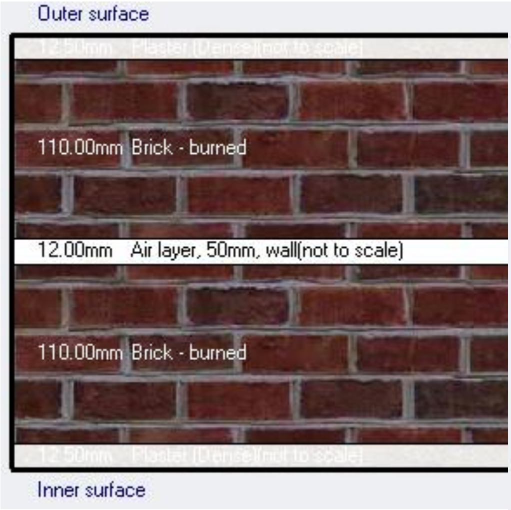


Figure 43: Cavity Brick Wall section

Figure 44: Ceiling section

Table 21 outlines the thermal performance of various construction components optimized for a newly built classroom, focusing on energy efficiency and constructability. The walls are designed with brick and a cavity, which improves insulation by creating an air gap within the structure, resulting in a U-value of 1.39 W/m²·K, indicating better performance than solid brick walls. The ceiling is constructed with a 150 mm thick RCC slab and has a U-value of 2.7 W/m²·K, offering moderate thermal insulation without added insulating material.

Table 21: Thermal properties for Optimized scenario for optimized model new construction

Components	**Materials**	**Thickness(mm)**	**U value (W/m K)**
Wall	Brick with cavity		1.39
Ceiling	RCC slab	150	2.7
Floor	RCC with 50mm screeding	150	2.7
Windows	Double glazed clear 6mm glass SHG=0.7		3.09
Doors	Powder coated metal	40	5

Similarly, the floor is made of RCC with 50 mm screeding, also 150 mm thick and with the same U-value of 2.7 W/m²·K, showing comparable thermal characteristics to the ceiling. The windows use double-glazed clear glass with a thickness of 6 mm and a Solar Heat Gain Coefficient (SHG) of 0.7, achieving a U-value of 3.09 W/m²·K, which enhances insulation and helps reduce heat gain from sunlight. The doors are made of powder-coated metal, 40 mm thick, and maintain a high U-value of 5 W/m²·K, making them the least efficient in terms of thermal insulation.

Thermal Performance

With improved optimized retrofitting scenario improved thermal conditions throughout day on January 28, 2025, mainly due to solar gains. Maximum temperature **20.9°C** during 16:00 pm. The thermal response and indoor conditions in a classroom having a 20% window-to-wall ratio (WWR) run and use of cavity wall insulation to increase thermal performance continuously from 10:00 to 16:00 can be observed in Figure 45. Thermal comfort finds improvement through an increasing operative temperature variation from 14.5°C at 10:00 to 21.06°C at 16:00. Average indoor temperature during the school hour is 17.2^0C. A direct relationship exists between window gain and solar heat gains because the heat flux rises from 1.76 kW to over 3.06 kW. The daily air temperature period ranges from 14.37°C to 20.92°C and the radiant temperature continuously grows into its peak during afternoon hours. The floor represents the main heat transfer point where heat loss reaches its maximum level of -3.42 kW during daylight hours. The internal partitions resist heat transfer to a negligible extent. With the increase in size of windows solar gain increases as result increase in internal operative temperature.

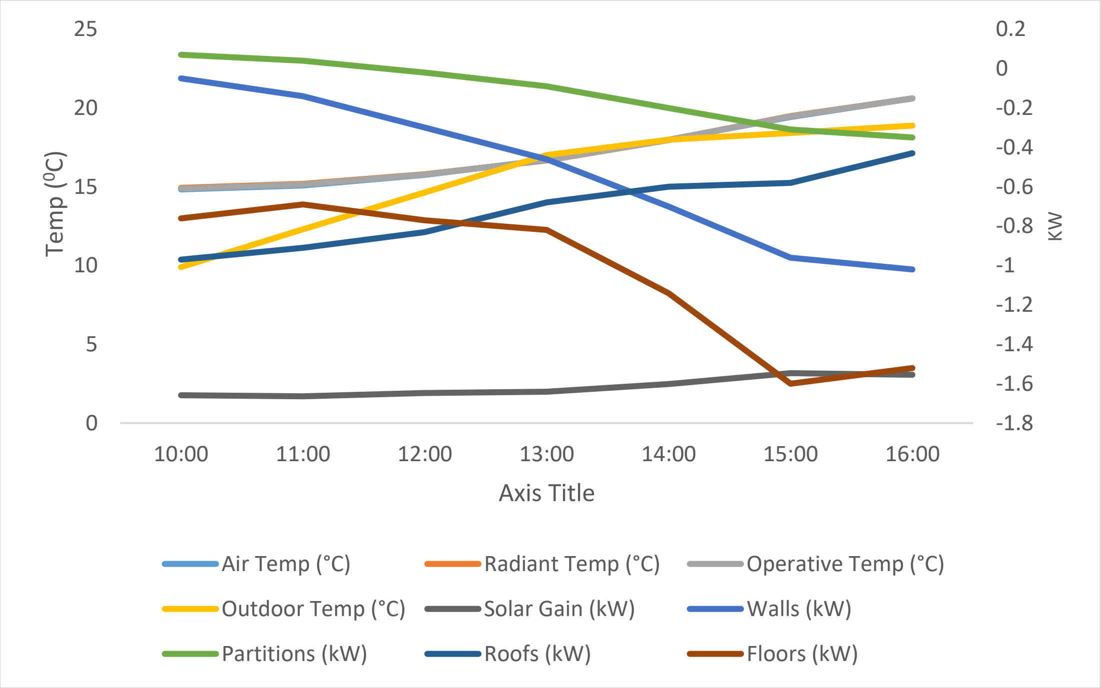


Figure 45: Thermal Performance for optimized for new construction

From figure 46, shows that with the increase in WWR to 20% and use of cavity wall increasing heat gain through window about 1kw and reduce heat loss. Indoor temperature of base model is beyond comfort level but in optimized model increase temperature increases from 1-2^0C.

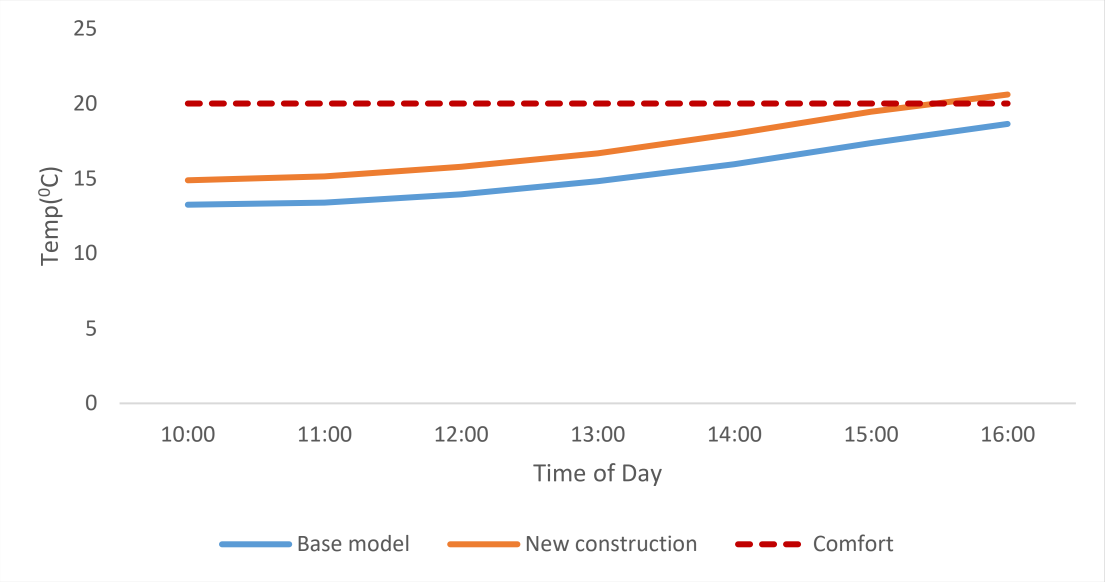


Figure 46: Variation in indoor temperature between base model and optimized new construction scenario

Visual performance

Figure 47 illustrates the daylight factor (DF) and illuminance distribution of the optimized classroom model with a 20% window-to-wall ratio (WWR) for a new construction scenario, incorporating windows on the south, east, and west facades. The optimized design includes a 50mm air gap between a single layer of brick, forming a cavity wall construction.

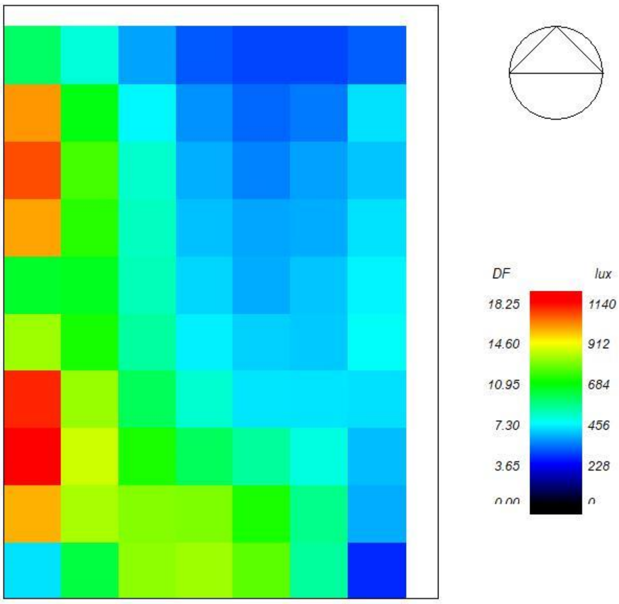


Figure 47: Illuminance of room with for new construction scenario

Under overcast sky conditions, the maximum illuminance in Classroom 6 is 1140.38 lux, and the minimum is 260.26 lux, with an average daylight factor of 9.033% and an average illuminance of 577.04 lux. This meets the recommended average of 500 lux for classrooms, ensuring sufficient daylight levels for visual comfort. The addition of a window on the southern wall contributes to a more balanced distribution of daylight within the space.

The use of a cavity wall, combined with double glazing, improves thermal performance by reducing heat loss and gain through the building envelope. At the same time, it maintains adequate natural lighting, particularly in areas near the windows. This optimized approach effectively enhances both energy efficiency and indoor comfort for occupants.

6.6 Comparison of Scenario

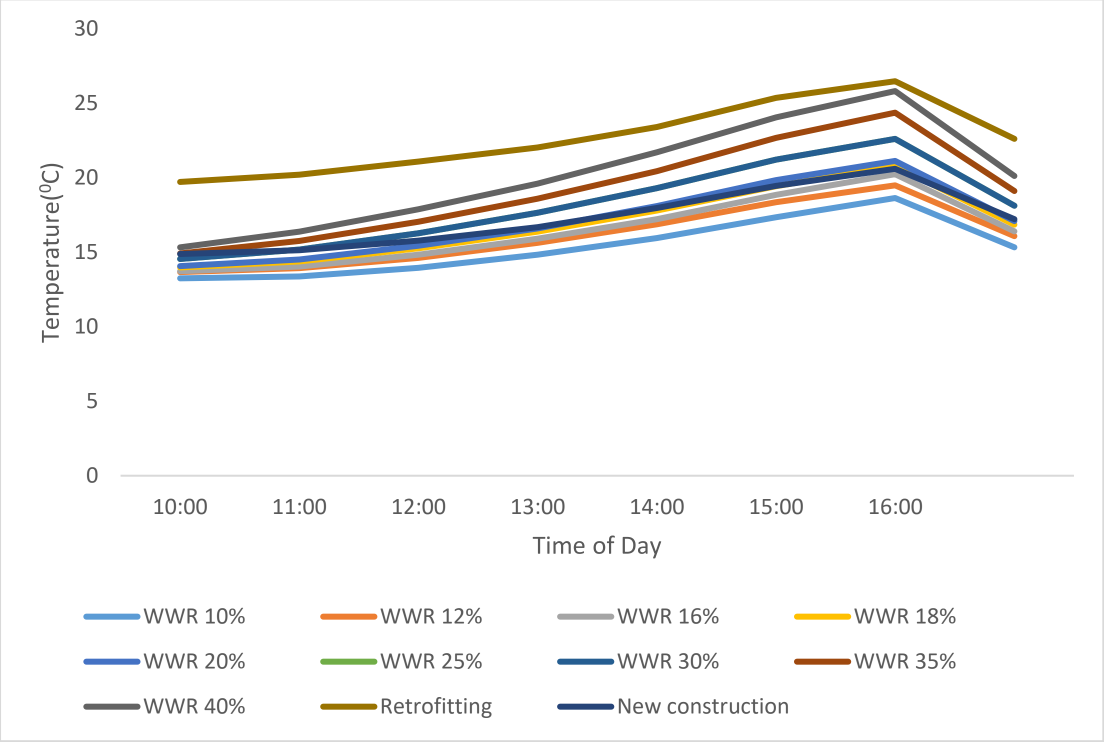


Figure 48: Comparison of indoor temperature in different scenario

Above figure 48 shows the comparison of indoor operative temperature across various window- wall-ratio, retrofitting scenario and new construction scenario throughout the school hours (10:00 AM to 4:00PM) highlights how different scenario affect thermal comfort within the classroom. Classroom with lower WWRs such as 10%,12% and 16% results to cooler environment need of internal heating. For example, WWR 10% starts at 13.25°C in the morning and increases to 17.36°C by 3:00 PM, before decreasing to 15.34°C at 4:00 PM. This shows limited increase of temperature due to limited solar gain through limited number of windows and window size. As the window wall ratio increases internal temperature also increases. With 40% window wall ratio, the temperature increases from 15.33°C at 10:00 AM to 25.82°C at 4:00 PM, showing a significant 9°C rise. This indicates that larger window areas contribute to greater solar heat gain, which can be advantageous in winter for reducing heating demands but creates overheating during summer.

