Journal of Engineering Issues and Solutions

Improving classroom thermal comfort of educational buildings: A case of Kantipur City College

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Received: November 14, 2022; Revised: March 20, 2023; Accepted: March 21, 2023

doi:https://doi.org/10.3126/joeis.v2i1.49486

Abstract

Well-designed and thermally comfortable learning spaces contribute to better academic performance, enhanced concentration, and improved productivity of students. Thermal comfort is often one of the most overlooked design parameters while constructing educational buildings in Nepal. The Nepalese government has yet to develop design guidelines or regulations which ensures optimum indoor thermal comfort. Due to this, classrooms either lack insulation, have poor ventilation, or have overall poor thermal performance. This study illustrates how the use of passive design measures such as thermal mass, insulation, and glazing can help in improving the thermal comfort of students in such classrooms. Kantipur City College, an engineering college in Kathmandu was selected as a case study to evaluate the thermal environment of the classrooms. The field study also determined the existing comfort levels of students based on their thermal sensations and preferences. Design Builder Software was used to carry out the thermal simulation analysis and evaluate the impacts of passive design strategies when applied to the base classroom model. Field survey showed that the indoor temperatures were in the range of 27-32 °C, and students felt quite uncomfortable during the lesson hours. Results from simulation analysis revealed that providing insulation to the walls and ceilings, applying thermal mass, or changing the window glazing lowered temperatures by 2-4 °C. The study concluded that careful consideration of appropriate passive design measures can help to significantly lower indoor temperature during the summer and maintain thermal comfort in the classrooms.

Keywords: *Educational building, Passive design, Simulation analysis, Thermal comfort*

1. Introduction

Providing a safe and comfortable environment is one of the basic requirements that any building must meet, however, the significance of indoor comfort in educational buildings simply cannot be overstated. Educational institutions are the academic centers which provide learning spaces to acquire new information, discuss different ideas, and carry out various scholarly works. These activities related to intellectual learning and working require focus and concentration for extended periods of time which is possible only when people are in comfortable thermal conditions. While thermal comfort has always been linked with health and general well-being, it also plays a major role in improving the performance, productivity, and concentration of students in educational buildings (Lamberti et al., 2021).

Students spend about 25–30% of their daily time in classrooms studying or engaging in different academic activities (De Giuli et al., 2012). Spending such long hours in the classrooms, it must be ensured that the comfort needs of the pupils are met so that they can perform at their optimum levels. The thermal environment of the learning space has a direct impact on the students' mood, concentration, physical and mental health, as well as learning efficiency (Zhang et al., 2022). Hence, given the specific learning and development needs of young people, particular attention in educational buildings should be given to the comfort of users, the work of students and teachers, and, where possible, energy efficiency. The quality of the classroom environment is directly co-related with learning performance (Zahiri et al., 2020). And one of the key indicators of a healthy living space is thermal comfort. The mental state of a person that reflects contentment with his/ her surrounding is known as thermal comfort (ASHRAE, 2017). There are several factors that can affect the comfort of occupants in the buildings. These maybe either climatic or environmental or personal factors. Climatic or environmental factors include very low or high temperatures, poor ventilation, increased humidity levels, etc. whereas personal factors include age, gender, clothing, metabolic rate, etc. Hence, thermal comfort varies from person to person, and is generally measured through subjective assessment. To achieve thermal comfort in classrooms, the indoor environment should be regulated by controlling the effect of outdoor factors such as solar radiation, wind speed, air pressure variations, etc. Studies on the thermal satisfaction of students in learning spaces have attributed parameters such as design, layout, and décor to have a significant influence on the quality of the learning experience (Cheryan et al., 2014).

Nepal lacks severe thermal comfort studies regarding educational buildings. As of 2020, there are more than 35,000 public and private schools, over 1400 colleges, and more than 300,000 students enrolled at the university level of education (Gurung, 2020). But, there are hardly any research or studies done regarding the thermal sensations or preferences of students studying in these classrooms. At present, there are no design guidelines or standards for maintaining optimum thermal comfort in any types of buildings in Nepal (Gautam et al., 2019). Due to this, students especially in educational buildings, are forced to study in learning spaces with a difficult thermal environment. Also, the materials which makeup the building envelope are not selected based on the climate or location of the educational building (Shrestha et al., 2021). In majority of the educational buildings, especially public ones, the classrooms are free running i.e., they are naturally ventilated which means the classroom's indoor environment is highly influenced by outdoor climatic factors, which makes it more difficult to attain comfort during the hot summers and cold winters. Hence, there is a need for a new paradigm shift in the approach of how educational buildings are designed to create better and more comfortable learning environments.

Passive design is the practice of creating spaces which are climate-responsive, and thus optimize the comfort of building occupants with varying local environmental conditions (Lamberti et al., 2021). It utilizes the approach of increasing solar gains, facilitating natural ventilation, maintaining optimal temperatures, etc. by making changes in the building fabric, optimizing spatial planning, and altering the form or architecture style. Different passive design strategies for a building can be adopted in terms of the site location, orientation, thermal mass, openings, shading, roof, material and technology, color and texture, and vegetation. Instead of using purchased power sources like grid electricity or natural gas, passive design solutions utilize natural energy sources. Hence, passive design is a simple yet cost-effective approach. At present, designers or planners can use a variety of building simulation tools and technologies to evaluate the thermal performance of the building under different conditions and gauge the thermal comfort of its occupants accordingly. These approaches have been widely utilized in foreign countries but have not been given much importance or prevalence in Nepal. There may be a lack of concept or awareness regarding the use of passive design solutions to improve the thermal environment of occupied spaces in modern Nepalese buildings. Several past studies (Alwetaishi et al., 2021; Manandhar et al., 2015; Trebilcock et al., 2016) which utilized simulation tools to apply passive strategies to the existing buildings found significant improvements in thermal comfort as well as notable reductions in energy use for heating or cooling.

In the context of Nepal, the use of passive design strategies has been extensively found in buildings constructed following traditional forms of architecture. Besides, being culturally significant to their ethnic people, these buildings which are made from local buildings materials adapt well with changes to the local climate. The traditional homes are found to have overall better thermal performance than their modern counterparts (Datta et al., 2009; Algifri et al., 1992). Bajracharya (2014) found that the traditional Newari houses in Kathmandu Valley were 1°C to 2°C warmer during the winter, and 1°C to 2°C cooler during the summer when compared to the modern buildings. In the study of housing across different parts of Nepal, Rijal (2012) found that applying passive strategies such as increasing air tightness, or providing insulation to the roof, walls and floor to the buildings aided in increasing the indoor air temperatures during the winter season. Through these thermal improvements, a better comfortable thermal environment was achieved in the improved model whose temperatures were 4.4 K to 12.7 K higher than that of the base model.

