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Assessment of Pedestrian Thermal Comfort on Sidewalks

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Abstract
With the growing problem of urban densification and the urban heat island effect, the thermal comfort of pedestrians in the outdoor spaces of urban areas has deteriorated. Since the street is the most important outdoor space that can promote physical activity, and especially with the emerging concept of walkable cities, thermal comfort in streets should be given utmost importance. Thermal comfort for pedestrians is the absence of any sense of discomfort when interacting with the outdoor thermal environment. Considering that a thermally comfortable street promotes walkability, this study aims to identify the comfort parameters in the sidewalks of the street and evaluate the thermal environment through a questionnaire survey. The study adopted a quantitative approach and chose the questionnaire survey as a research method to achieve its objective. The survey was conducted on both sidewalks of Durbarmarg, one of the dense and busy streets of Kathmandu, with a random sample of 18 people. The results of the study showed that the physical characteristics of the street, such as building shade, the presence of vegetation, and the paving material, are the most important factors for pedestrian comfort. The survey also found that the selected street section was not thermally comfortable in summer, as the majority of people felt hot, warm, or very hot sensation and preferred cooler air temperature, weaker sunlight, and stronger wind. The study concludes that subjective assessment of the thermal environment through a comfort survey is important and probably the first step before taking measures to improve thermal comfort, especially under the climatic conditions in Kathmandu.

Keywords
Pedestrian, Thermal Comfort, Sidewalks

1. Introduction

Rapid population growth has resulted in dense urban areas that are changing urban morphology. The change in the proportion of vegetation and the type of land cover led to the phenomenon of urban heat island effect [1] . This has and worsens urban comfort conditions. The outdoor environment in cities includes the variety of activities for pedestrians. The comfort level of pedestrians is one of the determining factor for the number of the people outside. The rough definition of the pedestrian comfort is the pleasant feeling that people get when interacting in the environment. The concept of pedestrian thermal comfort falls under the umbrella concept of pedestrian comfort.

ASHRAE (American Society of Heating and Refrigeration and Air conditioning Engineers) defines human thermal comfort as condition of the mind that expresses satisfaction with the thermal environment which is determined by environmental and individual variables. The thermal comfort of streets is particularly important because they have a high potential to promote physical activity. This is evidenced by the fact that they are frequently used for walking and other outdoor activities. Sidewalks are pedestrian paths that run along a street. Sidewalks provide pedestrian mobility and access to the buildings, parks and other amenities.

Street has its own microclimate. The amount of solar radiation absorbed by street surfaces, as well as their orientation and geometry, create their own microclimate. The microclimate of streets affects the comfort of pedestrians walking. Walking is the most natural and most common way of transportation in cities including Kathmandu. Walking for short distances could be one of the promising strategies to reduce Vehicle Miles Traveled (VMT), transport-related energy consumption, and associated environmental impacts [2]. Walkability, or the ease

with which pedestrians can move around a city, is cited by many urban planners as the factor that makes a city livable. Thermal comfort is one of the most important factors influencing pedestrian health, and increasing thermal comfort improves walkability [3].

The Kathmandu Valley, with an estimated population of 2.54 million, is growing at an annual rate of 6.5 percent, making it one of the fastest growing metropolitan areas in South Asia[4]. Mishra, et al, [5] study of the urban heat island in Kathmandu found an average temperature difference of 5°C between forested and urban areas in the Kathmandu Valley. Moreover, an annual increase of 0-2°C was found over the last 18 years. This means that Kathmandu is getting hotter day by day. The current urbanization and motorization in Kathmandu does not provide a safe and pleasant environment for walking. Most streets do not even have sidewalks, and those that do exist are either poorly maintained or occupied by parked vehicles and street vendors. Electricity and telecommunication poles were placed indiscriminately throughout the city, often in the middle of sidewalks[6]. Many street improvement projects carried out under the Municipal Infrastructure Improvement Project (MIIP), Kathmandu Sustainable Urban Transport Project (KSUTP) have focused on vehicular movement and drivers' convenience rather than pedestrian comfort, convenience and safety [7].