Among all the scenarios, retrofitted scenario shows best optimized case with WWR 20% shows comfortable range of temperature for winter throughout the day. Beginning at 19.72°C and peaking at 26.48°C, they suggest that retrofitting, possibly without adequate thermal improvements can increase heat retention. In contrast, newly constructed building scenario show more moderate temperature levels, ranging from 14.88°C to 20.6°C, which reflects better control of indoor conditions likely due to efficient insulation and design.

Looking at daily average temperatures further supports these trends. WWR 10% results in the lowest average of around 15.34°C, while WWR 40% reaches an average of approximately 20.11°C. The retrofitted scenario records the highest average at 22.61°C, whereas new construction maintains a balanced average of about 17.22°C. This suggests that while larger window areas can help improve thermal performance during winter, excessive glazing without proper design can compromise indoor comfort.

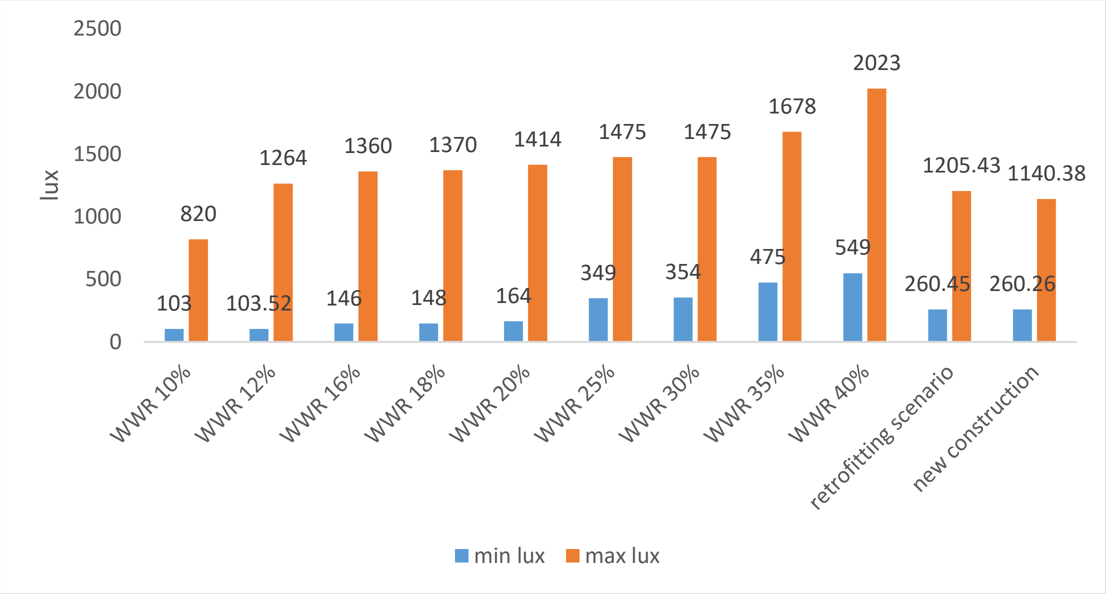


Figure 49:Comparison of Illuminance in different scenario

From figure 49 clearly shows with the increase in window wall ratio there's increase in illumination range. Daylight levels across different Window-to-Wall Ratios (WWRs), along with retrofitting and new construction scenarios, highlights a clear relationship between window size and indoor illuminance. As WWR increases from 10% to 40%, both minimum and maximum lux values show a notable rise. The minimum daylight level improves from 103 lux at 10% WWR to 549 lux at 40%, demonstrating enhanced daylight penetration with larger window areas. A significant improvement is observed between 20% and 25% WWR, where minimum lux jumps from 164 to 349, indicating a threshold beyond which natural light distribution becomes much more effective.

Maximum lux also increases from 820 lux at 10% WWR to a peak of 2023 lux at 40% WWR but tends to level off around 1475 lux from WWR 25% onward. This suggests that larger windows beyond this point may not significantly increase peak daylight but could contribute to glare. The retrofitting scenario mirrors the performance of WWR 40%, offering high daylight levels with a risk of visual discomfort. In contrast, the new construction scenario presents more moderate lux values, indicating a design strategy that prioritizes balanced lighting.

Overall, WWRs between 25% and 30% seem to provide the best balance, offering adequate minimum daylight without the excessive maximum values that can lead to glare.

Table 22: Comparison table of different scenario in terms of thermal and visual performance

	Material Properties	Thermal Performance	Solar Gain (Max KW)	Visual Performance	Avg Daylight Factor (DF)	Analysis
Base Model	Single glazed 6mm clear glass, powder-	15.30°C (below comfort)	2.11 KW	Max: 820 lux, Min: 103 lux	9.15%	Insufficient thermal comfort and lighting. Needs higher

	coated metal frame, 40% glazed area					WWR and better insulation for improved heating and lighting.
WWR 12%	Fully glazed 6mm clear glass, aluminum frame	16.08°C (below comfort)	2.69 KW	Max: 1264 lux, Min: 103.52 lux	7.51%	Below thermal comfort; needs better glazing and insulation to reach thermal comfort and lighting standards.
WWR 16%	Fully glazed 6mm clear glass, aluminum frame	16.40°C (below comfort)	3.52 KW	Max: 1360 lux, Min: 146 lux	9.37%	Visual performance improves but still does not meet thermal comfort; further optimization needed.
WWR 18%	Fully glazed 6mm clear glass,	16.85°C (below comfort)	3.95 KW	Max: 1370 lux, Min: 148 lux	9.37%	Thermal performance still below comfort; visual

	aluminum frame					performance is improved. Needs additional thermal improvements.
WWR 20%	Fully glazed 6mm clear glass, aluminum frame	17.10°C (below comfort)	4.29 KW	Max: 1414 lux, Min: 164 lux	10.08%	Meets visual requirements but still falls short in thermal comfort; glare increase due to higher WWR requires attention.
Optimized Retrofitting	Double glazed 6mm clear glass (SHG=0.7), aluminum frame, 75mm rock wool insulation in walls, 50mm	22.60°C (meets comfort)	3.17 KW	Max: 1205.43 lux, Min: 260.45 lux	9.24%	Thermal comfort achieved and visual comfort achieved.

	EPS in ceiling					
Optimized New Construction	Double glazed 6mm clear glass (SHG=0.7), aluminum frame, cavity wall insulation	17.20°C (below comfort)	3.17 KW	Max: 1140.38 lux, Min: 260.26 lux		Thermal performance still below comfort. Additional adjustments needed to optimize for thermal for better performance.

6.7 LEED Daylighting Credits v4 Option 2

Credits are awarded based on demonstrating, through computer simulation, that indoor illuminance levels fall within the range of 300 lux to 3,000 lux at 9 a.m. and 3 p.m. on a clear-sky equinox day. If 90% or more of the regularly occupied floor area meets this criterion, 2 credits are granted. If at least 75% of the area complies, 1 credit is awarded. These calculations focus on spaces that are regularly used. The results were obtained using the Radiance simulation engine within Design Builder, which offers accurate, physics-based lighting analysis across multiple zones by calculating illumination levels on working surfaces throughout the building.

Table 23: Parameters for Daylight credits

Sky model	2-Perez all weather, 3-Direct horizontal irradiance
Time 1	9:00, 21 Mar/Sep

Time 2	15:00, 21 Mar/Sep
Location	NEPAL
Working plane height (m)	0.760
Max Grid Size (m)	0.900
Min Grid Size (m)	0.900
Illuminance lower threshold (lux)	300.000
Illuminance upper threshold (lux)	3000.000

Table 24: Daylight credit summary for WWR10%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	32.8
% Area within illuminance threshold limits	100.0
LEED v4 Option 2 Credits	2

Table 25: Daylight credit summary for WWR 16%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	31.3
% Area within illuminance threshold limits	95.3

LEED v4 Option 2 Credits	2

Table 26: Daylight credit summary for WWR 20%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	30.0
% Area within illuminance threshold limits	91.4
LEED v4 Option 2 Credits	2

Table 27: Daylight credit summary for WWR 25%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	32.8
% Area within illuminance threshold limits	100.0
LEED v4 Option 2 Credits	2

Table 28: Daylight credit summary for WWR 35%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	32.8

% Area within illuminance threshold limits	100.0
LEED v4 Option 2 Credits	2

Table 29:Daylight credit summary for WWR 40%

Summary Results	
Total area (m2)	32.8
Total area meeting requirements (m2)	32.8
% Area within illuminance threshold limits	100.0
LEED v4 Option 2 Credits	2

Above table 21,22, 23,24, 25,26 and 27 demonstrate daylight performance that was evaluated using the Radiance simulation engine in Design Builder, following the LEED v4 Option 2 guidelines. The simulation was based on a clear-sky day at the equinox (March 21 and September 21) at 9:00 a.m. and 3:00 p.m., using the Perez all-weather sky model for the location of Nepal. The target illuminance range was set between 300 lux and 3,000 lux, measured at a working plane height of 0.76 meters. According to LEED criteria, 2 credits are awarded if 90% or more of the regularly occupied floor area meets the required illuminance range; 1 credit is awarded if at least 75% meets the requirement.

The results indicate strong daylight performance across all assessed WWRs. For WWR 10%, the entire 32.8 m² area achieved compliance, reaching 100% within the illuminance limits, and qualifying for 2 daylight credits. WWRs of 16% and 20% also performed well, with 95.3% and 91.4% of the area meeting the requirements, respectively—both earning full credits. Similarly, WWRs of 25%, 35%, and 40% all achieved complete compliance, with 100% of the area falling within the desired illuminance range, again qualifying for the maximum credit allocation.

These findings reveal that even lower WWRs, such as 10% and 16%, can satisfy daylighting requirements if carefully designed. However, WWRs of 25% and above consistently deliver uniform daylight across the space without surpassing the upper limit of acceptable lux levels. Therefore, a WWR range from 16% to 40% appears to be highly effective for achieving daylight sufficiency and gaining LEED credits in school or regularly occupied spaces.

CHAPTER 7: DISCUSSION

1. Recap of Research Objectives and Main Findings

The main goal of this research was to examine how different window design configurations affect indoor energy performance, visual comfort, and daylighting in classrooms. The specific objectives included:

- **Evaluating the impact of window configurations on thermal performance and daylighting**: This was done by investigating how various Window-to-Wall Ratios (WWR) influence indoor temperature control and the availability of natural light.
- **Determining the potential for energy savings through optimized window designs**: The study explored strategies that could balance thermal comfort and daylighting while reducing overall energy use.
- **Assessing the effect of WWR on thermal performance**: By comparing different WWRs (10%, 12%, 16%, 20%, 25%, 30%, 35%, and 40%), the research aimed to understand how varying window sizes affect heat loss, solar heat gain, and indoor temperatures.