Manandhar et al. (2015) discovered that changing the orientation, building size, thermal mass, or window design of buildings lying in the hot humid region of Nepal can significantly lower indoor temperatures and improve thermal comfort during the hotter months. The study showed that when building is oriented towards the N-S axis (longer side), glazed windows are provided in the north, or even when a simple overhang shade is used, the cooling load demand can be reduced by more than 10-15%. Similarly, Borgkvis (2016) found that passive design techniques, such as use of insulation and passive solar heating can help in achieving comfortable thermal conditions in the residential houses of Ghorepani and Dhulikhel. The mean indoor temperature increased to 5 °C when insulation was added to the roof and walls, whereas when double glazed windows were used, about 10 °C increase in temperature was observed for the coldest winter day. The study also discovered that the additional insulation would lower the indoor temperature during the warm days, thus maintaining indoor comfort. Chaulagain et al. (2019) carried out a study based on Building Energy Modelling (BEM) in one of the highly populated city in Nepal, Biratnagar. This study utilized a simulation approach using BEM, SketchUp and OpenStudio GUI (Graphical User Interface) to determine the effects of various passive design interventions on the indoor thermal comfort of the occupants in the model building. It was found that application of simple passive design strategies such as wall and roof insulation, increasing building airtightness, reflective coating on exposed wall and roof surfaces, window glazing, etc. lead to considerable reduction in thermal loads (up to 68%) and increment in the indoor comfort hours (up to 86%).

Passive strategies implemented in different buildings across Nepal have showed improvements in comfort, savings in energy use, and the practice of sustainable design. Therefore, this paper aims to evaluate the thermal environment, determine the level of thermal comfort of students, and apply various passive design solutions through thermal simulation analysis to improve the thermal performance of classrooms in educational buildings.

2. Materials and Methods

A survey and case study-based methodology was adopted to conduct this research work. The methods used in this study consist of a field survey and thermal simulation of the building. The field study was conducted for two weeks in June, which represents the hottest month of the year in Kathmandu. The field research involved monitoring indoor air temperature: a thermal comfort parameter. A questionnaire-based survey was also conducted to determine the thermal comfort perception or satisfaction of the students in the classroom. Moreover, a thermal simulation analysis of a classroom located on the southern side of the case study building was performed to evaluate different passive design measures for enhancing comfort during lesson hours.

2.1 Description of climatic conditions, case study building, and classrooms

The study area of the case study building lies in Kathmandu, the capital city of Nepal. Kathmandu valley is located in the central part of the country, lying between 27°36' to 27°50' north latitude and 85°7' to 85°37' east longitude with the mean elevation of about 1300 meters (4265 feet) above the sea level (Upadhyay et al., 2006). Situated in the cool temperate region of Nepal, Kathmandu has a mean monthly maximum temperature of 29.30°C and a mean monthly minimum temperature of 0.90°C (Rai, 2014). The two coldest months of the year are January and December, which have an average temperature of 10˚C to 11˚C. On the contrary, the hottest months of the year are June, July, and August, which have average temperatures lying between 24 ˚C to 25˚C. However, maximum temperatures can reach over 30˚C during the day in these summer months. Because of rapid urbanization and unplanned development, it has been found that Kathmandu's annual mean temperature has been rising at an alarming rate of 0.06˚C/year (Thapa et al., 2021). This indicates that the need for better thermal comfort conditions in the buildings lying inside the Kathmandu valley has to be addressed sooner, than later. The case study chosen for this research is an engineering college named 'Kantipur City College' which is situated at Putalisadak, Kathmandu. The case study building is six-storey tall with a total of 12 rooms, with 2 classrooms on each floor (Figures 1-3).

Figure 1: Case study building (east facade) showing the classrooms used for the study

Figure 2: Classroom 'S'

Figure 3: Classroom 'N'

The college building is representative of commonly found building typologies for educational buildings around the Kathmandu Valley. It is elongated along the north-south axis with window openings on both the north and south side of the building that allow for natural light and ventilation into the classrooms. The building is a reinforced cement concrete (RCC) frame structure, with external walls made of exposed bricks whereas the inner wall surfaces were finished with mortar and plaster. The construction materials along with the thermal properties of the case study building are shown in Table 1.

Table 1: Materials, thickness, and U-value of building components in the case study building

Components	Materials	Thickness (mm)	U-value (W/m K)
Walls	Bricks with plaster	130	1.8
		230	2.1
Ceiling	RCC with plaster	125	3.5
Floor	PCC with cement screeding and punning	125	2.03
Windows	Aluminum (Single Glazed)	6	5.44
Door	Core Timber	30	3.11

In this study, the classrooms selected for thermal measurements and simulation were located on the second floor of the case study building as shown in Fig. 1, 2, and 3. The size of the classrooms is 7.6 m x 5.25 m. These two classrooms are assumed to represent all classrooms facing south (S) and north (N) in the building, as the classrooms are identical in their size and layout.

2.2 Field measurements

During the field study, the indoor air temperatures in the classroom were measured using a digital thermo-hygrometer for a period of two weeks in June 2022. Table 2 shows the characteristics of the instrument used. The instrument was placed in the center location of the classroom at the desk height of 800mm from the floor. Readings were taken at an interval of 15 minutes from 10:00 am to 2:00 pm. This time frame was chosen as students told that they felt most uncomfortable during this period. Field measurement results found that the mean indoor temperatures in classrooms S and N were 28.4 °C and 27.9 °C during the study period respectively. The higher temperature range in classroom S as compared to Classroom N, maybe because the south-facing classroom receives more sunlight during the day, whereas the classrooms in the north receive very little sunlight and tend to remain cooler.

These indoor temperatures are beyond the adaptive temperature comfort range for people in Kathmandu based on the studies done by Bajracharya (2014) and Shrestha et al. (2019). Based on Nicol's graph as seen in Fig 4. which showcases the monthly mean temperature of Kathmandu, Bajracharya (2014) found that the highest temperature which can be considered to be comfortable during summer in Kathmandu is 26°C.

Table 2: Characteristics of the digital thermo-hygrometer used

S. No.	Specifications	Details
1	Model name	HTC - 1
2	Temperature measurement range	-20□ to 60□
3	Accuracy	± 1□(1.8□)
4	Response Time	500 Milliseconds
5	Sample Rate	Once every ten seconds

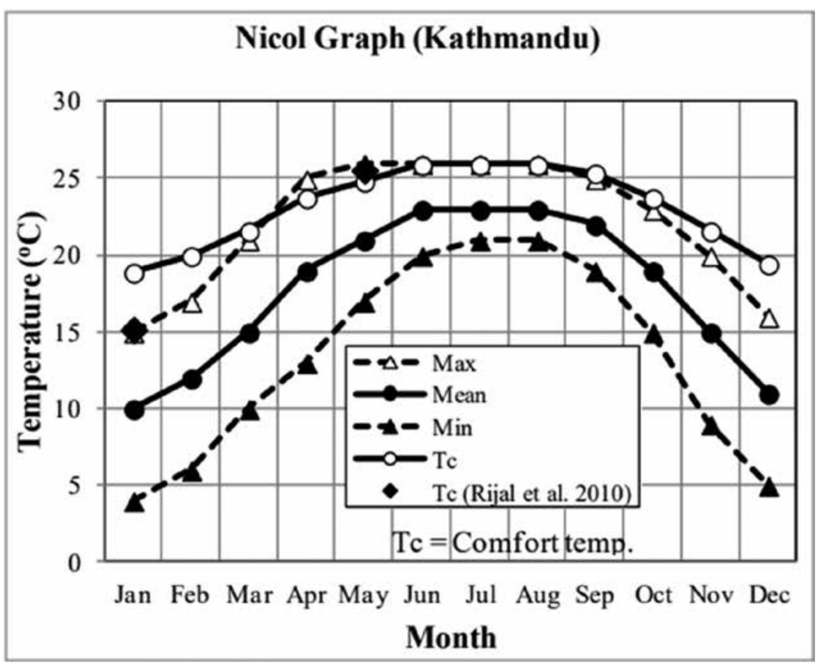

Figure 4: Nicol's graph showing comfort temperature (T_c) for buildings in Kathmandu Source: (Bajracharya, 2014)

Similarly, Shrestha et al. (2019) found that the comfort temperature for students in naturally ventilated school buildings in Kathmandu is around 26°C. Figure 5 shows the variation in indoor temperature on different days at specified times of the day during the study period. The mean indoor temperatures in the classrooms were found to be above 26°C during the lesson hours, which shows that the classrooms are not thermally comfortable for students during the summer season.

