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Analysis of Solar Radiation for Pedestrian comfort in the streets of hot and humid climate, A case of Lumbini, Nepal

Apekshya Ghimire [a], Sanjaya Uprety [b], Ashim Ratna Bajracharya [c]

[a, b, c] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 076mseeb002.apekshya@pcampus.edu.np, [b] suprety@ioe.edu.np, [c] ashim@ioe.edu.np

Abstract

The development of road sections is a very important and critical responsibility in changing the local pedestrian behavior. The construction of roadside building structures should be carried out keeping in mind the solar shading it provides to that road section, especially in hot and humid regions. Walking outside in Lumbini's hot and humid climate is challenging, even for short distances, due to the bright sunshine during the day. Shading of the walkways influences the commuting behavior of pedestrians significantly. So, the study seeks to examine the effect of buildings and vegetation on pedestrian thermal comfort due to shading by existing buildings and vegetation. A structured questionnaire and solar analysis using Sketchup were used to examine the present conditions of the street connecting Mahilwar to Majhediya and the comfort it provides to pedestrian. In a typical east-west oriented street section, it was found that buildings over three stories performed better as shading agents compare to the buildings less than 2 stories on the southern side while plantation of local trees provides shading all over the year regardless of the direction. The buildings present in the street of Lumbini Sanskritik Municipality performed poorly in providing shade to the pedestrian walkway during the summer when it is mostly desired. Thus, this study concludes that constructing buildings over three stories provides shading to the southern walkway, and planting local trees helps in shading of the pedestrian walkways even in the north direction.

Keywords

Shading, Pedestrian Thermal comfort, Solar Analysis

1. Introduction

Walking outside in Lumbini's hot and humid climate is challenging, even for short distances, due to the bright sunshine during the day. Since direct sun radiation and high temperatures cause thermal stress on the human body, pedestrians tend to change their outgoing time during the morning or evening. Direct sun radiation exposure can lead to health issues such as heat exhaustion and dehydration. Furthermore, people's preference for going outdoors has a detrimental impact on the region's economic and tourism activity. As a result, the streets must be shaded to increase the number of people and their thermal comfort.

Basically, thermal comfort refers to a condition where people feel neutral and do not desire to change the thermal condition. According to [1], thermal comfort is the state of mind that is assessed by subjective evaluation that expresses satisfaction with the thermal environment. Outdoor thermal comfort is an important issue that seems to be neglected most of the time, especially in the context of Nepal. The energy consumption pattern of the households along with internal thermal comfort has been studied in past but there is less importance given to outdoor and pedestrian thermal comfort. Department of road and Department of Urban Planning have looked into pedestrian comfort from the field of safety but pedestrian thermal comfort is yet to be studied.

A route that can be walked from start to finish without raising the core temperature of the human body or causing perceived discomfort is a thermally comfortable pedestrian route (TCPR) [2]. Shading the streets by any means such as vegetation, artificial shading devices or building itself makes the route thermally comfortable. Many types of research claim shading as an effective way to reduce thermal discomfort in outdoor thermal conditions [3][4] [5]. For a route to be comfortable for all the summer days, the shading coverage should be more than 62 percent [2].

Thermally as well as aesthetically comfortable streets promote walkability and sustainability as it encourages people to not rely on a vehicle for short distances. In order to establish and sustain walkability, it is important to make urban streets comfortable as far as the ambient climate permits [6]. The configuration of buildings and vegetation creates an obstruction to the direct solar radiation that strikes the street thus helping in the reduction of temperature thereby improving thermal comfort. Hence, it is imperative to study the effect of buildings and vegetation on direct solar radiation.

Since, the temperature ranges between 22 °C to 41 °C in Terai region of Nepal, it is difficult to carry out outdoor activities during the sunny day. People tend to shift their outgoing time to only in the early morning or late evening due to scorching solar radiation during the daytime. In the context of Nepal, there is not much research carried out that provides ideas to reduce direct solar radiation in the street. This research examines the effect of buildings and vegetation on solar radiation in a street of Lumbini Sanskritik Municipality for pedestrian comfort.

1.1 Outdoor Thermal Comfort

Outdoor thermal comfort is an indicator that cannot be quantified easily. However, it can be described as the range of climatic conditions where most of the people feel comfortable [7]. Outdoor thermal comfort is dependent on different climatic variables along with other parameters such as psychological and physiological. The major climatic variables that affect outdoor thermal comfort are air temperature, mean radiant temperature, humidity, and air speed. If all these parameters are in balanced condition with the heat energy balance of human body, then thermal comfort can be achieved.