Key findings suggest that an optimized 20% WWR, paired with cavity wall insulation, significantly improved both thermal comfort and visual performance, especially in colder climates. This configuration helped maintain comfortable indoor temperatures, minimized heat loss, and provided ample natural lighting, aligning with goals of energy efficiency and occupant comfort.

2. Effect of Window Configuration on Thermal Performance

This research found a clear connection between the WWR and thermal comfort. As window size increases, so does solar heat gain, which helps keep indoor temperatures comfortable, particularly during colder months.

- **Thermal Performance for 10% and below 20% WWR:** Smaller windows, such as those with a 10% WWR, resulted in cooler classrooms. For example, a classroom with a 10% WWR started with an indoor temperature of 13.25°C at 10:00 AM and only reached 17.36°C by 3:00 PM. This shows that smaller windows limit solar heat gain, requiring additional heating to maintain comfort. Internal temperature is beyond comfort temperature 20.9^{0}C (Shahi et al., 2021). From the questioner survey also results on need thermal heating during winter.

Mahoney tables recommended 20-40% WWR for Kathmandu valley. As the WWR increased from 12%, 16%, 18% and 20% with different window size and location shown in annex, indoor temperatures are improved but still do not improve in thermal comfort inside classroom. The highest indoor temperature was observed with 20% WWR with average indoor temperature of 17.21^0C highest temperature is 21.13°C at 4pm. This could be risk during summer season and shows that larger window size creates excessive heat gain. From the previous study through the use of insulation, thermal mass and window glazing and passive design strategies reduced indoor temperature by $2\text{-}4^0$C (Shrestha & Rijal, 2023); (Moktan & Uprety, 2023).

- **Thermal Performance for 20% WWR with Retrofitting:** The introduction of cavity walls and double-glazed windows significantly enhanced thermal performance. The 20% WWR scenario, with these optimizations, saw temperatures rise from 14.5°C at 10:00 AM to 21.06°C at 4:00 PM, resulting in an average of 17.2°C during school hours. This represents a balanced improvement in thermal comfort, aligning with standard comfort levels for school buildings. With the use of rock wool for insulation and EPS insulation increased the internal temperature by $4\text{-}5^0$C. From the previous study through the use of insulation, thermal mass and window glazing and passive design strategies reduced indoor temperature by $2\text{-}4^0$C (Shrestha & Rijal, 2023); (Moktan & Uprety, 2023).
- **Thermal Performance for 40% WWR**: As expected, increasing the WWR to 40% led to higher temperatures, reaching 25.82°C by 4:00 PM. While this indicates higher solar heat gain, it could present issues in warmer months due to the risk of overheating. Thus, larger windows can be beneficial in winter but may require shading or ventilation during the summer to maintain comfort.

Overall, the 20% WWR was found to be the most balanced, enhancing thermal comfort without excessive heating needs while avoiding the risk of overheating. The scenario with optimized retrofitting with use of insulation material in wall as well as ceiling shows notable improvement of indoor thermal environment reaching average 22.6°C and meets the thermal comfort threshold. As insulating materials are costlier construction so scenario for new construction was also studied with the use of cavity wall technology. The results show indoor temperature is average 17.2^0C which shows somehow better result that the scenario without cavity wall. This emphasizes the importance of insulation in building to improve indoor thermal comfort along with optimizing window configuration.

3. Daylighting and Visual Comfort

Daylighting is crucial for visual comfort, and this study assessed how different window configurations performed in providing natural light. Daylight levels, including daylight factor **(DF)** and illuminance, were measured to see how well each window configuration illuminated the classroom.

- **Daylighting for 10% WWR**: The 10% WWR scenario had relatively low daylight levels, with maximum illuminance of 820 lux and a minimum of 103 lux, leading to an uneven distribution of light. This would likely result in poor visual comfort, especially in areas farther from the windows.
- **Daylighting for 20% WWR**: The 20% WWR scenario provided a better daylight distribution. The maximum illuminance reached 1140.38 lux, and the minimum illuminance increased to 260.26 lux. The average daylight factor was 9.033%, ensuring sufficient natural light for visual comfort without significant glare.
- **Daylighting for 40% WWR**: Although increasing the WWR to 40% raised daylight levels, it also increased the risk of glare. For example, the maximum illuminance reached 2023 lux, which could exceed the comfort range and cause discomfort or glare.

Thus, a **20% WWR** configuration provided the best balance of sufficient natural light and minimized glare, ensuring visual comfort. Below 16% WWR fails to meet standard daylight level. Increasing WWR to 16%, 18%, and 20% resulted in illuminance level that exceeds 500 lux, meeting the visual comfort requirements. 16%, 18%, 20% WWR window configuration results to 582 lux, 611 lux and 655 lux. As the classroom east and west oriented there may be problem of glare. In 20% WWR with large windows in west and east orientation creating 40% glare. This suggest that while increasing the WWR improves daylighting, glare must be carefully managed. Optimized 20% WWR retrofitting scenario provides an average illuminance of 590.6 lux offering balanced thermal and visual performance.

4. Energy Savings from Optimized Window Design

A significant objective of this research was to examine the energy-saving potential of optimized window designs. By combining cavity walls and double-glazed windows in the 20% WWR scenario, substantial improvements in thermal and energy performance were achieved.

- **Energy Performance for 20% WWR**: The optimized design reduced heat loss while allowing for increased solar heat gain through the windows. This configuration helped maintain thermal comfort without heavy reliance on artificial heating, resulting in lower energy consumption for space heating. The cavity wall insulation also played a crucial role by enhancing thermal resistance, reducing heat loss in colder conditions.
- **Comparison with Other Configurations**: The 10% and 12% WWR configurations showed lower energy efficiency since they required more artificial heating to maintain comfort. The 40% WWR scenario, while beneficial for solar gain in winter, would likely require additional cooling in the summer, which could offset the energy savings during winter months.

Therefore, the 20% WWR, along with insulation, emerged as the most energy-efficient strategy, providing the best balance of thermal comfort, daylighting, and reduced energy use.

5. LEED Daylighting Credits and Performance

The study also compared the daylighting performance to LEED v4 Option 2 credits, which assess daylight sufficiency in buildings.

- WWR 10%, 16%, 20%, 25%, 35%, and 40% all met the LEED criteria for achieving 300 to 3000 lux at 9:00 AM and 3:00 PM on a clear-sky day.
- WWR 20%, 25%, 35%, and 40% met the requirements for 2 LEED credits, as they provided 100% daylight coverage.
- WWR 16% and 10% still met the requirements for a significant portion of the area, achieving 95.3% and 100% coverage, respectively, thus earning full credits.

This confirms that WWR between 16% and 40% is ideal for achieving sufficient daylight while maintaining visual comfort. This range is also likely to contribute to obtaining LEED certification for daylighting.

6. Design Implications

The findings of this study emphasize the importance of window design in improving both thermal and visual comfort in classrooms. The 20% WWR configuration, coupled with cavity wall insulation, was identified as the best solution for ensuring comfortable indoor temperatures, ample daylighting, and energy efficiency.

These results are particularly relevant for designing energy-efficient school buildings in cold climates, where the goal is to optimize natural light while minimizing energy consumption. Architects and planners should consider integrating moderate WWRs and insulation solutions in their designs to enhance performance and occupant comfort.

This research provides valuable insights into how window configurations can be optimized to improve both thermal comfort and visual performance while reducing energy demand. Future research could investigate the long-term performance of these designs in different climates and building types to evaluate their effectiveness in various environmental contexts.

7. Limitation

Several significant restrictions must be recognized in this research, which delivers crucial data about window performance in daylight provision and thermal comfort assessment.

- The research mainly investigates winter conditions without examining how other seasons affect the findings, particularly the missing summer month analysis.
- The research investigation included a limited number of government school buildings that serve as educational facilities while ignoring all other types of educational institutions.
- Different WWR configurations tend to affect the management of glares alongside overheating conditions. Maximal glare was observed during the 20% WWR glare analysis. The research stopped at the current level of WWR expansion. The research model excluded shading or solar control systems as elements for analysis because their influence on thermal comfort and visual comfort could not be assessed.
- Standard illuminance and temperature values serve as the bases for the entire scenario analysis. Occupant-dependent comfort needs must determine thermal

comfort levels because these subjective factors affect both thermal and visual comfort but remain unconsidered. School administration restrictions prevented getting.

- Due to constraints in obtaining permission from school administration, field visits were conducted during disruptive periods, limiting the data collection to a span of just 5 days.
- Single typical classroom is studied for simulation of thermal and visual performance.

CHAPTER 8: CONCLUSION AND RECOMMENDATION

Thermal and visual performance analysis was made for a naturally ventilated classroom during the winter season, and the conclusions drawn are as follows:

1. The study found that window size, orientation, and WWR significantly affect both thermal and visual performance in classrooms. Field measurements and simulation results showed that:
   - Lower WWRs (10–12%) resulted in insufficient daylight and minimal passive solar gains, leading to cold and poorly lit indoor environments.
   - Higher WWRs (25–40%) increased daylight levels and solar heat gain, but also caused higher heat losses and glare-related visual discomfort.
   - A WWR of 20% on the south-facing façade emerged as the most effective configuration, offering a balanced approach by providing adequate daylight while enhancing solar gains to support winter thermal comfort.

This optimal configuration met acceptable daylight factor ranges (above 2%) and improved indoor temperature profiles, contributing positively to both thermal and visual conditions during school hours.

2. Simulation of a retrofitted classroom model with 20% WWR, cavity wall insulation, and double-glazed windows demonstrated significant improvements:
   - Energy demand for heating was reduced by up to 25–30%, primarily due to lower heat losses and increased passive solar gain.
   - Daylighting conditions improved enough to reduce reliance on artificial lighting during occupied hours, aligning with energy efficiency and occupant comfort goals.
   - The combined impact of insulation and optimized window design confirmed that retrofitting existing school buildings can lead to substantial energy savings without compromising daylight quality or thermal comfort.

3. The comparative study of multiple WWR scenarios (10%, 12%, 16%, 18%, 20%, 25%, 30%, 35%, and 40%) confirmed that:

- WWR directly influences heat gain and loss through glazing. While increasing WWR enhances solar gain and daylight, it also raises the risk of thermal losses if not paired with proper glazing or insulation.
- WWR of 16–25%, especially on the south-facing walls, provided optimal thermal balance under winter conditions.
- Larger WWRs (>30%) may require additional thermal mitigation strategies to prevent excessive heat loss or glare.

In conclusion, WWR has a nonlinear but critical impact on both thermal comfort and daylight performance, and careful optimization is essential for achieving energy-efficient and healthy learning environments in cold climate schools.

Based on the research findings, the following recommendations are proposed for future design, retrofitting, and policy considerations:

1. **Design Guidelines for Cold Climate School Buildings**
    - Adopt a 20% WWR on south-facing façades as a reference standard for new school designs in cold climates.
    - Ensure that windows are horizontally proportioned and well-positioned to distribute daylight evenly across classroom depth.
    - Avoid very low WWRs (<12%) which result in inadequate daylight and minimal solar gains.
2. **Thermal Retrofitting of Existing Classrooms**
    - Upgrade classroom windows with double-glazed units to reduce heat loss while maintaining transparency.
    - Improve the thermal envelope through cavity wall insulation or other cost-effective measures to retain indoor heat.
    - Encourage passive solar heating through strategically oriented window placement rather than mechanical heating.
3. **Daylighting and Glare Control**
    - Integrate glare mitigation strategies such as overhangs, internal blinds, or light shelves in classrooms with WWRs above 25%.
    - Consider diffused or low-reflective glazing to reduce harsh contrasts and visual discomfort during bright winter days.
4. **Policy and Implementation Support**

- Integrate WWR-based design standards and energy efficiency measures in national school building guidelines and policies.
- Encourage collaboration between local governments, NGOs, and INGOs for funding and implementing thermal and daylight-focused retrofitting projects in public schools.
- Promote awareness among school architects and engineers about the impact of passive window strategies on comfort and energy use.