Figure 5: Measured indoor air temperature in classrooms N and S during the field survey

2.3 Questionnaire survey

Table 3: Major questions regarding thermal comfort that were asked to the students

1. How do you feel at this present moment in the classroom?

☐ Cold ☐ Cool ☐ Slightly Cool ☐ Neutral

☐ Slightly Warm ☐ Warm ☐ Hot

2. What would you like the classroom to be?

☐ A Bit Warmer ☐ No Change ☐ A Bit Cooler

3. Is the thermal condition in the classroom acceptable to you?

☐ Yes ☐ No

4. Does the indoor climatic conditions of the classroom affect your mood, concentration, or well-being during the lesson hours?

☐ Yes ☐ No

A structured questionnaire survey was conducted among the students in the classrooms. The questionnaire primarily consisted of inquiring students regarding their thermal sensation, thermal preferences, thermal acceptability, and effect on their learning experience due to the classroom's indoor thermal conditions. Altogether, 84 students, 53% (n = 44) males and 47% (n = 40) females, participated in the whole survey. In this study, all the students in the classrooms were enumerated i.e., census research approach was applied. The age range of students was from 20–24 years. To evaluate thermal sensation & preferences, a 7-point ASHRAE scale (ASHRAE, 2017) , and a 3-point Mc-Intyre scale (McIntyre, 1976) were used. The major questions regarding the comfort of students in the classrooms that were included in the survey are presented in Table 3.

2.4 Simulation

At present, there are many software tools for carrying out thermal simulations in buildings. For this research, DesignBuilder software v4.5 has been used. It uses the EnergyPlus engine developed by the US Department of Energy and has been extensively tested, validated, and used around the world (Deal, 2014). Design Builder (DB) is a comprehensive software for three-dimensional modeling of buildings and structures in different climatic zones of the world. It comes equipped with different templates for building materials, size of fenestration, use of energy sources, schedules for occupancy, etc.

Figure 6 and Figure 7 show zone and floor plan of classroom S which was selected for simulation to apply various passive design strategies for improving thermal comfort in the classroom.

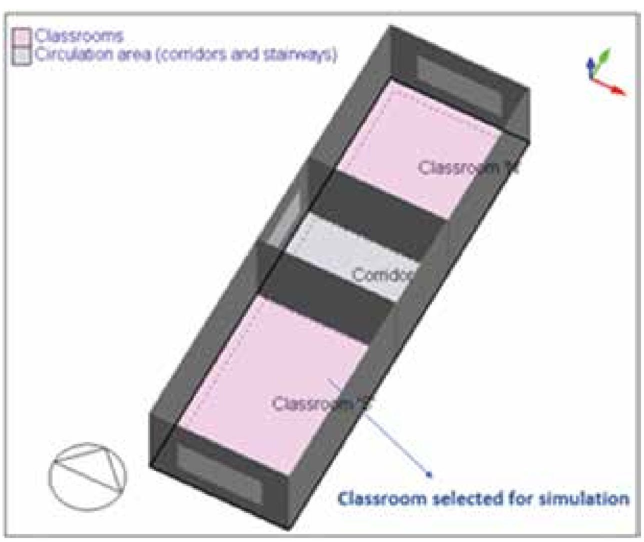

Figure 6: Simulated classroom in DesignBuilder

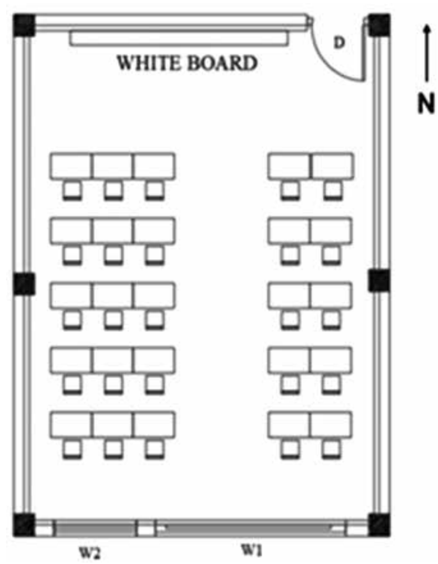

Figure 7: Floor plan of classroom

3. Results and Discussion

3.1 Thermal comfort survey results

The thermal comfort survey results indicated that the responses of the majority of students' fell into the hotter sensation side of the ASHRAE scale which are: slightly warm, warm, and hot. Regarding thermal preferences, votes for a cooler environment than the present condition in the classroom were seen. Figure 8 shows the overall distribution of thermal sensation votes of students obtained from the survey.

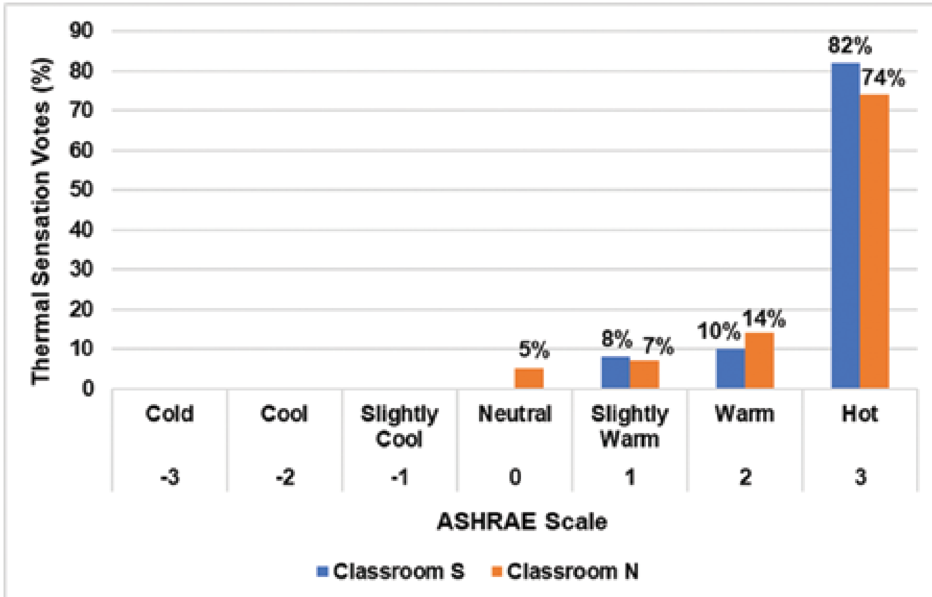

Figure 8: Thermal sensation votes in classrooms S and N

It can be seen that very few (only about 5%) of students who take classes in classroom N voted for feeling neutral with the classroom's thermal environment, whereas there were no votes regarding the 'neutral' thermal sensation from students in classroom S. Most of the students (N = 74 %, S = 82%) voted for feeling "hot" on the thermal sensation scale. This is also in conjunction with the responses for thermal preferences, in which students from both classrooms (N=86 %, S = 92 %) voted for a "cooler" thermal environment than the present condition as shown in Figure 9.