In such an environment, thermal comfort for pedestrians on sidewalks is a distant prospect. Therefore, the study aims to assess the comfort level of pedestrians and determine the comfort parameters on sidewalks in one of the street sections of Kathmandu.

2. Literature Review

The study of outdoor thermal comfort is the growing field of interest among researchers. The beginning of studies on outdoor thermal comfort dates back to the last few decades of the 20th century [3] . Majority of the researches were based on simulations or were experimental without subjective results. In 2001, one of the first studies in the field of outdoor thermal comfort was conducted based on human behavior. In this study Nikolopoulou et al. [8] investigated thermal comfort conditions in open spaces in Cambridge, United Kingdom. They rated the sensory perception of each individual on a scale of 1-5. In this study, only 35 percent of the participants experienced the desired thermal comfort. In last decades, over 500 studies were done with subjective results [9].

Outdoor thermal comfort is mainly related to thermo-physiology, i.e. physiology and heat balance of the human body [10] that is directly affected by meteorological conditions. There are various parameters for outdoor thermal comfort. They can be categorized into subjective and objective. The subjective parameter consists of behavioral and psychological aspect whereas the objective parameter consists of air temperature, mean radiant temperature, metabolic heat, wind, and humidity and clothing insulation. They can be further categorized as the personal and environmental factors. There are three approaches to defining thermal comfort. To begin, the psychological aspect refers to the mental expression of satisfaction with the outdoor thermal condition. Second, the thermo-physiological aspect influences biological reactions and thermal receptors on the skin in response to the external environment. Third, the energetic aspect is concerned with the flow of heat from and to the human body.

Sidewalks run parallel to street and Sidewalks and streets not only facilitate easy movement for pedestrians, but are also considered the most important public spaces in a city. Sidewalks mainly consists of 3 zones: Frontage zone, pedestrian through zone and street furniture/curb zone. The frontage zone is a section of the sidewalk that serves as an extension of the building. The pedestrian through zone is the main accessible pathway for pedestrians and the street furniture/curb zone consists of street furniture and amenities such as lighting, benches and bicycle parking. As per Urban Road Standard 2076, for comfortable movement of people with disabilities, the minimum clear width of a footpath should be 2.0 m, but 2.4 m is desirable, at least along arterial and secondary roads.

Several physical parameters determine the thermal environment for the pedestrians in the street: the pavement materials, presence/absence of vegetation, street aspect ratio, no. of the people and vehicles passing by the street. If a person feels "hot," it may be from the sun or from the materials used in the environment, such as asphalt used as pathway [11].

Sidewalks consist of trees and grass as soft landscaping elements and paving materials and street furniture as hard landscaping elements. Trees and Vegetation contributes to the modification of street

micro-climate in primarily providing shading, evapotranspiration and directing wind [12].Paving materials have a strong effect on the street micro-climate and represent one of the main contributors to the increase of urban heat island [1]. The different characteristics of vegetation like the foliage shape and dimensions, height of trunk, leaf area density has impact on outdoor thermal comfort. Similarly, the thermal properties of the pavement materials can be modified to enhance the thermal comfort in streets. Cool pavements have been identified as solution worldwide which are basically pavements with modified thermal properties than traditional pavements. They have different properties than regular ones in order to lower their surface temperature.

3. Research Setting

For this research, the street with proper sidewalks and immense flow of pedestrians was selected for case study. The selected case study area, Durbarmarg (informally known as Kings's way), is located in the metropolis of Kathmandu and is a very dense and lively street in Kathmandu. It leads to the royal palace of Narayanhiti. Durbar Marg, built in 1961 by the then Crown Prince Birendra Bir Bikram Shah Dev, was known as a center for travel business with airlines, travel agencies, restaurants and tourist shopping. Slowly, it has evolved into a business district that serves people as a shopping and entertainment destination. The pedestrian flow on the street is immense. The number of pedestrians passing the street at a certain point was recorded at different times of the day and on both sidewalks. It was found that pedestrian flow was greater on east facing Sidewalk than west facing sidewalk. On June 27 at 4:30 p.m., approximately 36 people passed in one minute.

