Adaptive Thermal Comfort and Energy Saving Potential in Naturally Ventilated School Building in Nepal

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Abstract. The energy use in schools relates to various factors such as local climate, architectural design, thermal comfort, and so on. The present study explores the thermal comfort of students in higher secondary schools in the temperate climatic region of Nepal during the summer of 2019. Altogether 246 students aged 12-18 years have participated in the survey. The indoor and outdoor temperature were measured together with the thermal comfort survey during the regular lesson. The students voted three times during the regular lesson: morning, midday, and afternoon. A literature review was conducted on energy use in schools in various countries. The comfort temperature in the afternoon was significantly higher than in the morning or in the midday. The comfort temperature is related to the air movement and operative temperature. The strategies such as insulation, shading, and ventilation are helpful to maintain indoor temperature which contributes to the energy saving in building. The Nepalese school students are adapting in the thermal environment of classrooms without energy use.

1. Introduction
A correct energy use may improve the thermal environment of school buildings. Energy use for thermal comfort relates to various factors such as local climate, architectural design, and so on. Users' comfort regarding indoor air quality, thermal, visual, and acoustic comfort is considered as “an integral part of the building performance approach” and is inevitably linked to the energy use [1]. After the payroll in schools, energy is another second higher expense in mechanically conditioned schools [1]. Thermal adaptation and energy use are commonly used behaviours to optimise thermal comfort. Behaviours of people used for adaptation in winter in cold climate have a lower comfort temperature which is an important way for energy saving [2]. The energy use rate in Nepalese schools is comparatively lower than in residential buildings. As most school buildings in Nepal are naturally ventilated (NV), students rely on natural ventilation and behaviours to maintain thermal comfort. Therefore, a very limited amount of energy is assumed to be used. The school buildings in Nepal are constructed using local materials that are suitable for the local climate and can create a comfortable thermal environment. But it may not always be the same, because of harsh outdoor climate in peak seasons, the indoor condition may reach uncomfortable. Knowing the adaptive thermal comfort and behaviours used by the students to mitigate the harsh indoor thermal environment in that period, the development of adaptive model and energy use potential can be understood. No studies are focusing on energy issues in the Nepalese school buildings. This study is aiming to identify the thermal comfort and behaviours of the students under the condition of natural ventilation. A literature review was conducted to evaluate the energy use in secondary schools in various countries.
2. Methodology

2.1. Investigated areas and school buildings
Nepal is topographically divided into a mountainous Himalayan region with a cold climate, the middle with a temperate climate, and the south with a sub-tropical climate. A field survey was conducted in 7 classrooms of 3 school buildings in the temperate climate, with altitude ranges from 600 to 3000 m. One school is from Kathmandu and two from Dhading districts. None of the classrooms were equipped with mechanical heating and cooling system. All classrooms have windows of different sizes for cross-ventilation and daylighting. The classrooms are mostly rectangular with approximate dimensions of 3.7 m × 3 m × 2.43 m to 7.5 m × 5.52 m × 2.5 m. The building walls were made of bricks and stones, and the wall surfaces were finished with mortar and plaster. All investigated classrooms were on the ground floor. The average number of students in classrooms is 35.

2.2. Survey on thermal comfort of students
This study collected data based on simultaneous environmental measurement and questionnaire survey. The study was conducted from 22 to 28 May 2019. The air temperature, globe temperature, relative humidity, and air movement were measured using digital instruments. All instruments were placed in the centre of the classrooms at a height of approximately 1.1 m above the floor level. Altogether 246 secondary level students, 145 females and 101 males, from 12 to 18 years old participated in the survey. The thermal sensation (Figure 1) was voted by the students in sedentary conditions without intervening the regular lesson in the morning, in the midday, and in the afternoon. The questionnaire was distributed to the students at the beginning of the lesson. First, we took 15 min to explain the purpose of this survey and how the questionnaire sheets should be filled out.

![Figure 1. Scale used for thermal sensation](image)

3. Results and discussion

3.1. Indoor and outdoor thermal environments during the voting time
Altogether 21 sets of measured environmental quantities were obtained. The mean radiant temperature \(T_{\text{mrt}}\) and operative temperature \(T_{\text{op}}\) was calculated using the measured value of indoor air temperature \(T_i\), globe temperature \(T_g\), and air movement \(V\) \[3\]. Table 1 summarizes the indoor and outdoor environmental quantities during the voting time. The mean indoor and outdoor temperatures \(T_o\) in the midday is significantly higher than in the morning or afternoon. The mean of indoor air, indoor globe, and operative temperatures are almost similar. The mean indoor relative humidity is 44–50%. The mean air movement is 0.25–30 m/s.
3.2. Comfort temperature of students