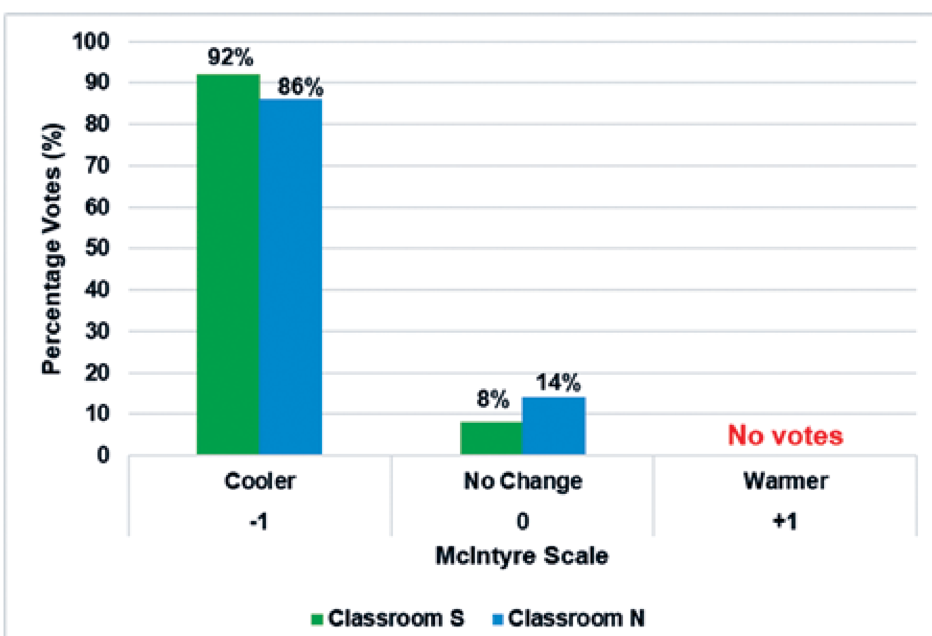

Figure 9: Thermal preferences votes in classrooms S and N

The reason for majority of the students not being thermally comfortable in these classrooms can be attributed to poor building envelope and ventilation. The outer face of the walls of the classrooms are exposed as shown in Figure 1. The classrooms also lack thermal insulation of any kind. This leads to high degree of heat transfer from the outside to inside. Due to this, when outdoor temperatures are high during summer, the students feel quite hot in the classroom as well. Additionally, the windows are located only in the southern side for classroom S and only on northern side for classroom N. Because of this, the movement of air inside the classrooms is limited with no possibility for cross-ventilation. Thus, the indoor temperatures cannot be regulated to keep the classrooms cool during the summer.

According to ASHRAE standard 55, for an indoor environment to be considered as comfortable, there should be more than 80% acceptability in the three central categories, but here the survey showed that was not the case for these classrooms under study. The high number of responses on the hotter side of the ASHRAE scale shows issues of comfort in the classrooms during summer. Hence, to shift the pupils' responses to the comfort side, the classroom's temperature needs to be reduced during summer.

3.2 Simulation results

3.2.1 Thermal insulation in walls

Buildings with good insulation slow down the rate of transfer of heat, which means there are no huge fluctuations between the inside and outside temperatures, resulting in a comfortable indoor thermal environment (Shrestha et al., 2022). Figure 10 shows the cross-section of the wall with rockwool insulation on the inner surface.

Figure 10: Wall cross-section with rockwool insulation

The overall U- value of the wall with rockwool insulation of different thickness applied to the walls of the simulation classroom model is as presented in Table 4. The addition of insulation to the exposed brick wall showed a clear improvement in the indoor temperature. Figure 10 shows the variation in the indoor temperature of the classroom after the use of rock wool as thermal insulation.

Table 4: Overall U-value of the external wall with rockwool insulation of different thickness

Thermal Insulation	Thickness (mm)	U-value (W/m² k)
Base Case	-	2.1
Rockwool	50	0.65
	75	0.48
	100	0.39
	125	0.32

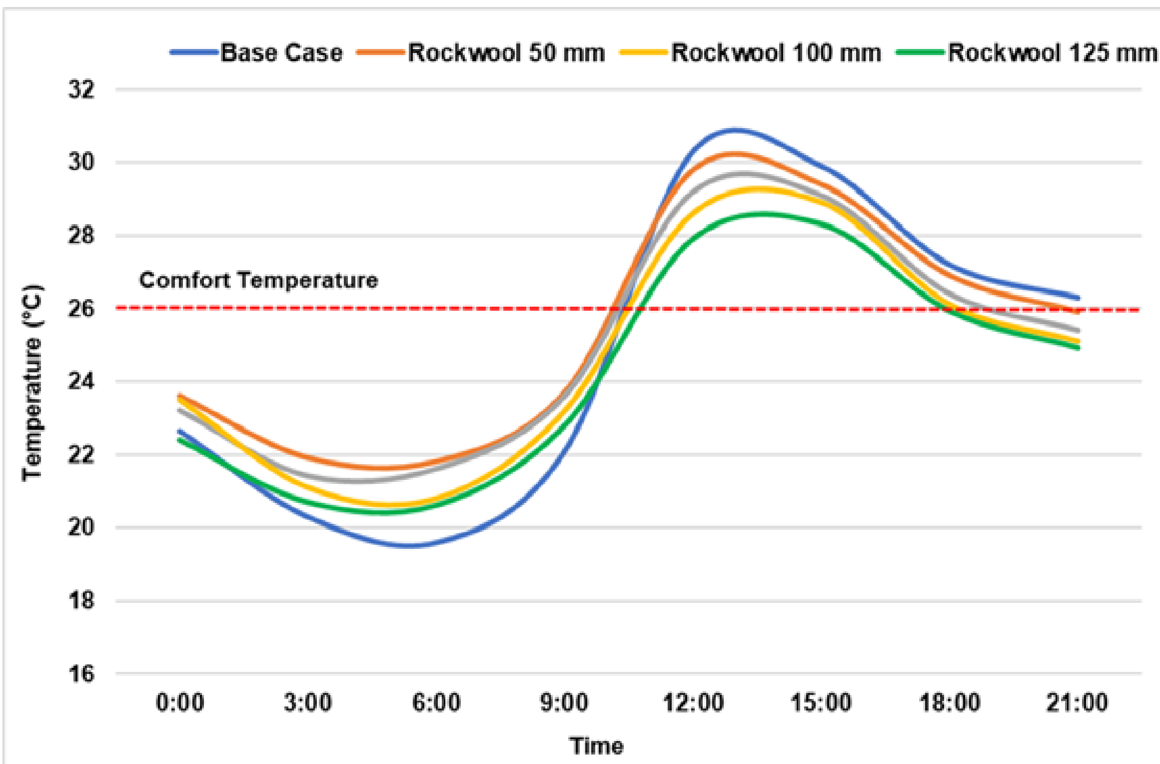

Figure 11: Variation in indoor temperature using different thickness of rockwool insulation

It can be seen that using even a 50 mm thickness of rockwool insulation can significantly improve the thermal performance of the building envelope. For 50 mm thick rockwool insulation, there was about a 0.7° C decrease in indoor temperature, at noon.