Psychological and physiological parameters also affect thermal comfort in outdoor conditions. Physiological parameters including skin and core temperatures, as well as perspiration rate and psychological factors like behavior, culture, alliesthesia, etc. are useful indicators of outdoor thermal comfort [8]. Out of all these parameters and factors, the most significant factor that affects heat gain and loss is solar radiation [9]. Hence, the arrangement of buildings and vegetation that provide shading to the street is an important aspect to look at so as to reduce the direct solar radiation in the street and to improve the thermal comfort in outdoor conditions.

1.2 Solar radiation access in the street

Solar radiation has a significant impact on many elements of urban life, including street temperature climate, day illumination, solar energy use such as photovoltaic cells, and the well-being of living creatures[10] [11]. Solar access and shading conditions have a significant impact on the street micro climate. The geometry of buildings, street orientation, and availability of vegetation determine the access of solar radiation incidents to the street. Shade surfaces in urban settings, such as streets, seating spaces, building facades, and roofs, limit direct sun radiation and so efficiently keep the temperature low [12].

In a study carried out at a university campus in Central Taiwan, it was found that suitable shading is required in outdoor spaces to ensure thermal comfort either by buildings or vegetation [13]. Another study concluded that shaded spaces provided more thermally comfortable conditions than unshaded areas since the shaded areas have a longer period of acceptable temperature range [14]. It was discovered that increasing the roadway width from 15 m to 20 m enhanced sun radiation by (17-20 percent)[15].

The exposure of direct solar radiation in the street is a critical parameter for pedestrian thermal comfort. The incident radiation during the daytime makes the street thermally uncomfortable, especially in a hot and humid region. The streets become thermally uncomfortable if no shadings are provided due to high-intensity solar radiation incident to the region. It is very difficult to walk during the daytime, especially during the summer season. Hence, streets should be designed in a way to utilize solar access to improve urban micro climate and pedestrian thermal comfort.

The shading can be done either from buildings or vegetation or artificial shading devices. The street surfaces receive the highest solar radiation when the aspect ratio is low [16]. The aspect ratio and orientation determine the quantity of solar radiation incident and also affect the ambient surface temperature of the street [17]. The increase in height of a building or decrease in width of the road increases the shading which decreases the air temperature and physiologically equivalent temperature, thereby improving the thermal comfort at the pedestrian level especially in the summer [18].

2. Methodology

The study used a mixed-method approach to investigate the influence of buildings and vegetation on pedestrian thermal comfort due to shading. Using Kobo Collect, a structured questionnaire was utilized to examine pedestrian perceptions of the shaded and unshaded outdoor environments. During the sunny outside settings, 15 samples were obtained. Sketchup was used to model a 100 m street as a reference for the solar analysis.

3. Study Area

3.1 Lumbini Sanskritik Municipality

The study area was chosen in Nepal's Lumbini Province, Rupandehi District, which is located in the Hot and Humid Climatic Zone. The research is carried out in a street of Lumbini Sanskritik Municipality which begins from gate number 5 to villages like Madhubani, Mahilwar, etc. The street near the Lumbini master plan consists of hotels and lodges with very few residences. The width of the street is 13 m (42.6'), with a 2 m (6.5') pedestrian sidewalk, while the surrounding buildings have 1 to 5 stories. Only two mango trees were found to be present in this road section.

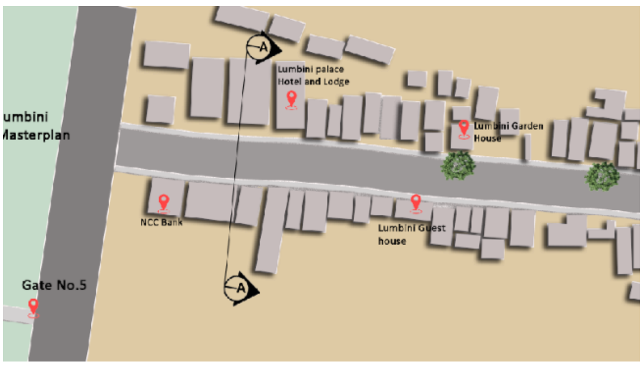

Figure 1: Site Selection Top View (Google Earth)

4. Findings and Discussion

The data collected from the field visit was used to model the buildings in SketchUp for solar analysis. This resulted in the presence of variations in building