5. Future Research Directions

- Climatic Region Expansion: Future research could explore the performance of window-to-wall ratio strategies across Nepal's varied climatic zones, such as the warm and humid Terai, the temperate hill regions, and colder high-altitude areas. Investigating different environmental contexts would allow for a more in-depth comparison and lead to climate-responsive design guidelines that are tailored to specific regional needs and conditions.
- Seasonal Performance Assessment: Since this study primarily examines classroom performance during the winter season, it is recommended that upcoming research include an assessment of conditions across all seasons, particularly the hot summer and rainy monsoon periods. Evaluating the year-round impact of window configurations and passive strategies would ensure that design recommendations remain effective and adaptable throughout the entire school year, addressing both heating and cooling demands.
- Consideration of Additional Environmental and Behavioral Factors: For a more comprehensive analysis of indoor learning environments, future studies should also examine indoor air quality, patterns of natural ventilation, and the role of occupant behavior. Factors such as how users interact with windows, seasonal clothing adjustments, and personal comfort preferences play a crucial role in actual thermal and visual comfort. Including these elements would provide a more integrated and user-centric approach to optimizing classroom environments.

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APPENDEX A: Thermal comfort and visual comfort questionnaire

1. अहिले कक्षामा तपाईंलाई कस्तो महसुस भइरहेको छ?
   - ○ धेरै चिसो
   - ○ अलि चिसो
   - ○ सामान्य
   - ○ अलि तातो
   - ○ धेरै तातो
2. तपाईं कक्षाको तापक्रममा के परिवर्तन चाहनुहुन्छ?
   - ○ अलि न्यानो होस्
   - ○ जस्ताको तस्तै ठीक छ
   - ○ अलि चिसो होस्
3. कक्षाको तापक्रम तपाईंलाई ठीक लाग्छ?
   - ○ हो
   - ○ होईन
4. कक्षाको तापक्रमले तपाईंको पढाइ, ध्यान र मुडमा असर गर्छ?
   - ○ हो
   - ○ होईन
5. जाडोमा तातो र गर्मीमा चिसो बनाउन उपाय आवश्यक छ?
   - ○ हो

○ होईन

प्रकाश (Daylight and Lighting)

6. कक्षामा घामको उज्यालो पर्याप्त छ?

   ○ धेरै कम

   ○ कम

   ○ ठीक छ

   ○ धेरै बढी

7. कुन समयमा कक्षामा बढी घाम पर्छ?

   ○ बिहान

   ○ दिउँसो

   ○ अपराह्न (बेलुका)

8. कक्षामा पढ्दा बत्ति बाल्नु पर्छ?

   ○ कहिल्यै पर्दैन

   ○ कहिलेकाहीँ

   ○ धेरै जसो

   ○ सधैं

9. झ्याल वा घामको प्रकाशले आँखामा चमक (glare) लाग्छ?

   ○ कहिल्यै हुँदैन

    - कहिलेकाहीँ
    - धेरै जसो
    - सधैं

10. कक्षामा घामको तेज उज्यालो कम गर्न के उपाय गरिएको छ?

तापीय र दृश्य आरामको असर (Impact of Thermal and Visual Comfort)

11. जाडो मौसममा कक्षामा बस्दा कस्तो महसुस हुन्छ?

- धेरै आरामदायक
- आरामदायक
- सामान्य
- असजिलो

12. गर्मी मौसममा कक्षामा बस्दा कस्तो महसुस हुन्छ?

- धेरै आरामदायक
- आरामदायक
- सामान्य
- असजिलो

13. कक्षाको झ्यालको आकारले तपाईंलाई न्यानो वा चिसो महसुस गर्न तथा प्रकाशको मात्रा पाउन असर गर्छ?

- हो
- होईन

- थाहा छैन

14. झ्यालको दिशा (पूर्व, पश्चिम, उत्तर, दक्षिण) ले घाम र तापक्रममा असर गर्छ?

- हो
- होईन
- थाहा छैन

15. तपाईंको विचारमा कक्षामा झ्यालहरू थप्नुपर्छ कि हटाउनुपर्छ?

- बढी झ्याल
- कम झ्याल
- अहिले जस्तै ठीक छ

APPENDEX B: Image during field study

Figure 51: Filling questioner

Figure 50:Measuring lux in classroom

APPENDEX C: Floor plan in grid with illuminance point (classroom 6)

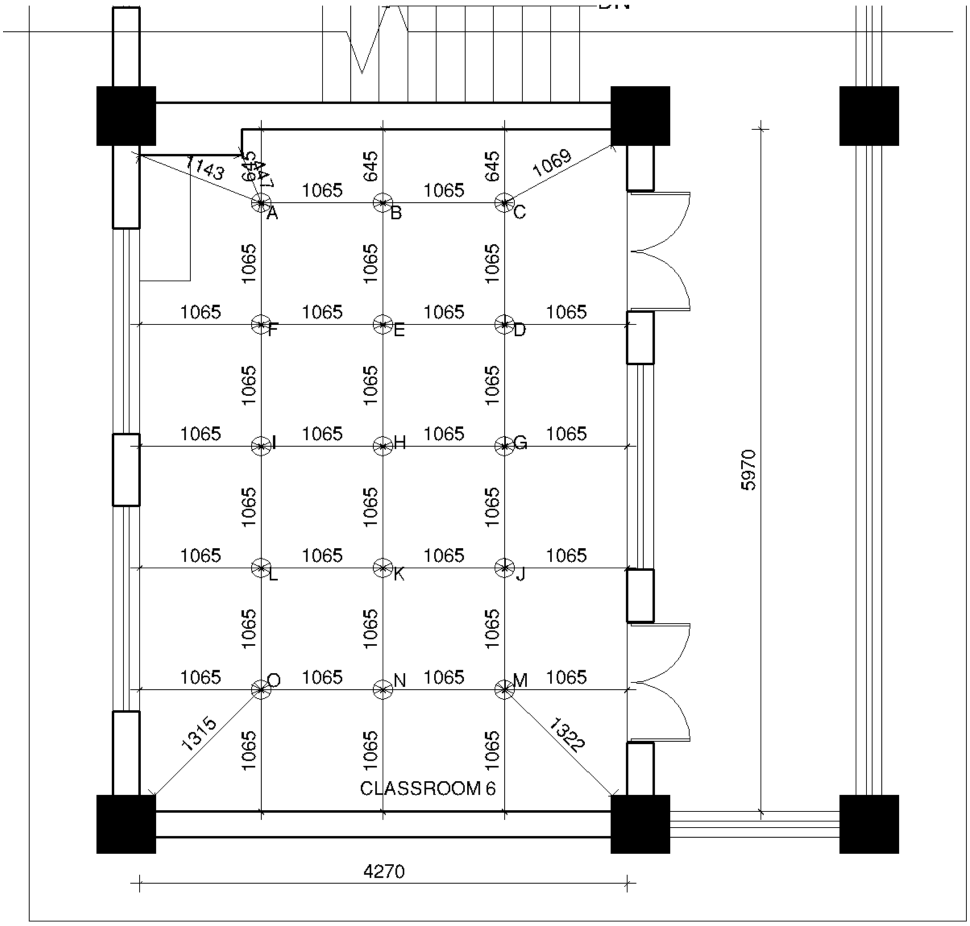
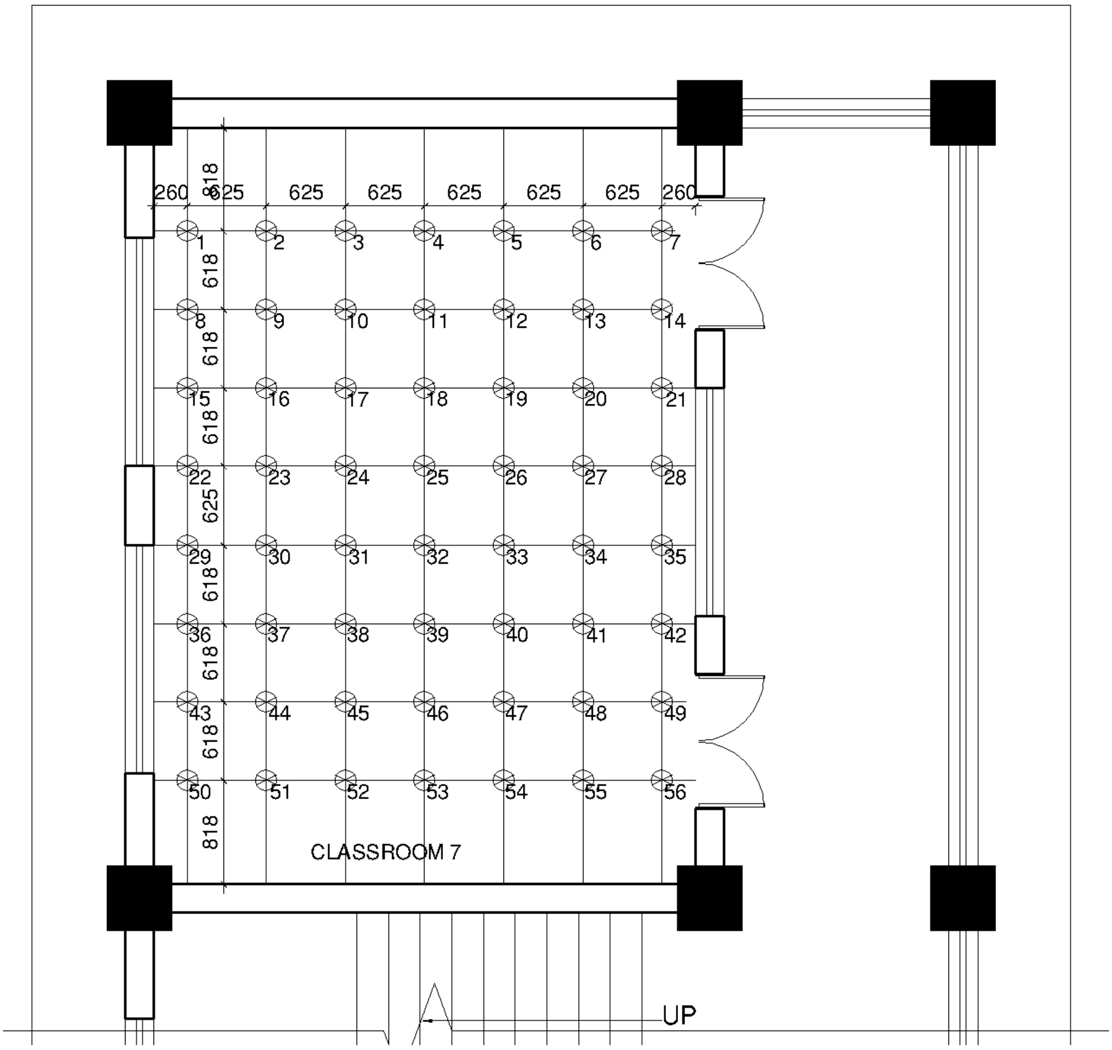


Table 30: Validation

Points	Field	Simulated	Error
A	278	354	-76
B	170	237	-67
C	115	249	-134
D	302	266	36
E	273	267	6
F	441	414	27
G	264	261	3
H	314	266	48