With a gradual increase in the thickness of insulation, the U-value of the wall assembly gets lowered further. This may be due to the decrease in the rate of thermal conduction toward the interior surfaces of the walls. The maximum indoor temperature in the classroom when a 200 mm thick rockwool insulation is placed into the walls is about 2.4°C lower than for the base model. Thus, this analysis indicated that the indoor temperatures of the classroom could be reduced effectively with thermal insulation in walls. The results of this simulation also align with study done by Gupta and Deb (2022), who found that increasing the envelope's insulation reduced indoor temperatures by up to 60% annually along with largest reductions in cooling loads.

3.2.2 Thermal insulation in ceilings

The ceiling of the classroom is an RCC slab (with plaster) of 125 mm thickness with no thermal insulation. The ceiling generally transfers heat from the floor above it or directly from the roof. Figure 12 represents the cross-section of ceiling installed with Expanded Polystyrene (EPS) insulation.

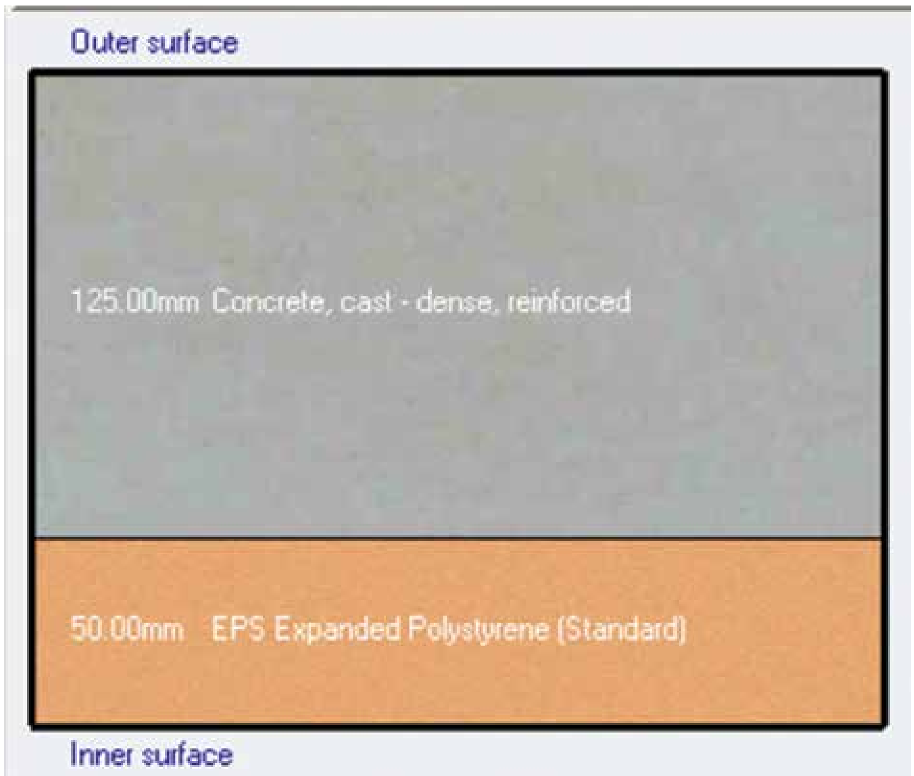

Figure 12: Ceiling cross-section with EPS insulation

For this study, EPS insulation of 50 to 125 mm thickness was applied similarly to the ceiling as to the walls as discussed in section 3.1. Table 5 presents the overall U-value of the ceiling using different thickness of EPS insulation.

Table 5: Overall U-value of the ceiling with EPS insulation of different thickness

Thermal Insulation	Thickness (mm)	U-value ($W/m^2 k$)
Base Case	-	3.5
EPS	50	0.65
	75	0.46
	100	0.36
	125	0.29

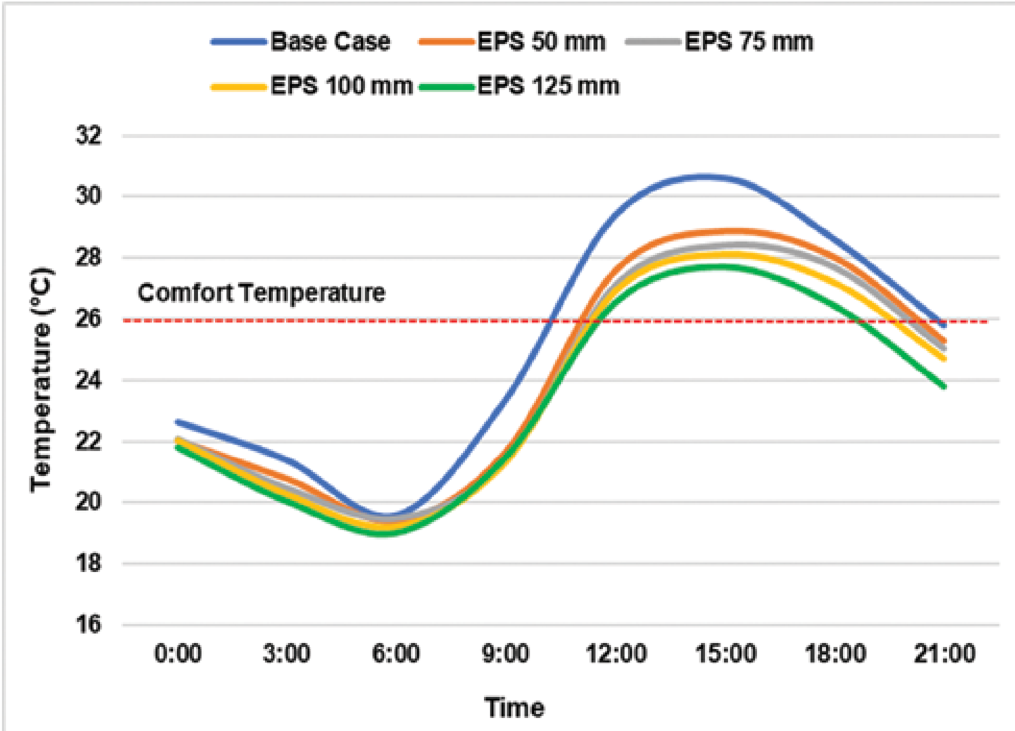

Figure 13: Variation in indoor temperatures using different thickness of EPS insulation in the ceiling

Figure 13 shows the indoor temperature variations in the classroom when EPS insulation of different thicknesses are applied to the ceiling. It can be seen that the application of 50 mm thick EPS thermal insulation showed only minor improvements in the indoor temperature. When 75 mm thick EPS insulation is used, the overall U-value reduces to 0.46 W/m K, and the temperature gets lowered by 0.4°C when compared to the base model. For 200 mm thick EPS insulation, when the classes are running at noon, the indoor temperature is maintained at 26.5°C, which is very close to the comfort temperature required during summer. These results showed that for the ceiling, insulation of greater thickness is required to have any significant change in the indoor air temperature. This may be because hot air tends to flow up, and the ceiling presents a greater potential for heat loss than the walls. More heat can be lost at the ceiling or attic level as that is where hot air tends to collect. Hence, there is a need for thicker insulation in the ceiling than walls.