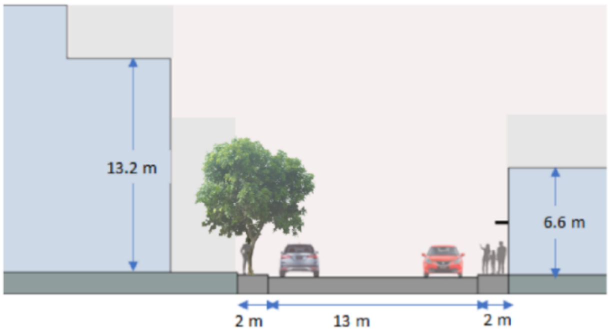

Figure 2: Site Section View

heights in the base case. It was observed that a few buildings on the western side of the south section of the road possessed cantilever slabs of 800 mm which acted as shading devices for the pedestrian walkway. Figure 3 depicts the variation of heights available in the study area.

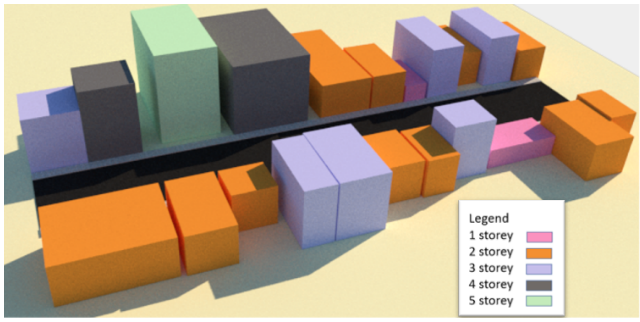

Figure 3: Building Heights in the selected site

4.1 Questionnaire Survey

The questionnaire survey was carried out on July 22. Thermal conditions before 8 am were determined to be tolerable, whereas temperatures between 9 am and 10 am were found to be suitable for some and unacceptable for others. The thermal conditions in the afternoon were found to be unacceptably hot, however, the thermal conditions in the evening after 4 p.m. were determined to be rather pleasant.

Most of the people prefer moving to the shaded area rather than using umbrellas to reduce clothing.

4.2 Solar Analysis

From figure 6, it can be seen that the southern buildings cast a shadow on the southern pedestrian walkways while northern pedestrian walkways are illuminated all along the year in East-West oriented streets. The buildings of different heights cast shadows differently as seen in the figure. The tree

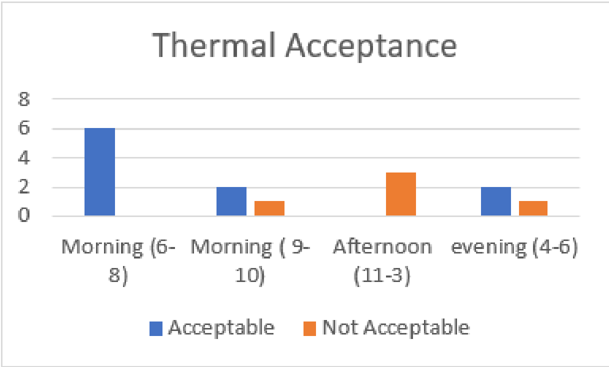

Figure 4: Thermal Acceptance

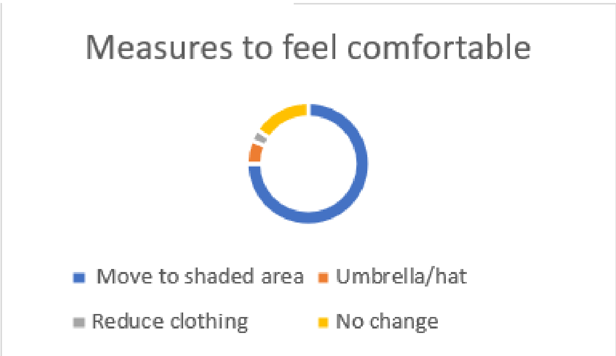

Figure 5: Measure to feel comfortable

casts a shadow around it making the pedestrian walkway around the tree thermally comfortable. For