I	700	633	67
J	258	207	51
K	330	238	92
L	879	820	59
M	153	103	50
N	296	300	-4
O	523	529	-6

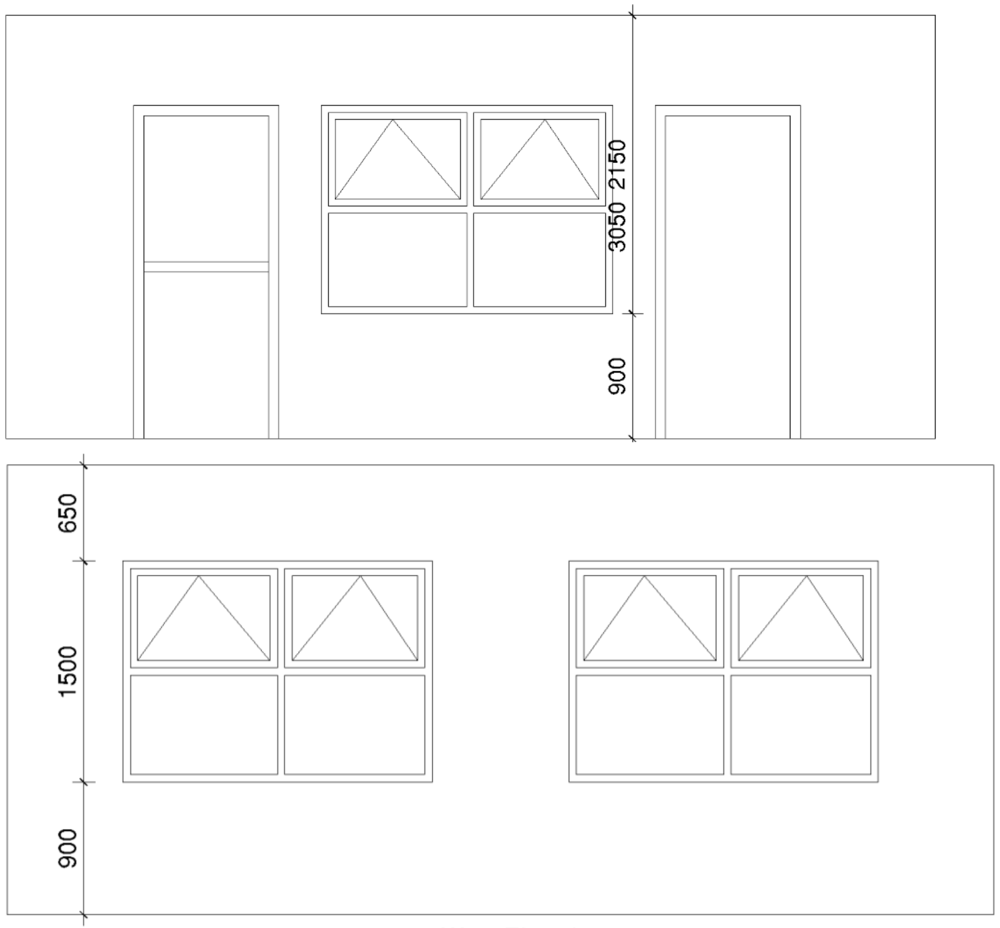
APPENDEX D: Floor plan in grid with illuminance point (classroom 7)



APPENDEX E: Illuminance field data of classroom 7

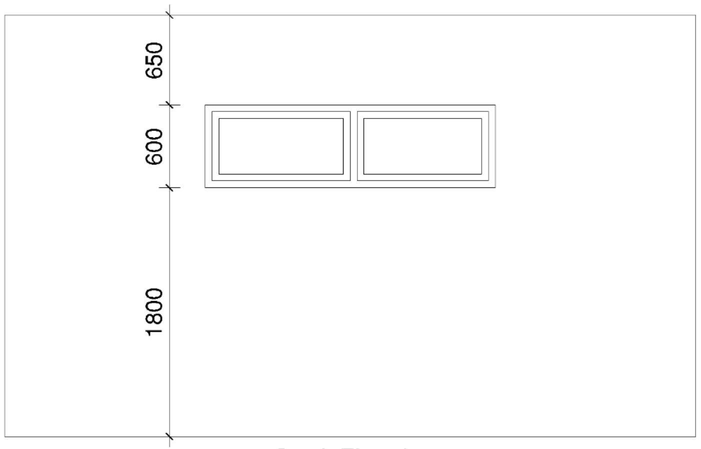
points	Field	points	Field
1	135	29	15
2	267	30	45
3	163	31	57
4	110	32	82
5	117	33	157
6	183	34	272
7	21	35	60
8	23	36	17
9	162	37	34
10	123	38	44
11	132	39	64
12	173	40	122
13	240	41	216
14	20	42	18
15	17	43	20
16	63	44	35
17	75	45	34
18	106	46	47
19	134	47	74
20	192	48	110
21	37	49	14
22	10	50	14
23	37	51	24
24	76	52	27
25	124	53	44
26	144	54	56
27	148	55	65
28	40	56	18

APPENDEX F: 14% WWR Scenario windows in elevation

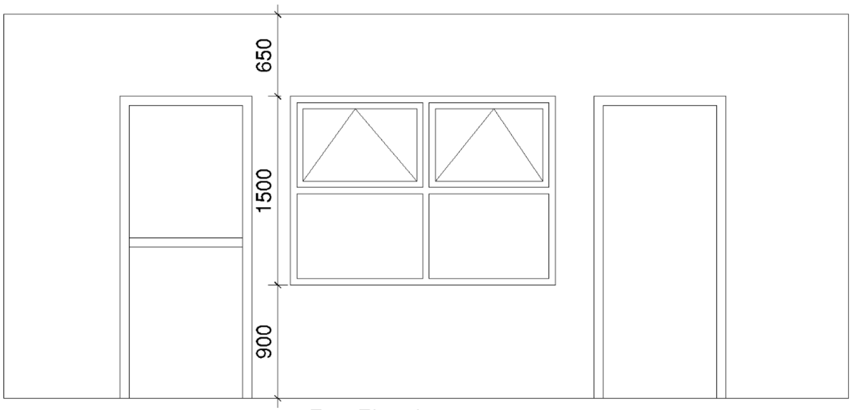


West Elevation

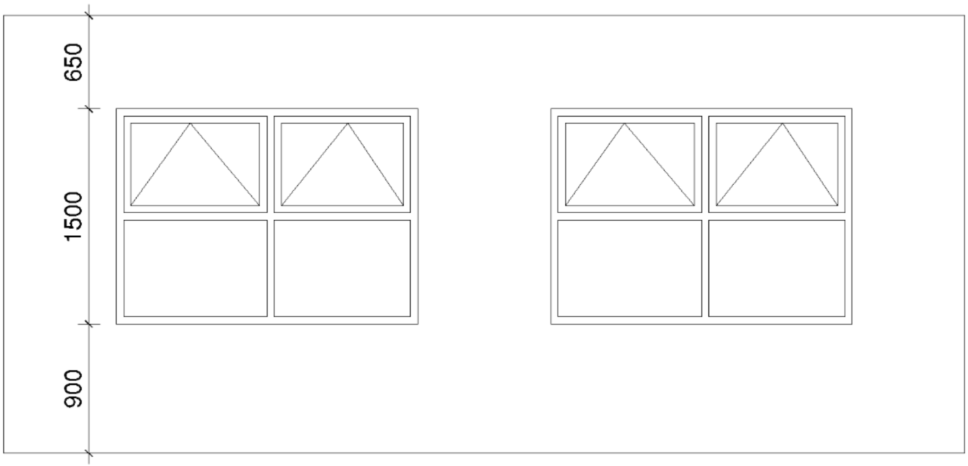
APPENDEX G: 16% WWR Scenario windows in elevation



South Elevation

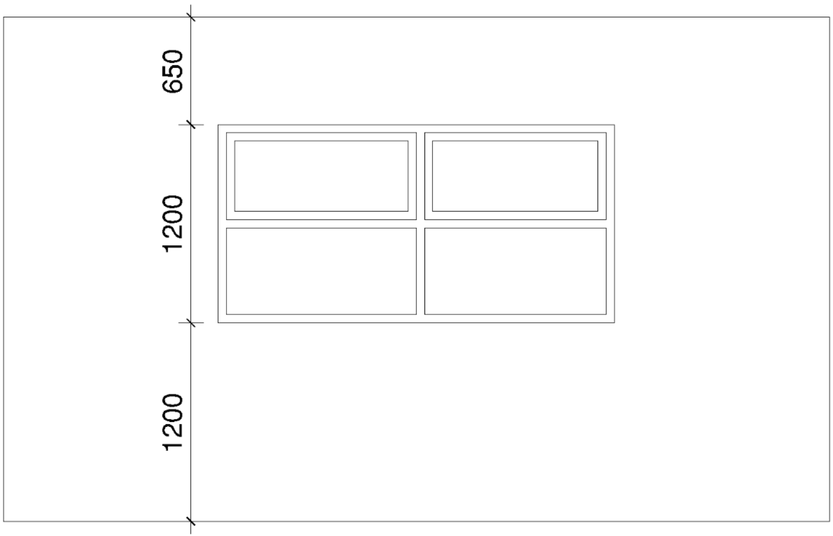


East Elevation

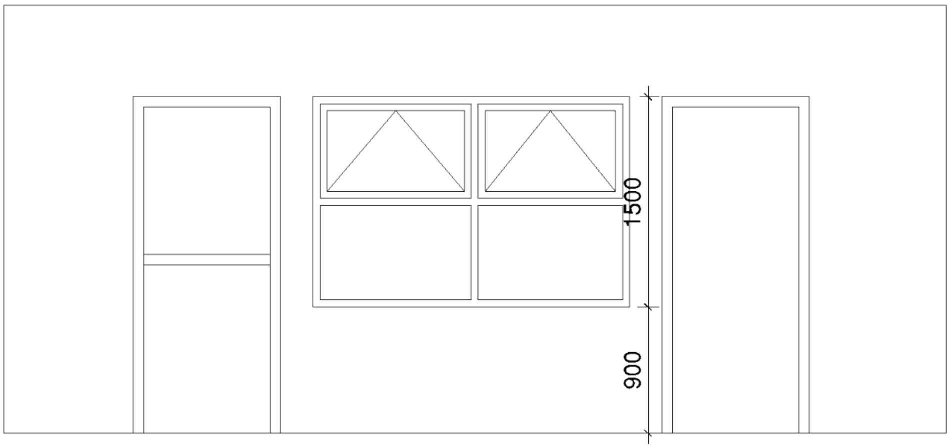


West Elevation

APPENDEX H: 20% WWR Scenario windows in elevation



South Elevation



East Elevation

APPENDEX I: Field data of temperature and illuminance

Date	Time	Point 1	Point 2	Temp	Humidity	Mean temp
1/24/2025	10:30	621 lux	298 lux	16^{0}C	37%	17.1
	13:30	723 lux	334 lux	19.1^{0}C	30%	
	16:30	520 lux	310 lux	16.2^{0}C	39%	
1/26/2025	10:30	473 lux	343 lux	16.7^{0}C	37%	16.8
	13:30	606 lux	245 lux	17.6^{0}C	30%	
	16:30	520 lux	310 lux	16.1^{0}C	38%	
1/27/2025	10:30	581 lux	341 lux	16.2^{0}C	40%	17.1
	1:30	581 lux	341 lux	18.6^{0}C	45%	
	16:30	376 lux	441 lux	16.5^{0}C	44.20%	
1/28/2025	10:30	757lux	600 lux	15.5^{0}C	60%	16.4
	1:30	481 lux	234 lux	17.2^{0}C	30%	
	16:30	434 lux	257 lux	16.5^{0}C	42.20%	
1/31/2025	10:30	576 lux	242 lux	15.3^{0}C	56%	17.1
	1:30	348 lux	320 lux	17.7^{0}C	47%	
	16:30	556 lux	407 lux	18.3^{0}C	43.20%	

APPENDEX J: Thermal performance simulation result under different scenario

Time	WWR 10%	WWR 12%	WWR 16%	WWR 18%	WWR 20%	WWR 25%	WWR 30%	WWR 35%	WWR 40%	Retrofitting	New construction
10:00	13.25	13.67	13.73	13.98	14.07	14.55	14.55	14.92	15.33	19.72	14.88
11:00	13.38	13.93	14.05	14.38	14.52	15.19	15.19	15.77	16.38	20.2	15.14
12:00	13.95	14.63	14.84	15.26	15.44	16.28	16.28	17.04	17.89	21.09	15.78
13:00	14.83	15.63	15.9	16.39	16.59	17.65	17.65	18.59	19.6	22.03	16.68
14:00	15.96	16.87	17.23	17.79	18.11	19.31	19.31	20.45	21.71	23.41	17.97
15:00	17.36	18.36	18.86	19.43	19.85	21.21	21.21	22.68	24.06	25.36	19.46
16:00	18.64	19.49	20.24	20.77	21.13	22.61	22.61	24.37	25.82	26.48	20.6

APPENDEX K: Thermal performance of best-case retrofitting scenario

	1/28/2025 10:00	1/28/2025 11:00	1/28/2025 12:00	1/28/2025 13:00	1/28/2025 14:00	1/28/2025 15:00	1/28/2025 16:00
Air Temperature (°C)	19.65	20.15	21.07	22.03	23.25	25.14	26.33
Radiant Temperature (°C)	19.78	20.24	21.11	22.03	23.57	25.58	26.62
Operative Temperature (°C)	19.72	20.2	21.09	22.03	23.41	25.36	26.48
Outside Dry-Bulb Temperature (°C)	9.9	12.3	14.63	17	17.98	18.4	18.88
Walls (kW)	-0.12	-0.14	-0.18	-0.21	-0.26	-0.32	-0.31
Partitions (int) (kW)	-0.07	-0.09	-0.15	-0.2	-0.31	-0.46	-0.49
Roofs (kW)	-0.31	-0.3	-0.27	-0.23	-0.2	-0.18	-0.14
Floors (ext) (kW)	-1.02	-1	-1.17	-1.28	-1.68	-2.26	-2.2
Solar Gains Exterior Windows (kW)	1.76	1.7	1.9	1.99	2.47	3.17	3.06