According to Heracleous et al. (2021), insulating the roof/ceiling is a very effective passive design measure for improving thermal comfort in the building. Proper construction of roof can reduce the operative temperature by 20% resulting in 3.25 times fewer thermal discomfort hours for students (Alghamdi et al., 2022).

3.2.3 Thermal mass in external walls

Thermal mass is the capacity of a material to either store or release heat (Shafigh et al., 2018). It can be used in the walls or floor of a building to improve the thermal performance of the building envelope. Using high thermal mass materials such as concrete, stone, earth, etc. reduces the indoor temperature during summer season (Haseh et al., 2018).

Table 6: Overall U-value of external walls using different thickness of cast concrete as thermal mass

Thermal Mass	Thickness (mm)	U-value (W/m² k)
Base Case (Brick)	-	2.1
	100	1.78
Cast Concrete	200	1.53
	300	1.35

For public buildings, concrete with a high specific heat capacity and low thermal conductivity is generally preferable (Shafigh et al., 2018). Hence, cast concrete has been used as the thermal mass material in this study. Table 6 shows the various thickness of cast concrete used as the thermal mass on the walls and their corresponding U-values.

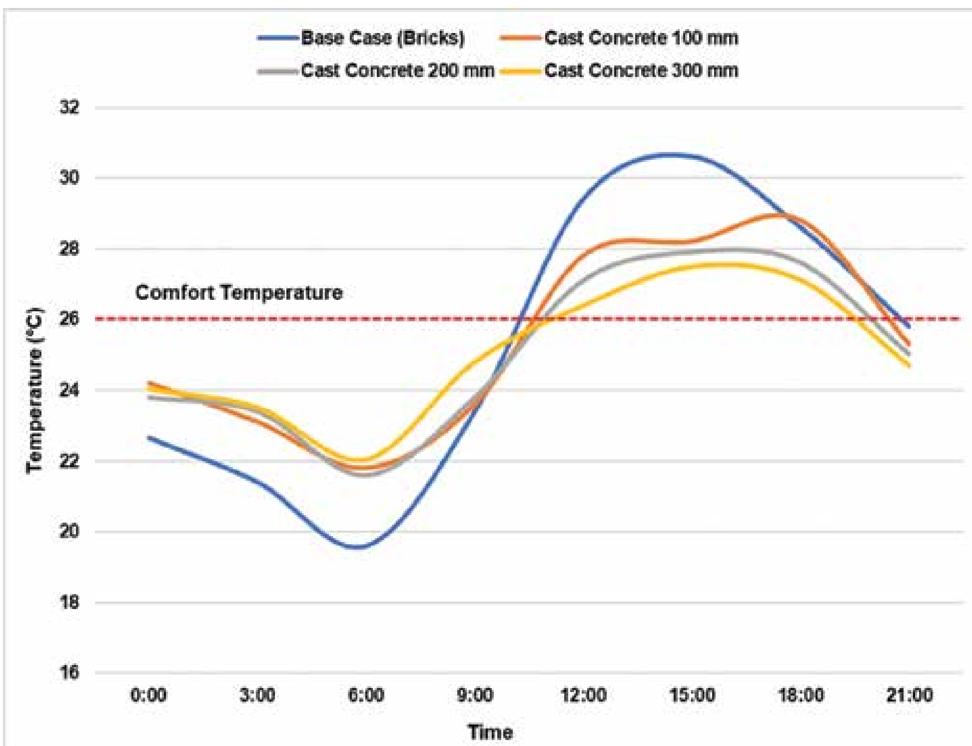

Figure 14: Variation in indoor temperatures using different thickness of cast concrete in the walls

3.2.4 Window glazing

Figure 14 shows the indoor temperature variations in the classroom using cast concrete as thermal mass with different thicknesses. The application of the cast concrete in the walls resulted in lower temperatures during the day, than in the early mornings or evenings due to the longer time lags. The temperature in the classroom at noon is about 3 °C lower than the base case model when using cast concrete of 300 mm thickness. The temperature only peaks after 3:00 p.m., but the classes are already completed by that time. This can be attributed to the storage of heat by the cast concrete during the early time of the day and releasing it only later. Hence, it is suggested to use a lightweight thermal mass material (for Kathmandu) having thickness (100–150mm thick) to reduce the indoor temperature and prevent overheating of the classroom during the warm season.

A previous study done by Kuczyński et al. (2021) in a temperate climate setting showed that increasing thermal mass of a room led to the reduction of the average peak temperature by 3.7K in a day. Similarly, Balaras (1996) found that during summer, heat gets stored in the thermal mass during the day, and gets released only during the evening hours, thus comfort conditions are maintained in the building for most hours of the day.

A window's glazing is its interior glass. It can either be single, double, or triple-glazed. For reducing cooling demands in a building, it has been suggested to improve the U-value of the window glazing. Studies have shown that increased pane count can lower the U-value of the window and thus improves the thermal performance of the glazing (Ford et al., 2006). In this study, the effect of different window glazing on the indoor temperature of the classroom was investigated by applying double and triple-glazing to the classroom windows.

The base case classroom has aluminum windows, which are single glazed, and fitted with 6 mm clear glass. Two simulation scenarios were created by providing first double glazing, with both 6 mm clear glass and air in between, and then, providing triple glazing, with 6-6-6 mm clear glass with air in between. Figure 15 shows the effect of various glazing types on indoor air temperature.