The selected stretch is about 300 metres long and oriented in the N-S direction. The street consists of commercial buildings that vary from 2 to 5 floors. A variety of stores, restaurants and bars, shopping centres and offices can be found in the selected area.

The street consists of the vehicular zone and pedestrian zone. Vehicular zone consists of the 4 lanes. The sidewalks are on both sides. For convenience: they are named East facing sidewalk and West facing Sidewalk.

The frontage zone of the sidewalks varies between 2 and 3 m, the pedestrian passage zone is 2.8 m, and the curb zone is 1.3 m. There is little street furniture on the

Figure 1: Location map of the selected street section

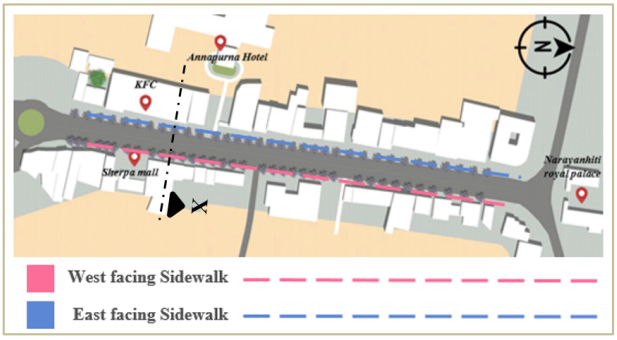

Figure 2: Plan of Selected street section

east-facing sidewalk. The tree species planted in the street is Jacaranda Mimosifolia, and on the sidewalks there are different paving materials that vary in the building frontage and pedestrian zone.

4. Methodology

The methodology adopted for the study of the outdoor thermal comfort so far includes the use of simulation software, questionnaire survey and measurement and combination of simulation software and questionnaire survey.However, the study adopted a quantitative approach and chose the questionnaire survey as a research method to achieve its objective. It is the method used to collect data from the target group of respondents in order to gain knowledge about the topic of interest.

The questionnaire was prepared and first tested among the few pedestrians, and the necessary changes were made. The questionnaire was divided into demographic information, purpose of visit, thermal sensitivity, and micro-climate preference.

Demographic information included gender, age group, weight, etc. Reason for visit included purpose, frequency, and time of visit. The heat sensation survey is a standard parameter in most thermal experiments. It is a 7 point scale ranging from -3 (cold), neutral (0) to +3 (hot).The survey was done for 7 days from 27th of June to 6th of July on favorable climatic conditions on the both sidewalks. Random sampling was done for the survey. Most of the pedestrians did not want to take part in the survey due to various reasons and hence and the total number of respondents were limited to 18.

5. Data Set, Analysis and Discussion

The following figures show the results of the questionnaire survey. Data analysis was performed using the Kobotool box and the software IBM SPSS.

5.1 Demographic details

Though the target group for this survey were pedestrians, few security guards and street vendors were also surveyed. Among the no. of respondents, 61 percent of them were male and 67 percent of them were from the age group 20-30 and the weight of the respondents ranged from 60-80. Figure 5 shows the

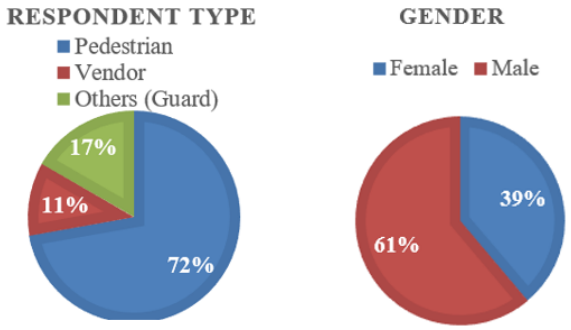

Figure 3: Respondent type and gender

sky conditions during the survey. 33 percent of the survey time the sky was mostly sunny, 28 percent partly sunny and the rest of the time the sky was mostly cloudy or overcast. The survey was carried out in both sidewalks and the percentage of no. of respondents in the sidewalks in shown in the figure 8. Most of people either preferred east facing sidewalk (45 percent) or both sidewalks (33 percent). As mentioned earlier the pedestrian movement is more in east facing sidewalk, the reason might be because of the presence of the street furniture, restaurants and shops. Since the people have tendency to walk in the