APPENDEX L: Article IOEGC

IOE Graduate Conference
[Placeholder for
Publication
Information]

Analysis of Thermal and Visual Performance in Naturally Ventilated Secondary School Buildings in Nepal

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Abstract

Thermal and visual comfort play an important role in enhancing the health and performance of both students and teachers in classrooms. Most Nepalese school buildings are naturally ventilated with wooden shutters or open windows, whose performance depends on external weather conditions. The daylight and thermal comfort are strongly influenced by these factors. Poor indoor environments can negatively affect the academic performance of students. Therefore, necessary actions must be taken to improve the thermal and visual performance of schools. Limited research has been conducted on indoor environmental quality related to thermal comfort in Nepalese school buildings. A field investigation was carried out at Shree Balpremi Secondary School in Madhyapur Thimi, Bhaktapur, involving temperature and daylight illuminance measurements during January 2025, together with a student survey. The findings show that the mean indoor temperature (16.4–17.1℃) is below the thermal comfort range for Kathmandu's winter. More than 56% of the students reported comfort and preferred a slightly warmer classroom. Illuminance data indicated that the south-facing classroom (grade 6) experienced fluctuating levels (723–215 lux), while the north-facing classroom (grade 7) had steadier but lower levels (811–110 lux). Both classrooms had insufficient daylight in the back, with 50% of the students reporting inadequate lighting at noon and 73% occasionally relying on artificial lighting. The results emphasize optimizing window size, orientation, and glazing to improve indoor environmental comfort. Future research incorporating simulations across different seasons and climates is recommended to better understand these factors.

Keywords

Thermal and Visual Performance, Naturally Ventilated School Building, Thermal Sensation, Illuminance

1. Introduction

Thermal and Visual comfort are important issues in school building design, as students spend a significant amount of time indoors. Students spend about 25–30% of their daily time in classrooms studying or participating in different academic activities [1]. Poor indoor conditions can have a negative effect on the health and performance of both students and teachers. An appropriate indoor environment gives educational buildings a sense of space and attractiveness and generates an impression of vitality and a general feeling of satisfaction [2]. Windows, being weaker components of the envelope compared to walls, are more prone to heat loss or gain, thus receiving significant attention for energy optimization strategies [3]. The windows in the school play a key role in both thermal performance and visual comfort. Among all the elements of façade design, the window-to-wall ratio (WWR) has a deep impact on introducing the amount of daylight in any room [4]. Increasing the window-to-wall reduces the total energy consumption for lighting, but after a certain window-to-wall, no reduction is seen in lighting energy, but the cooling energy of the building increases due to heat gain [5].

From previous research, the minimum and average daylight factor for classrooms have been defined as 2% and 5%, respectively [6]. Natural light is considered the main source of light during the day, with an average day light factor of 4-5%, while in the common teaching areas of a school, a minimum illuminance of not less than 300 lx is required [7]. A classroom is thermally comfortable where more than 80% of the students perceive it to be thermally acceptable [8]. However, most of the school building does not meet these standards. In addition, the absence of government regulation generally does not consider climate-sensitive design strategies or apply any energy- efficient technology [9]. Nepalese school buildings rely on natural ventilation through windows and doors for airflow, daylighting, and thermal comfort, with wooden shutters or open windows whose performance depends on the outside weather [10]. In residential and office buildings, residents can adjust their thermal comfort through adaptive behaviors, such as changing clothes, changing position, or adjusting the windows. However, students in classrooms face limitations in doing so, as they are restricted from modifying their clothing, seating arrangements, or window settings [11]. Hence, it is necessary to analyze the thermal and visual comfort inside the school classrooms.

So, the objective of this study was to analyze visual and thermal performance in a naturally ventilated classroom in a school building. The case study of the Shree Balpremi Secondary School building in Madhyapur Thimi, Bhaktapur, will present a typical case of the school building. This study will evaluate key design parameters, including window size, orientation, glazing type, and daylighting strategies, with the objective of proposing context-specific recommendations that balance thermal comfort, visual comfort, and energy efficiency.

Only a small number of research has been conducted on indoor environmental quality associated with thermal comfort in Nepalese school buildings [10]

2. Literature Review

2.1 Window Configuration

The configuration of the openings can modify the intensity and distribution of daylight to create appropriate luminous environments [12]. The window configuration can be dealt with on the basis of side lighting, window location, and window wall ratio. In a classroom that does not use mechanical ventilation, the window is expected to ventilate the room for significant thermal comfort. Many factors with respect to windows, such as type, size, and position, that could affect indoor airflow, indoor air distribution, and air exchange rate could contribute to obtaining the thermal condition in the classroom [13].

2.2 Visual Performance

Visual performance and comfort criteria will be divided into illuminance and glare-based criteria, as they need separate consideration when measuring visual satisfaction in the workplace [14]. The Illuminating Engineering Society of North America (IESNA) defined glare as 'the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss of visual performance and visibility.' The study of [15] concludes that the discomfort glare in classrooms often exceeds acceptable limits (DGP > 0.35) on sunny days. Adding shading devices and optimizing window designs effectively reduced glare, highlighting the need for advanced glare metrics such as DGP in design standards to improve visual comfort in schools.

2.3 Thermal Performance and Thermal comfort

Large hot or cold surfaces such as windows and skylights can affect the thermal comfort of the occupants. Compared to other surfaces within a room, windows generally undergo more significant changes in surface temperature. Heat radiation from window surfaces can cause considerable discomfort for occupants, even when the room air temperature is kept at an acceptable level. A hypothetical study by [14], an office room with varying WWRs (10–100%) and evaluated four orientations using EnergyPlus. They recommend 30% WWR for the north and 20% for the south, east, and west for minimal energy use, while 50–70% (north) and 50–60% (others) ensure visual comfort. [16]found that passive strategies such as glazing, insulation, and thermal mass reduced indoor temperatures by 2 to 4°C in a Tehran school, improving comfort with minimal heating energy during the winter season. The south-facing classrooms performed best, highlighting the need to balance efficiency with overheating risks. [2] found that higher glazing ratios (40-50%) improve thermal comfort, reducing energy use by 15-18% and heating demand by 8.5%. The study highlights the importance of window design in optimizing thermal performance.

2.4 Role of Windows in thermal and Visual Performance

The study of [17], found that modifying building orientation, size, thermal mass, or window design in Nepal's hot, humid region could significantly reduce indoor temperatures and improve thermal comfort. This study shows that in the hot and humid climate of Nepal, changing window orientation, orienting buildings along the NS axis (longer side), providing glazed windows on the north side, or using simple overhang shades can reduce cooling load demand by more than 10-15% [17]. Thermal performance analysis on residential buildings in Butwal by [18], observed that as the window-to-wall ratio (WWR) increases, the annual thermal energy consumption also increases. Specifically, with a WWR of 0.9, energy consumption increased by 5.24% for south-facing orientations and 7.16% for northeast-facing orientations.

The International Building Code and British Standard BS 8206 have also recommended minimum window areas, with the former requiring a minimum net glazed area of not less than 8% of the floor area of the room and the latter recommending a minimum window area of 20% of the external window wall for a room measuring less than 8 m in depth and 35% of the external wall for rooms deeper than 14 m [12]. The study of WWR by [18] in residential buildings in Butwal influences annual thermal energy consumption, with a WWR of 0.9 leading to increases of 5.24% for south-facing and 7.16% for northeast-facing orientations.The building is rectangular in plan with a floor area of 118.30 sqm.

3. Methodology

3.1 Study Area and Building

The case study chosen for this research is the school building named Shree Balpremi Secondary School located at Madhyapur Thimi-4, Bhaktapur. Block 4-C-8 is a 4-story building with two classrooms on each floor.

Figure 1: Case study building East facade showing the classroom used for study

The building is elongated towards the south-north direction, oriented towards the east. The classroom is designed for 25 students.

Figure 2: Classroom 7 interior

Table 1: Instruments Used

Specification	Details
1. Digital Hygrometer	HTC-2
Temperature and measurement range	50 \textasciitilde{} +70 degree (-58 \textasciitilde{} +158°F)
Accuracy	±1°C (1.8°F)
2. Digital lux meter	HTC LX-101
Ranges	0-50,000 lux
Sampling Time	0.4 sec
Operating Temperature	0° to 500 C(32°-122°F)
Operating Humidity	Less than 80% R.H

The building is a frame structure construction with 230mm thick brick masonry walls, maintaining uniform thickness for both exterior and partition walls. Rebuilt after the 2072 earthquake, the structure complies with government-issued school design guidelines and is classified as a disaster-resilient school building.

The classrooms were naturally ventilated with a sill height of 3'-0" and typical windows (6'-0" X 4'-0") and doors (3'-6" X 7'-0"). It features powder-coated metal doors and windows, with openings with 50% glazed shutters. Artificial lighting is installed in classrooms to improve illuminance during class hours, while ceiling fans are provided to cool down in the summer to help maintain thermal comfort.

3.2 Methodology applied

The field study was conducted for five days in January 2025, measuring indoor air temperature and daylight illuminance in a classroom. Table 1 presents the specifications of the instruments used.

3.3 Thermal and Visual Comfort Survey

A structured questionnaire survey was conducted among students in the classroom to gather information on their thermal sensation, preferences, and acceptability. The survey also aimed to understand their visual sensations, preferences, and the impact of these factors on their learning experience.

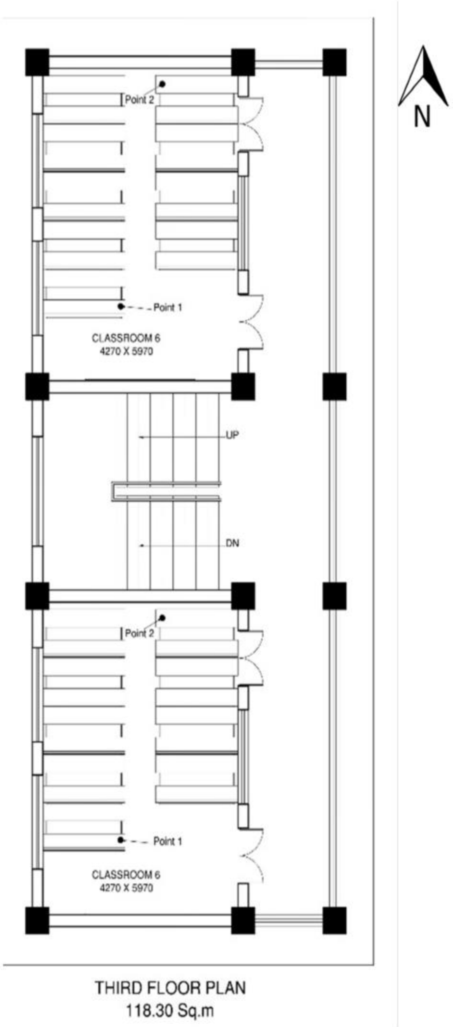

Figure 3: Selected Classroom Floor Plan

Table 2: Scales used for questionnaire survey

Scale Assigned	Thermal Sensation	Thermal Preference	Visual Preference
1	Cold	A Bit Warmer	Very Insufficient
2	Slightly Cold	No Change	Insufficient
3	Neutral	A Bit Cooler	Adequate
4	Slightly Warm		Excessive
5	Warm		
6	Hot		
7	Very Hot		

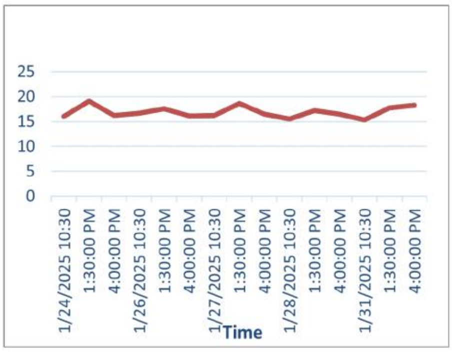

Figure 4: Measured indoor air temperature in classroom during field study

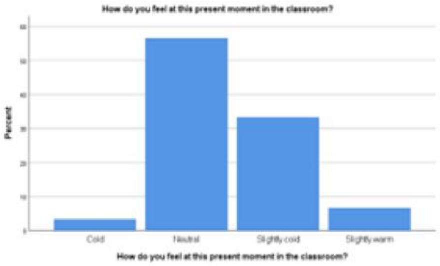

Figure 5: Distribution of Thermal Preference

4. Result and Discussion

4.1 Indoor Temperature

In naturally ventilated classrooms, the indoor environment is strongly influenced by outdoor conditions. During the survey, classroom windows were kept closed, with partially glazed openings. The mean indoor temperature recorded in the classroom was 16.9°C, which falls below the thermal comfort range from the study of [19]mean comfort temperature estimated using Griffiths method is 20.9° C for Kathmandu during the winter season.