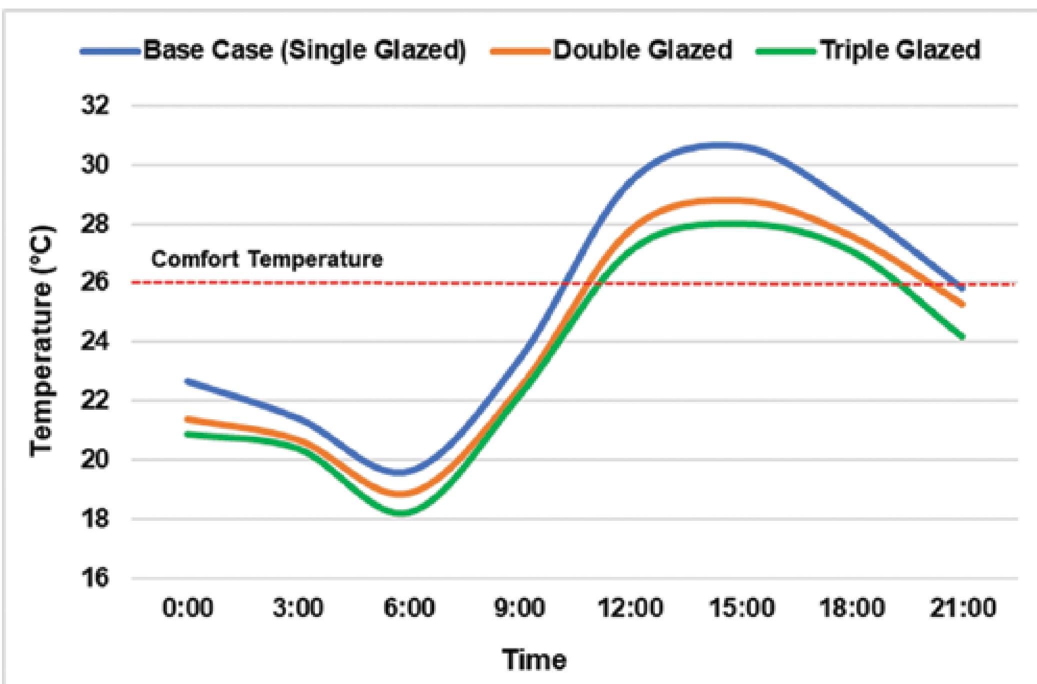

Figure 15: Variation in indoor temperatures using different glazing types

Figure 15 shows the variation in indoor temperature of the classroom when different types of glazing are used in the windows. The indoor temperature decreased for both the simulation scenarios when the double and triple-glazed windows were applied to the base case. The maximum temperature was lowered by 1.8°C for double glazing, and by 2.3°C for triple glazing. This may be because air is trapped between the panels of the glass which limits the amount of heat transfer from one side of the window to the other. Hence, it leads to the cooler temperature inside the classroom. The simulation showed that both the double and triple glazing had almost identical effects on the temperature of the classroom, hence any one of them can be used.

Since double pane is cheaper than triple pane, double pane should be preferred to save costs.

The effect of window glazing in this study is in agreement with the comprehensive analysis of double-glazed windows for different climates done by Banihashemi et al. (2015) which showed that using double glazed windows is far more beneficial when compared to just using single glazed windows as double glazing allowed for better saving of energy loads in both the hot and cold months.

Thus, the simulation study showed that applying all these passive design measures can significantly lower indoor temperatures and help in improving thermal comfort inside the classroom.

4. Conclusions

In this study, the classroom thermal comfort of an educational building during summer was evaluated and improved using passive design strategies through a building thermal simulation tool. The field measurements during June in the classrooms showed that the indoor temperatures were quite high and ranged between 27-32 °C during the class hours. The mean indoor temperature is beyond the adaptive thermal comfort range of 18 – 26 °C for people in Kathmandu. Results from the questionnaire survey among the students illustrated that changes are needed to be made in the classroom as a majority of the students (>80%) felt uncomfortable and are dissatisfied with the classroom's thermal environment. They preferred the classroom to be cooler than the present condition. Then, the simulation of the base case model was performed by applying various kinds of passive design strategies such as thermal insulation, thermal mass, and glazing. The individual simulation results of each strategy showed that the indoor temperature of the classroom was lowered significantly by 2-4 °C, (below 28°C) which is the required comfort temperature for the students during the summer. Thus, the study concludes that applying an appropriate passive design strategy, either during the early design phase or later as a retrofit can help in achieving a comfortable thermal environment in classrooms with minimal costs.

Every research has various obstacles to overcome and limitations to work within, and this study is no exception. This research is a simulation-based study, where the researchers investigated the effects of a specific component (indoor temperature) on the thermal comfort of students in the classroom. It mainly focused on the relationship between indoor temperature (as the variable) and achieving thermal comfort (as the target). Therefore, this paper did not consider the effects of other variables such as relative humidity, air speed, and radiant heat which are required to perform a comprehensive thermal comfort analysis.

Prior research studies regarding thermal comfort of students in Nepalese educational buildings are very limited; hence, this research aimed at presenting a case study to highlight the need for better classroom. Further research is recommended for analyzing more variables and for assessing and enhancing the thermal comfort of both students and teachers in different educational buildings of Nepal.

Acknowledgements

We would like to thank all the students who participated in the questionnaire survey and the teachers and college administration for their help and cooperation during the field study.

Declaration of Competing Interest

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

References

Alghamdi, S., Tang, W., Kanjanabootra, S., & Alterman, D. (2022). Effect of Architectural Building Design Parameters on Thermal Comfort and Energy Consumption in Higher Education Buildings. *Buildings 2022, Vol. 12, Page 329, 12*(3), 329. https://doi.org/10.3390/BUILDINGS12030329

Algifri, A. H., Bin Gadhi, S. M., & Nijaguna, B. T. (1992). Thermal behaviour of adobe and concrete houses in Yemen. *Renewable Energy, 2*(6), 597–602. https://doi.org/10.1016/0960-1481(92)90024-W

Alwetaishi, M., Al-Khatri, H., Benjeddou, O., Shamseldin, A., Alsehli, M., Alghamdi, S., & Shrahily, R. (2021). An investigation of shading devices in a hot region: A case study in a school building. *Ain Shams Engineering Journal, 12*(3), 3229–3239. https://doi.org/10.1016/J.ASEJ.2021.02.008

ASHRAE. (2017). *ANSI/ASHRAE Addendum d to ANSI/ASHRAE Standard 55-2017*. www.ashrae.org

B. Ford, R. Schiano-Phan, D. Z. (2006). The Passivhaus standard in European warm climates: design guidelines for comfortable low energy homes. *Instituto Nacional de Engenharia, Tecnologia e Inovação (in Portuguese).*

Bajracharya, S. B. (2014a). The Thermal Performance of Traditional Residential Buildings in Kathmandu Valley. *Journal of the Institute of Engineering, 10*(1), 172–183. https://doi.org/10.3126/JIE.V10I1.10898

Bajracharya, S. B. (2014b). The Thermal Performance of Traditional Residential Buildings in Kathmandu Valley. *Journal of the Institute of Engineering, 10*(1), 172–183. https://doi.org/10.3126/JIE.V10I1.10898

Balaras, C. A. (1996). The role of thermal mass on the cooling load of buildings. An overview of computational methods. *Energy and Buildings, 24*(1), 1–10. https://doi.org/10.1016/0378-7788(95)00956-6

Banihashemi, S., Golizadeh, H., Reza Hosseini, M., & Shakouri, M. (2015). Climatic, parametric and non-parametric analysis of energy performance of double-glazed windows in different climates. *International Journal of Sustainable Built Environment, 4*(2), 307–322. https://doi.org/10.1016/J.IJSBE.2015.09.002

Borgkvis, I. (2016). *Improving indoor thermal comfort in residential buildings in Nepal using Energy Efficient Building Techniques.* Lund University.