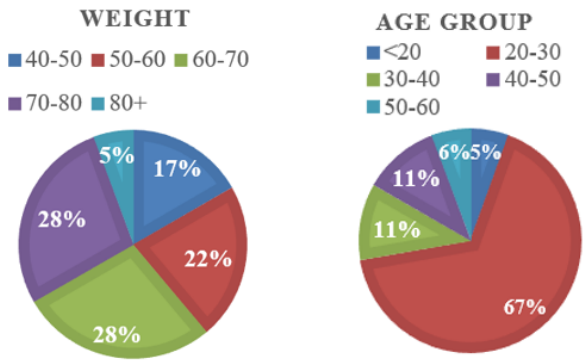

Figure 4: Weight and age group of Respondents

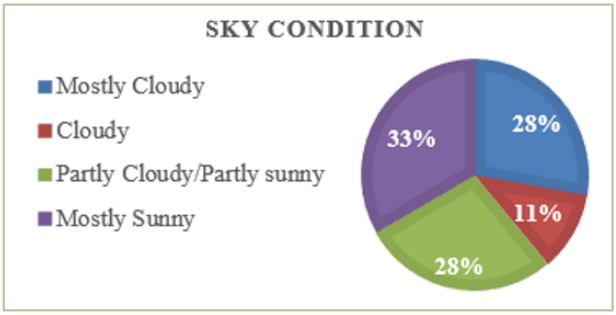

Figure 5: Sky condition during Survey

shade during summer, the thermal comfort might be also one of the reasons.