4.2 Thermal Sensation and Preference

The survey was conducted on January 31 between 1:30 and 2:00 PM. The thermal perception of the students was collected using the modified 7-point ASHRAE scale [8]. At that time, 56.7% of the students reported feeling comfortable, while 33.3% found the classroom slightly cold, as shown in Figure 6. 23% of the students responded comfortable during the winter season shown in Figure 6. According to the ASHRAE standard, the classroom needs 80% of the acceptability level to satisfy [8]. The classroom in this study cannot meet these criteria.

4.3 Visual performance and preference

Illuminance data from classrooms 6 and 7 were collected for 5 days: 24 January, 26 January, 27 January, 28 January, and 31 January. Data from two classrooms were compared for further analysis as shown in Figure 7. The reading was taken at desk height, 2'-6", turning off the artificial light. The 7th-grade classroom (north side) receives better daylight, maintaining more stable and higher illuminance levels throughout the day, likely due to the diffused and balanced light from the east and west openings. In contrast, the sixth-grade classroom (south side) experiences more significant variations, with strong morning light from the east but a significant drop in the afternoon, as the west-facing openings may be less effective due to shading or obstructions.

Figure 6: Distribution of Thermal preference during Winter season

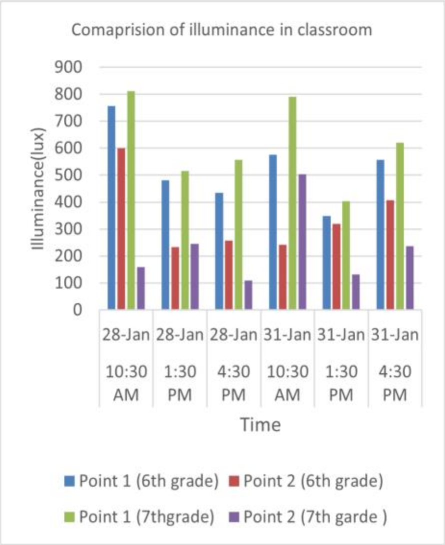

Figure 7: Comparison of Illuminance in classroom

Furthermore, point 2 in both classrooms shows lower illuminance, indicating limited daylight penetration deeper into the room. 50% of the students voted for insufficient daylight in the classroom, with most perceiving the highest levels of daylight around noon. Furthermore, 73% of the students occasionally felt the need for artificial lighting, while 46.7% rarely experienced glare issues. However, no measures such as curtains were implemented to reduce glare. Interestingly, most of the students were uncertain about the impact of window size on thermal and visual comfort in the classroom. Furthermore, 96.7% of the students preferred to keep the window size unchanged.

5. Conclusion and Recommendation

This paper presents the exploration of the impact of window configuration on thermal and visual performance conducted in a naturally ventilated school building in Nepal. The field measurement during January in the classroom shows that the indoor temperature was 16.1-19.1°C and the mean indoor temperature ranges from 16.4-17.1°C, which exceeds the thermal comfort range during the winter season in Kathmandu. From the questionnaire survey, most of the students (>80%) were dissatisfied with the classroom thermal environment and preferred the classroom to be a little warmer in the present condition. Similarly, illuminance is measured in a classroom of grades 6 and 7. The result shows that the illuminance on the south side of the classroom (grade 6) ranges from 723 to 215 lux, and the illuminance on the north side of the classroom (grade 7) ranges from 811 to 110 lux. In classrooms, the daylight illuminance in the last row does not meet the standard requirements. From the field survey it was found that on most days, morning and afternoon have the highest daylight illuminance. About 50% of the students reported insufficient daylighting during noon. Thus, the study concludes that the present window configuration significantly impacts thermal and visual performance.

This research is based on field investigation and survey data; the paper did not consider thermal and visual simulation of the surveyed classrooms, which are required to perform thermal and visual comfort analysis. More studies should be conducted in different seasons and climates to better understand thermal and visual performance due to window configuration.

Acknowledgments

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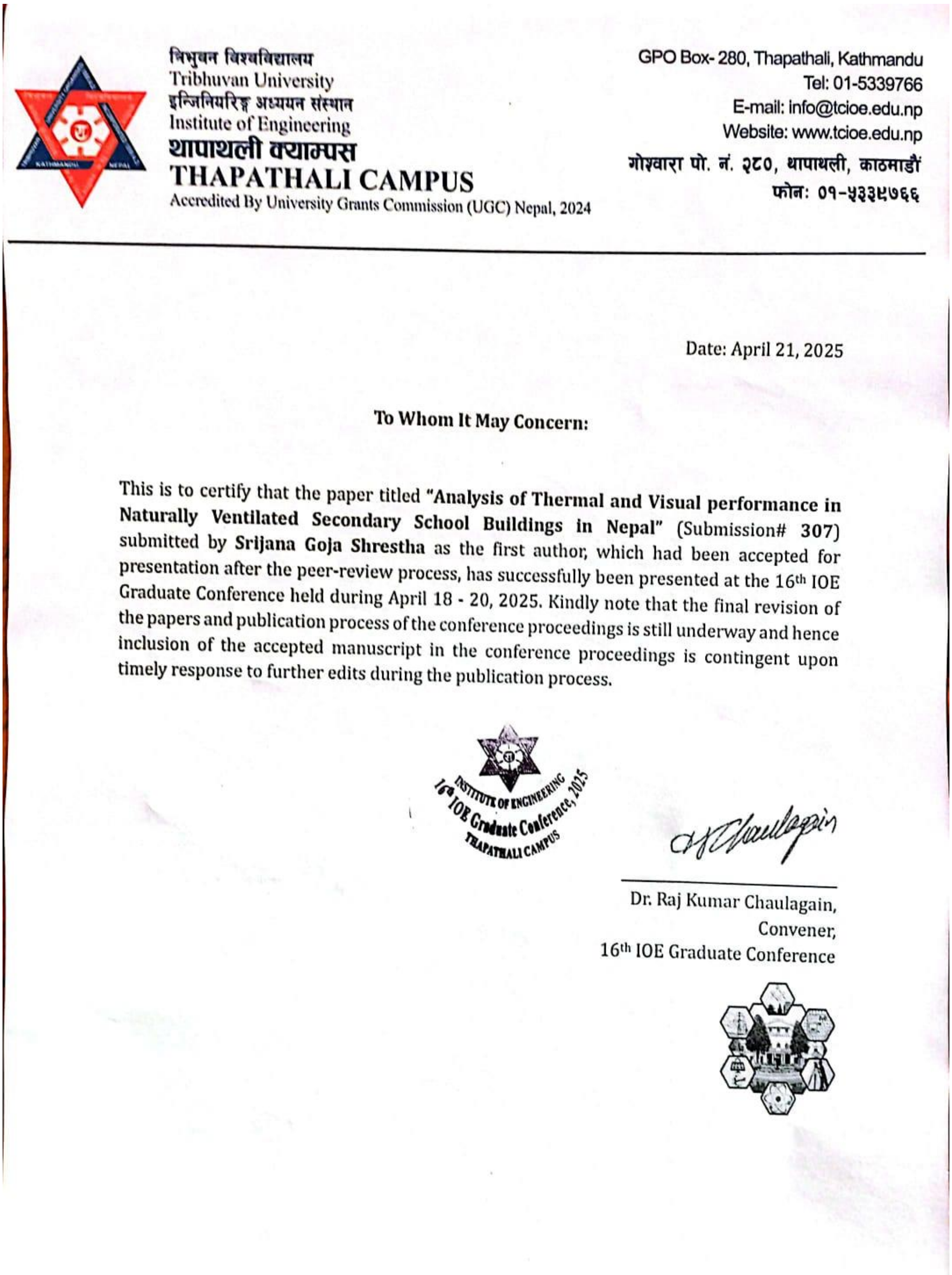
APPENDEX M: Letter of Acceptance



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Date: April 21, 2025

To Whom It May Concern:

This is to certify that the paper titled **"Analysis of Thermal and Visual performance in Naturally Ventilated Secondary School Buildings in Nepal"** (Submission# **307**) submitted by **Srijana Goja Shrestha** as the first author, which had been accepted for presentation after the peer-review process, has successfully been presented at the 16th IOE Graduate Conference held during April 18 - 20, 2025. Kindly note that the final revision of the papers and publication process of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon timely response to further edits during the publication process.

Chaulagain

Dr. Raj Kumar Chaulagain,
Convener,
16th IOE Graduate Conference

APPENDEX N: IOE Graduate Conference Certificate of Participation

IOE Graduate Conference

Certificate of Participation

THIS CERTIFICATE IS AWARDED TO

Srijana Goja Shrestha

in recognition of an invaluable contribution as

POSTER PRESENTER

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Organized by Tribhuvan University, IOE, Thapathali Campus in association
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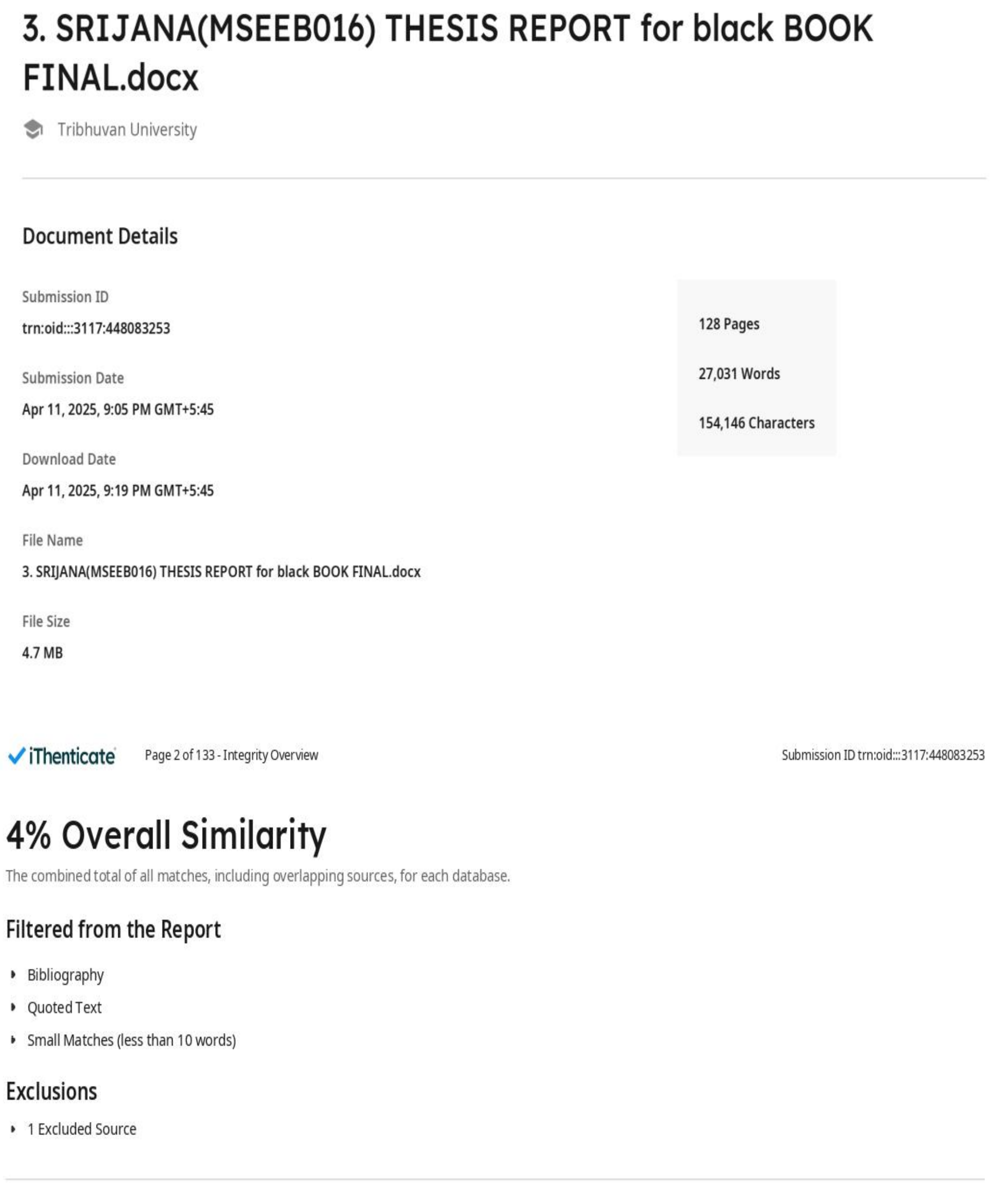