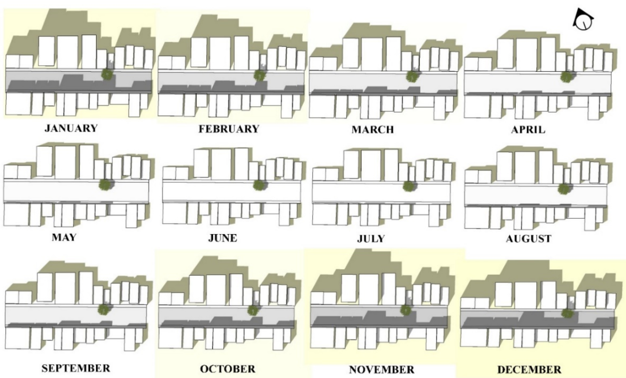

Figure 6: Monthly solar analysis of selected site

the months from November to February, being winter season, the buildings in the southern section of the road are efficient enough in shading the southern walkway while the northern walkway fails to be shaded. Only the part with the vegetation was found to be somewhat shaded. For the month of March, it was observed that the present buildings were somewhat feasible in terms of walkway shading but in the case of April and May, only the tall buildings (more than two storey) were able to provide shade to their walkway whereas short buildings (less than two storey) with protruding cantilever slabs were also actively involved in shading the walkway. For the month of June, no shading on the walkway was observed at all by the buildings whereas slight shading of the walkway begins from the month of July by only the tall buildings. Beyond august, the walkways are either partially or fully shaded by the present buildings during the peak time of 2 pm. Like in the winter months, September and October the current buildings were successful in providing complete shade to the walkways.

Thus, the pedestrian walkway towards the southern side is completely in shade from September to March. When the sun comes towards the zenith, the shaded portion begins to decrease as seen from the figure. Due to the low position of the sun during the winters, the present buildings were efficient enough to provide complete shading to the southern side of the road whereas in the summer due to the high position of the sun, the same buildings fail to provide enough shading to the same road section which is undesirable. From 7

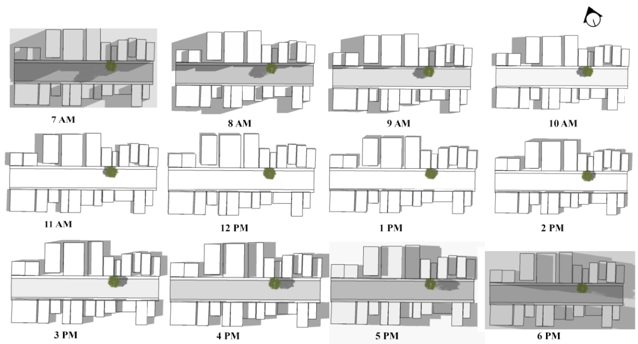

Figure 7: Hourly solar analysis on July 22nd

a.m. to 8 a.m., the northern half of the roadway is entirely shadowed by the northern buildings, with some shading at 9 a.m. The streets are entirely lighted after 9 a.m., with shade around the tree only until 12 p.m. After 12 p.m., the sun position shifts as the street's southern walkway begins to be shadowed. The buildings over three stories shade the southern walkway, however, the street is thermally unpleasant due to the height range of the buildings and the shaded walkway. The street is thermally uncomfortable 9 a.m. to 5 p.m. in the month of July.

From the monthly and hourly solar analysis, it was observed that the pedestrian walkways were shaded better by the buildings more than three stories all over the year but it is not enough to completely shade the entire walkway to the extent of improving pedestrian thermal comfort. The solar analysis as well as field survey proves that the current street is still not comfortable enough to the pedestrians to continuously interact with the public spaces present there.

5. Conclusion and Recommendation

The present building layouts in the road sections are not very efficient in shading every part of the walkway throughout the year which makes it more difficult for pedestrians to commute through this road. While it has been found that the same building section is shading the walkways during winter, it was found to be lacking during the summer when it is more desirable. The presence of vegetation also helped to shade the area around it which is quite encouraging in terms of pedestrian comfort as well as the street aesthetics. So, buildings of more than two storeys of height are recommended for the southern section of the road while plantation of local trees is strongly suggested to improve the shading of the northern section of the road. Thus, this study concludes that southern buildings over three storeys provide shading most of the time in the southern walkway however, trees can provide shading around it all over the year regardless of the direction of the streets.

6. Limitations

The study focuses on the current situation as it is, with no additional intervention. This study concentrates solely on the solar analysis of the first row of buildings on each side of the road and avoids the idea of the light plane altogether. To facilitate the study, homogeneous box models were utilized in place of the real building structures, with the height remaining constant. Only 100m of the road was chosen for analysis, which does not represent the entire situation of the Mahilwar to Majhediya road. Hence, further study can be conducted with interventions in building height and the positioning of vegetation that can provide improved shade. The influence of building shadowing on other rows of urban arrangement may also be explored.

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