Griffiths method [4] is applied to estimate the comfort temperature using a regression constant of 0.50. This method takes no adaptive behaviour used by students on the thermal environment and can estimate the individual comfort temperature. The following Griffiths equation is used:

\[ T_c = T_e + \frac{(4 - TSV)}{0.5} \]  

where \( T_c \): Comfort temperature (°C). Mean comfort temperatures in the morning, midday, and afternoon are 26.3 °C, 26.7 °C, and 27.8 °C respectively. Statistically, a significant difference is found in comfort temperature for morning and midday or afternoon (p<0.001) (Fig. 2). Fanger et al. [5] found that no significant difference between ambient temperatures preferred by subjects in the morning and the evening and they concluded that the same thermal comfort conditions can be used from morning to evening. Figure 3 shows the relationship between the comfort temperature and air movement. The higher the air movement, higher the comfort temperature is up to the air movement 0.4 m/s. Figure 4 shows the relationship between the comfort and operative temperatures. On increasing operative temperature, comfort temperature also increases. The comfort temperature of students is slightly lower than the actual temperature of the classrooms.

![Figure 2. The mean comfort temperature (Mean ± 2S.E.) by time.](image-url)
Figure 3. The mean comfort temperature (Mean ± 2S.E.) by air movement binned at 0.1 m/s.

Figure 4. Relationship between the comfort and operative temperatures

3.3. Adaptive behaviours used by the students in classrooms

Behaviours are used by the students to optimise thermal comfort in the classrooms using available opportunities. We asked how they control the thermal environment of the classroom to adapt during summer and the result of their answers are shown in Figure 5. The result showed that the use of controls is a significant part of adaptive behaviours to adapt in the classroom thermal environment. Maximum responses were obtained for the opening windows and drinking water out of all behaviours. Such behaviours are to react to the thermal environment of the classrooms passively and it can, therefore, help to reduce building energy demand. It is found in previous studies [2, 6, 7] that not only good passive building design and temperature setting but also various adaptive behaviours of people, such as clothing adjustment and window opening closing save energy.
Figure 5. Adaptive behaviours used by the students. Multiple options of behaviours were chosen by students.

4. Energy use in school buildings

The energy use intensities in university and school levels are different because of various factors such as the number of students, laboratory equipment, and operating time. A study conducted in a French university campus [1] noticed an appropriate recommendation to increase thermal comfort of students reducing energy consumption such as retrofitting. In Luxembourg, a study conducted in 68 school buildings found [8] that insulation and air tightness can reduce the energy demand. The authors pointed out in the context of the USA [9] that the 173 and 257 kWh/m² energy is used in terms of the global (total) energy consumption in primary and secondary schools. For Ireland, typical energy consumption (fossil fuel and electricity) was 131 and 142 kWh/m², respectively [10]. A recent study in Korea [11] found that the annual average consumption was 133 kWh/m². Wang [12] reported that the annual energy consumption of elementary, middle, and high schools in Taiwan was 17, 16, and 26 kWh/m², respectively, and that of universities was 79 kWh/m². Energy use intensity was low in elementary and middle schools because of alternative practices such as opening windows and the use of an electric fan. Gil-Baez et al. [13] in Spain studied that 18 to 33% of primary energy can be saved using the natural ventilation system while maintaining the thermal comfort of students in the classroom. By using natural ventilation, the energy use over the academic year was lower than when mechanical ventilation was used. Figure 6 shows a review of articles on energy use intensity in schools in various countries [8, 15-22]. In the USA, 80% of energy is used for heating, cooling, lighting, and ventilation [21]. Figure 7 shows general information on energy consumption in the USA. Maximum energy is used for space heating. Rijal et al. [6] reviewed that a significant amount of heating and cooling energy can be saved if the temperature setting is lowered or increased used for heating or cooling respectively in air-conditioned buildings. And this study raised the strategy to save energy using passive building design and adaptations. Especially, the window opening and clothing adjustments are effective ways to optimise the thermal comfort in naturally ventilated buildings. A study in China [18] showed that energy consumption in school buildings is declining because of the priority of passive technology such as buildings insulation.

In Nepal, approximately 84% of the total energy is used by residential and 2% by commercial and public sectors [23]. There is no quantitative study on energy use pattern in schools in Nepal which inform how much energy is using to maintain the thermal comfort of the students. It is considered that because of the economic condition of Nepal, a very limited amount of energy is assumed to be used to maintain the thermal comfort of students. As we presented the results above, students mostly rely on adaptive behaviours to maintain thermal comfort. Electricity is the primary energy to run computer labs, lighting, and fan to mitigate harsh indoor temperature in public and private schools in urban areas. Some schools in rural areas meet energy demand using solar for lighting, operation of basic science equipment, computer, and printing machine. Simple passive solar heating and cooling system could
reduce the utility costs of electricity. Fuller et al. [24] investigated a method of improving thermal comfort in high altitude buildings in Nepal by increasing ceiling insulation levels. Energy consumption and energy efficiency awareness in schools highlighted the reduction in energy consumption [25]. Therefore, if we make a priority issue to adaptive behaviours and passive design of school buildings, we will have a significant energy saving potential in the coming future.