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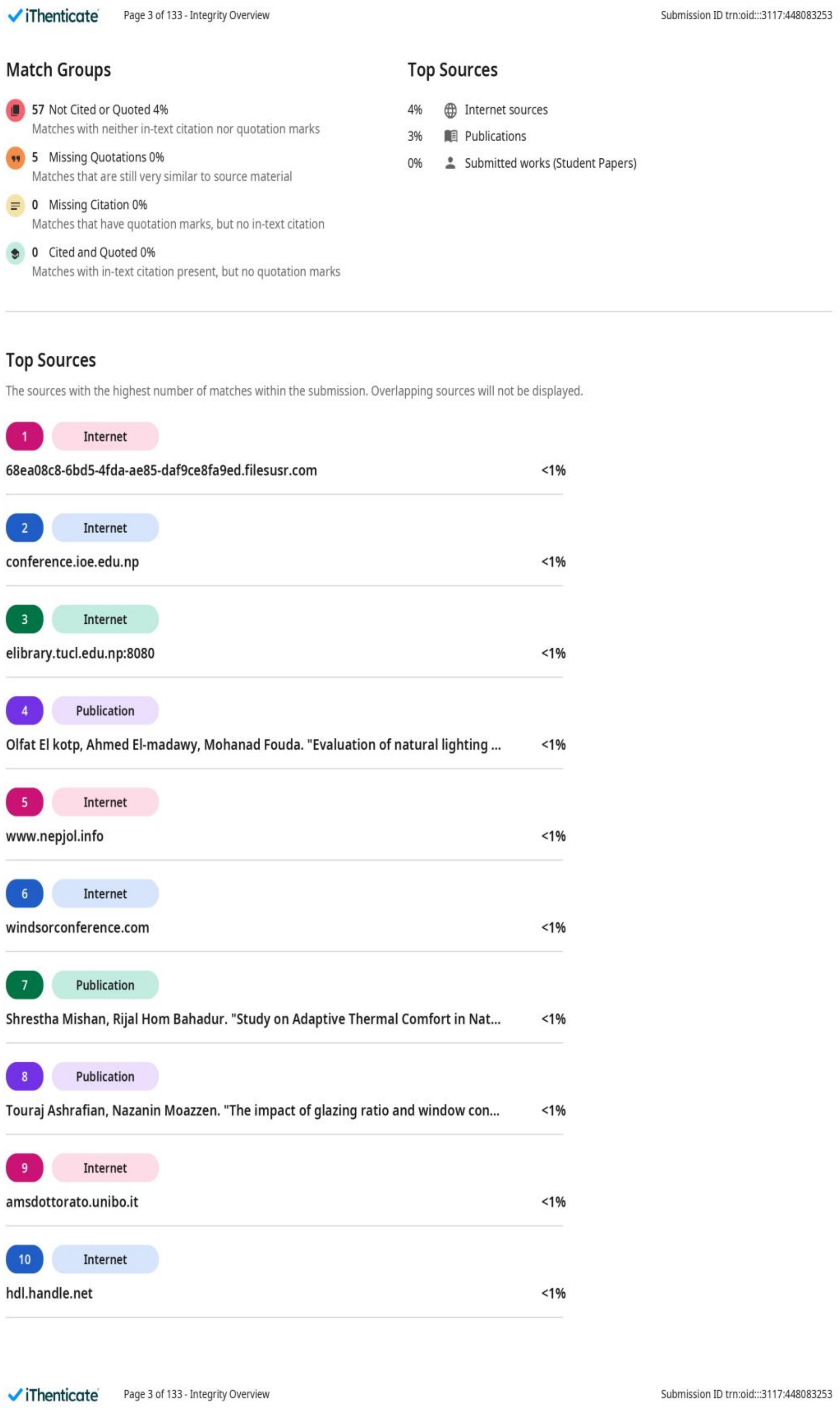

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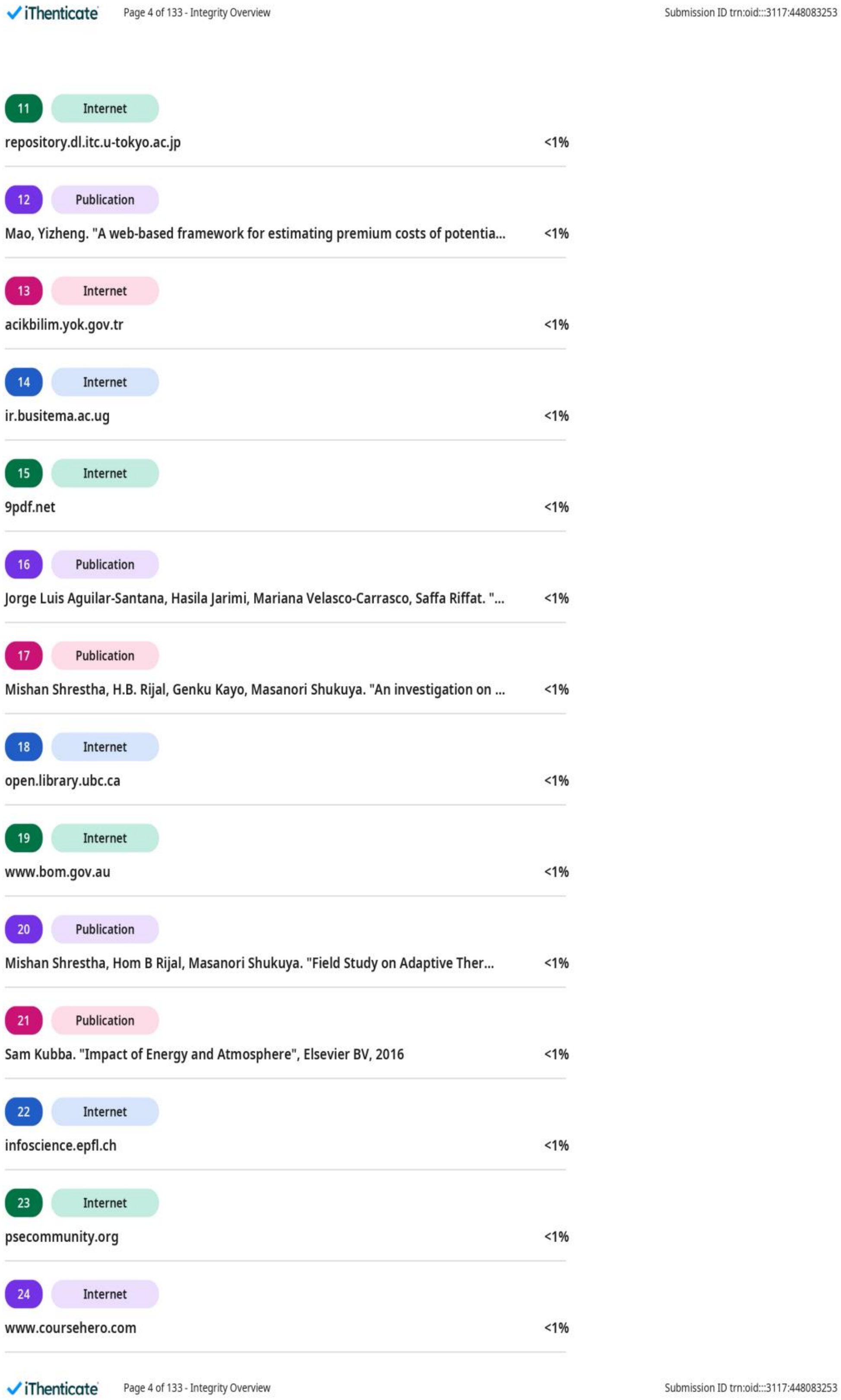

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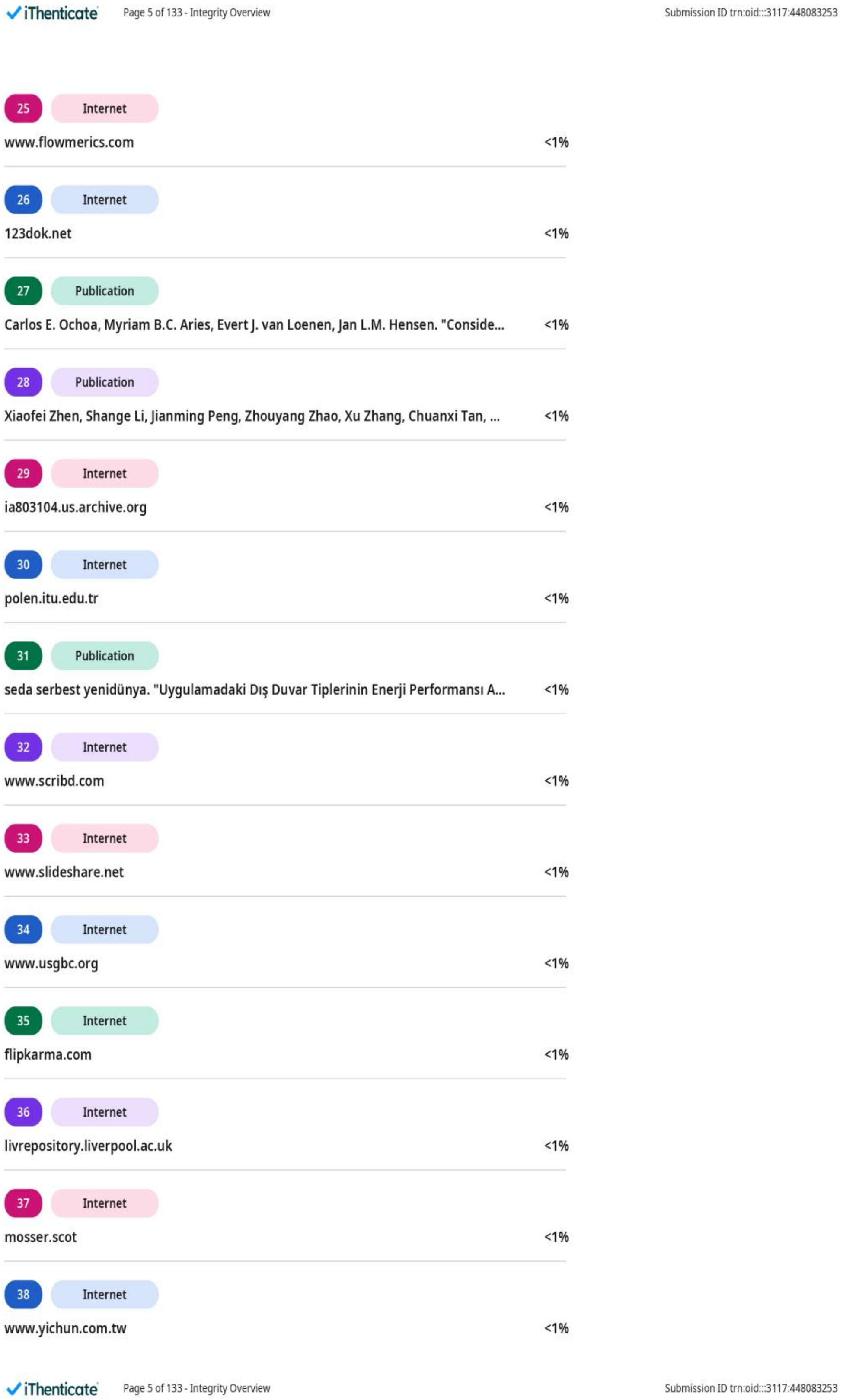

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