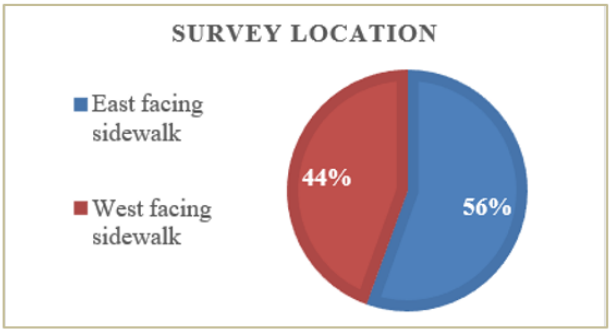

Figure 6: Survey Location

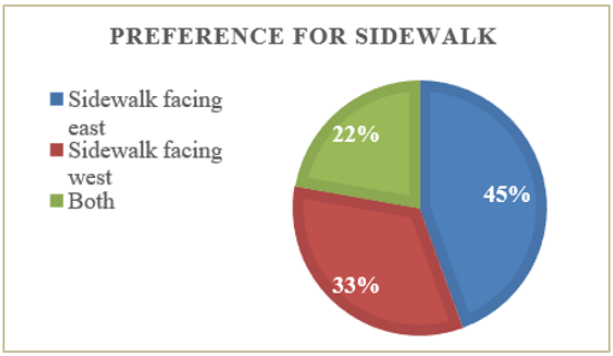

Figure 7: Preference for Sidewalks

5.2 Activity mapping during Survey

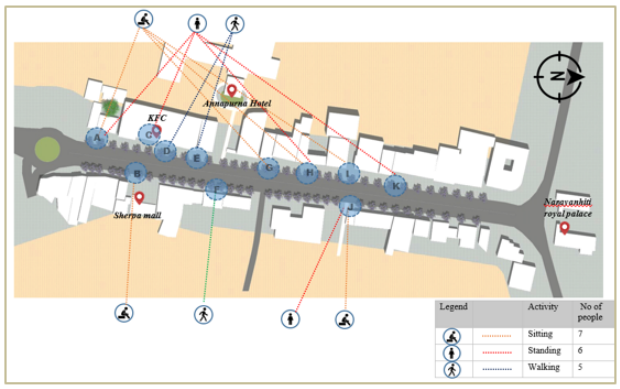

Figure 8: Activity mapping during Survey

Activity mapping was also done during the survey with its GPS location. The figure 8 shows the location of the survey within the site and the activity of the individuals during the survey. 39 percent of the individuals were sitting, 33 percent were standing, and 28 percent were walking during the survey. Most of the people surveyed were sitting on the benches along the roadside in east facing sidewalk and around Sherpa mall in west facing Sidewalk. Most

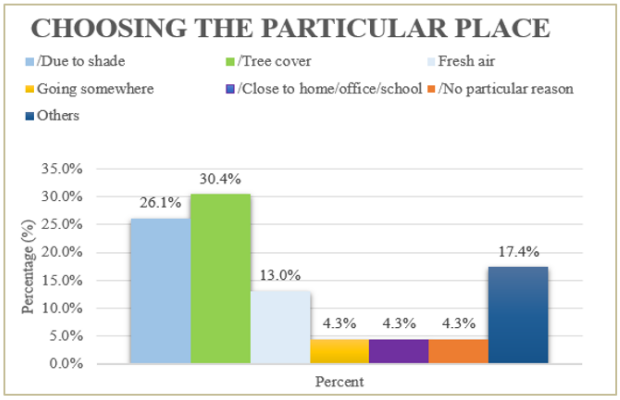

Figure 9: Choosing the particular place

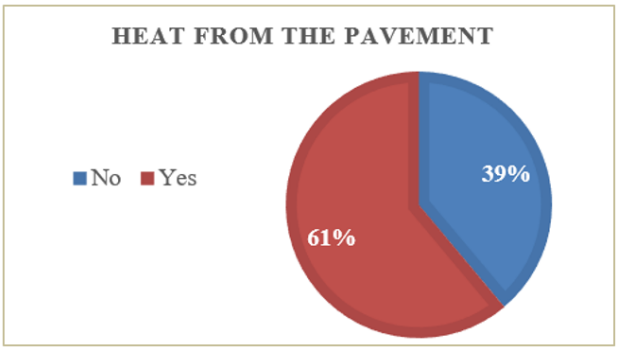

Figure 10: Heat from the pavement

respondents (30.4 percent) chose the particular place to sit/stand/walk mostly because of tree cover and 26.1 percent of them chose the place due to shade. As mentioned earlier, vegetation and the physical attributes of a place also influences the thermal environment of the place.

From the literature studies, the paver materials also affected the thermal environment of the sidewalks, hence the question was included. Majority of the respondents (61 percent) felt the heat from the pavement.

5.3 Reason and time of visit

The figures 11 and 12 show that the reason for visiting the street was work and that 50 percent of the respondents visits the street in the period from 10 am to 2 pm. The temperature is generally highest in the period from 10 am to 2 pm, but since the majority of respondents were there because of work, it can be assumed that thermal comfort has the least influence on visiting the street in this period.