Chaulagain, N., Baral, B., & Bista, S. R. (2019). Thermal Performance of Nepalese Building- A Case Study of Dhulikhel and Biratnagar. *Journal of the Institute of Engineering, 15*(3), 73–77. https://doi.org/10.3126/JIE.V15I3.32012

Cheryan, S., Ziegler, S. A., Plaut, V. C., & Meltzoff, A. N. (2014). *Designing Classrooms to Maximize Student Achievement.* https://ilabs.uw.edu/sites/default/files/14Cheryan_etal_Meltzoff_Designing Classrooms.pdf

Datta. A, M. B. (2009). A COMPARATIVE STUDY OF THE THERMAL PERFORMANCE OF MUD AND BRICK HOUSES IN BANGLADESH. *9th International Conference of Faculty of Architecture Research Unit (FARU).* https://www.researchgate.net/publication/326410455_A_COMPARATIVE_STUDY_OF_THE_THERMAL_PERFORMANCE_OF_MUD_AND_BRICK_HOUSES_IN_BANGLADESH

De Giuli, V., Da Pos, O., & De Carli, M. (2012). Indoor environmental quality and pupil perception in Italian primary schools. *Building and Environment, Complete*(56), 335–345. https://doi.org/10.1016/J.BUILDENV.2012.03.024

Deal, L. J. (2014). *DEPARTMENT OF ENERGY.* 203–204. https://www.energy.gov/buildings/energyplus/energyplus_testing.cfm

Gautam, B., Rijal, H. B., Shukuya, M., & Imagawa, H. (2019). A field investigation on the wintry thermal comfort and clothing adjustment of residents in traditional Nepalese houses. *Journal of Building Engineering, 26*, 100886. https://doi.org/10.1016/J.JOBE.2019.100886

Gupta, V., & Deb, C. (2022). Energy retrofit analysis for an educational building in Mumbai. *Sustainable Futures, 4*, 100096. https://doi.org/10.1016/J.SFTR.2022.100096

Gurung, L. (2020, March 2). *A brief note on the Education Levels of Nepal - Edusanjal.* https://edusanjal.com/blog/education-levels-nepal/

Haseh, R. H., Khakzand, M., & Ojaghlou, M. (2018). Optimal Thermal Characteristics of the Courtyard in the Hot and Arid Climate of Isfahan. *Buildings 2018, Vol. 8, Page 166, 8*(12), 166. https://doi.org/10.3390/BUILDINGS8120166

Heracleous, C., Michael, A., Savvides, A., & Hayles, C. (2021). Climate change resilience of school premises in Cyprus: An examination of retrofit approaches and their implications on thermal and energy performance. *Journal of Building Engineering, 44*, 103358. https://doi.org/10.1016/J.JOBE.2021.103358

Kuczyński, T., Staszczuk, A., Gortych, M., & Stryjski, R. (2021). Effect of thermal mass, night ventilation and window shading on summer thermal comfort of buildings in a temperate climate. *Building and Environment, 204*, 108126. https://doi.org/10.1016/J.BUILDENV.2021.108126

Lamberti, G., Salvadori, G., Leccese, F., Fantozzi, F., & Bluyssen, P. M. (2021). Advancement on thermal comfort in educational buildings: Current issues and way forward. *Sustainability (Switzerland)*, *13*(18). https://doi.org/10.3390/su131810315

Manandhar, R., & Yoon, J. (2015a). A Study on Passive Cooling Strategies for Buildings in Hot Humid Region of Nepal. *KIEAE Journal*, *15*(1), 53–60. https://doi.org/10.12813/KIEAE.2015.15.1.053

Manandhar, R., & Yoon, J. (2015b). A Study on Passive Cooling Strategies for Buildings in Hot Humid Region of Nepal. *KIEAE Journal*, *15*(1), 53–60. https://doi.org/10.12813/KIEAE.2015.15.1.053

McIntyre, D. A. . G. R. (1976). *SE-2416 -- Man's Thermal Sensitivity During Temperature Changes at Two Levels of Clothing Insulation and Activity*. https://www.techstreet.com/standards/se-2416-man-s-thermal-sensitivity-during-temperature-changes-at-two-levels-of-clothing-insulation-and-activity?product_id=1856943

Rai, Y. (2014). *Improving Thermal Comfort of residential buildings in Kathmandu- Using Passive design Strategies*. https://www.academia.edu/18504114/Improving_Thermal_Comfort_of_residential_buildings_in_Kathmandu_Using_Passive_design_Strategies

Rijal, H. B. (2012). Thermal Improvements of the Traditional Houses in Nepal for the Sustainable Building Design. *Journal of the Human-Environment System*, *15*(1), 1–11.

Shafigh, P., Asadi, I., & Mahyuddin, N. B. (2018). Concrete as a thermal mass material for building applications - A review. *Journal of Building Engineering*, *19*, 14–25. https://doi.org/10.1016/J.JOBE.2018.04.021

Shrestha, M., & Rijal, H. B. (2022). *Study on Summer Thermal Comfort and Passive Design Strategy for the Thermal Improvement in Naturally Ventilated Nepalese School Buildings*. https://papers.ssrn.com/abstract=4156101

Shrestha, M., Rijal, H. B., Kayo, G., & Shukuya, M. (2021). A field investigation on adaptive thermal comfort in school buildings in the temperate climatic region of Nepal. *Building and Environment*, *190*, 107523. https://doi.org/10.1016/J.BUILDENV.2020.107523

Shrestha, M., Rijal, H. B., & Shukuya, M. (2019). Field Study on Adaptive Thermal Comfort in Naturally Ventilated Secondary School Buildings in Nepal. *Journal of the Institute of Engineering*, *15*(3), 317–325. https://doi.org/10.3126/JIE.V15I3.32212

Thapa, A., Silwal, A., Sharma, P., Gautam, S. P., Nepal, C. K., Bhattarai, S., & Timsina, D. (2021). Surface air temperature trends in Kathmandu Valley for 2011-2017. *BIBECHANA*, *18*(2), 95–104. https://doi.org/10.3126/BIBECHANA.V18I2.29495

Trebilcock, M., Piderit, B., Soto, J., & Figueroa, R. (2016). A parametric analysis of simple passive strategies for improving thermal performance of school classrooms in Chile. *Https://Doi.Org/10.1080/00038628.2016.1150251*, *59*(5), 385–399. https://doi.org/10.1080/00038628.2016.1150251

Upadhyay, A. K., Yoshida, H., & Rijal, H. B. (2006). Climate Responsive Building Design in the Kathmandu Valley. *Journal of Asian Architecture and Building Engineering*, *5*(1), 169–176. https://doi.org/10.3130/JAABE.5.169

Zahiri, S., & Altan, H. (2020). Improving energy efficiency of school buildings during winter season using passive design strategies. *Sustainable Buildings*, *5*, 1. https://doi.org/10.1051/SBUILD/2019005

Zhang, J., Li, P., Ma, M., Wu, Y., Liu, Z., Kong, Z., Zhang, J., Li, P., & Ma, M. (2022). Thermal Environment and Thermal Comfort in University Classrooms during the Heating Season. *Buildings 2022, Vol. 12, Page 912*, *12*(7), 912. https://doi.org/10.3390/BUILDINGS12070912