![Figure 6. School’s energy use intensity in different countries](image)

![Figure 7. Average energy use percentage of schools in the USA [21]](image)

5. Conclusions
The present study identified the thermal comfort condition of Nepalese secondary school students during the summer of 2019. The major findings are as follows.
1. The comfort temperature was higher in the afternoon than in the morning or midday. This might be related to the thermal adaptation of students at different times of the day. The comfort
temperature is related to the air movement and operative temperature. An appropriate opportunity to use adaptive behaviours is key in school buildings for improving the thermal comfort.

2. The annual energy consumption in secondary schools in various countries was different based on the strategies used. A priority on passive building design and behavioural adjustments would be energy saving strategies in the Nepalese school buildings.

6. References

[1] Allab Y, Gau X, Pellegrino M, Nefzaoui E, Kindinis A 2017 Energy Build. Energy and comfort assessment in educational building: Case study in a French university campus 143 2002-19
[2] Rijal HB 2021 Energy Build. Thermal adaptation of buildings and people for energy saving in extreme cold climate of Nepal 230 110551
[3] Shrestha M, Rijal HB, Kayo G, Shukuya M 2001 Build. Environ. A field investigation on adaptive thermal comfort in school buildings in the temperate climatic region of Nepal 107523
[4] Griffiths ID 1990 Report to the commission of the European communities Thermal comfort in buildings with passive solar features: Field studies University of surrey, Guildford, UK
[5] Fanger PO, Højbjerre J, Thomsen J 1974 Int. J. Biometeo. Thermal comfort conditions in the morning and in the evening 18 16-22
[6] Rijal HB, Yoshida K, Humphreys MA, Nicol JF 2021 Architectural Science Review Development of an adaptive thermal comfort model for energy saving buildings design in Japan 64(1-2) 109-122
[7] Rijal HB, Humphreys MA, Nicol JF 2018 Japan. Arch. Rev. Development of a window opening algorithm based on adaptive thermal comfort to predict occupant behavior in Japanese dwellings 1(3) 310-321
[8] Thewes A, Maas S, Scholzen F, Waldmann D, Zürbes A 2014 Energy Build. Field study on the energy consumption of school buildings in Luxembourg 68 460-70
[9] Pereira LD, Raimondo D, Corgnati SP 2014 Renewable and Sustainable Energy Reviews Energy consumption in schools – A review paper 40 911-22
[10] Jones PG, Turner RN, Browne WDJ, and Illingworth PJ Energy benchmarks for public sector buildings in Northern Ireland 1–8
[11] Kim T, Kang B, Kim H, Park C, Hong W 2019 Energy Reports The study on the Energy Consumption of middle school facilities in Daegu, Korea, 5 993-1000
[12] Wang J 2016 Energy Build. A study on the energy performance of schools’ buildings in Taiwan 133 810-22
[13] Gil-Baez M, Paudra AB, Huelva MM, Chacartegui R 2017 Energy Natural ventilation systems in 21st century for near zero energy school buildings 1-15
[14] Katafygiotou MC, Serghides K 2014 Energy Build. Analysis of structural elements and energy consumption of school building stock in Cyprus: Energy simulations and upgrade scenarios of a typical school 72 8-16
[15] Lourenco P, Pinheiro MD, Heitor T 2014 Energy Build. From indicators to strategies: Key Performance Strategies for sustainable energy use in Portuguese school buildings 85 212-24
[16] Hernandez P, Burke K, Lewis JO 2008 Energy Build. Development of energy performance benchmarks and building energy ratings for buildings: An example for Irish schools 40 249-54
[17] Hong SM, Paterson G, Mumovic D, Steadman P 2014 Build. Res. Inf. Improved benchmarking comparability for energy consumption in schools 42 47-61
[18] Ma H, Lai J, Li C, Yang F, Li Z 2019 Energy Procedia Analysis of school building energy consumption in Tianjin, China 158 3476-81
[19] Fillipin C 2000 Build. Environ. Benchmarking the energy efficiency and greenhouse gases emissions of school buildings in central Argentina 35 407-14
[20] Butala V, Novak P 1999 Energy Build. Energy consumption and potential energy savings in old school buildings 29 241–46
[21] Good Practice Guide - 343 (GPG343) 2003 Saving Energy – A whole school approach
[22] Natural resources Canada 2013 Survey of commercial and institutional energy use: establishments 2009
[23] Nepal energy sector assessment 2017 strategy and road map, ADB
[24] Fuller RJ, Zahnd A, Thakuri S 2009 Build. Environ. Improving comfort levels in a traditional high altitude Nepali house 44 479-89
[25] Pietrapertosa F, Tancredi M, Salvia M, Proto M, Pepe A, Giordano M, Afflitto N, Sarricchio G, Leo SD, Cosmi C 2021 Journal of Cleaner Production An educational awareness program to reduce energy consumption in schools 278 123949

Acknowledgments
We would like to thank all the students and teachers for their cooperation in our field study despite of them regular lessons. This research did not receive any specific grant from funding agencies.