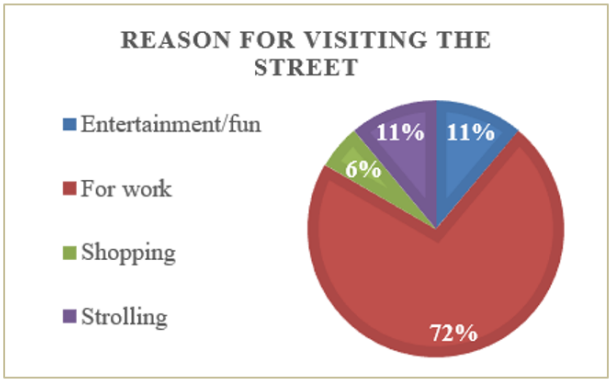

Figure 11: Reason for visiting the street

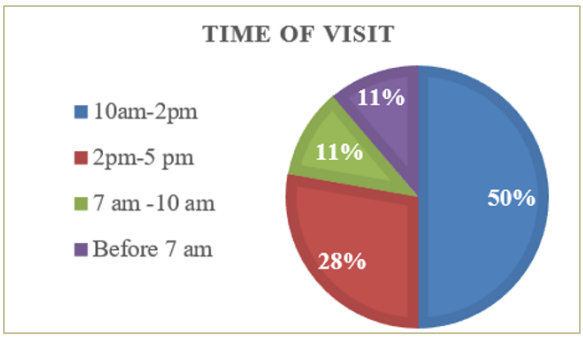

Figure 12: Time of visit to the street

5.4 Thermal Sensation

7 point scale was used to assess the thermal sensation of the respondents. Around 33.33 percent felt neutral thermal whereas the rest of them felt either warm, hot or very hot sensation during the survey. The table 1

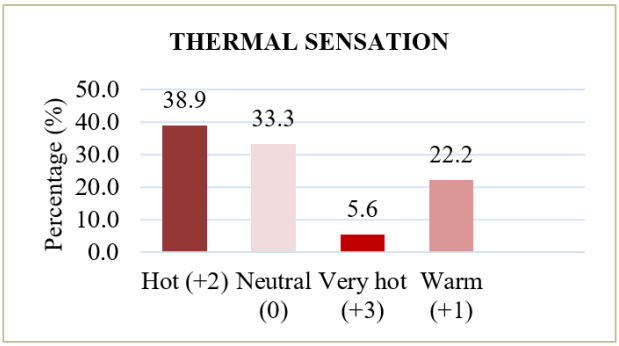

Figure 13: Thermal Sensation

shows the relation between Sky condition and thermal sensation. Since the solar radiation has major role to play for the thermal comfort, it is expected that the pedestrians feel most uncomfortably warm or hot during the sunny bright day in summer. As seen from

Table 1: Relation between Thermal Sensation and Sky Condition

Sky condition	Thermal Sensation				Total
	Hot (+2)	Neutral (0)	Very hot (+3)	Warm (+1)	
Mostly Cloudy	11.1%	5.6%		11.1%	27.8%
Cloudy		5.6%		5.6%	11.1%
Partly Sunny	11.1%	5.6%	5.6%	5.6%	27.8%
Mostly Sunny	16.7%	16.7%			33.3%
	38.9%	33.3%	5.6%	22.2%	100.0%

the table 1 , out of the 33.33 percent of sunny sky condition same percentage of people (16.7percent) felt hot and neutral despite of the sky condition, it might be because of the clothing level, activity level of respondents and also the location of the pedestrians within the street. Other climatic factors such as wind, relative humidity can also affect the comfort level of pedestrians.

5.5 Preference for microclimate

The last part of the survey dealt with the preference for microclimate. 66.7 percent of respondents wanted a cooler air temperature, while the remaining 33.3

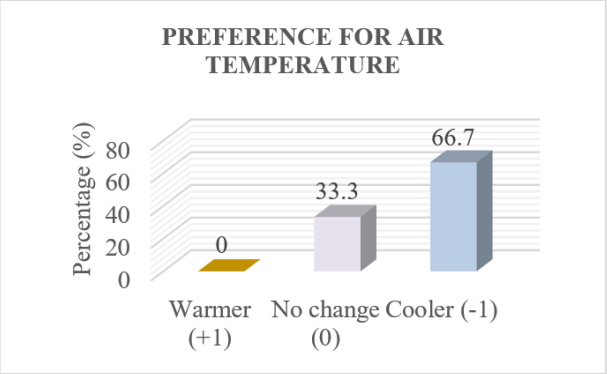

Figure 14: Preference for air temperature

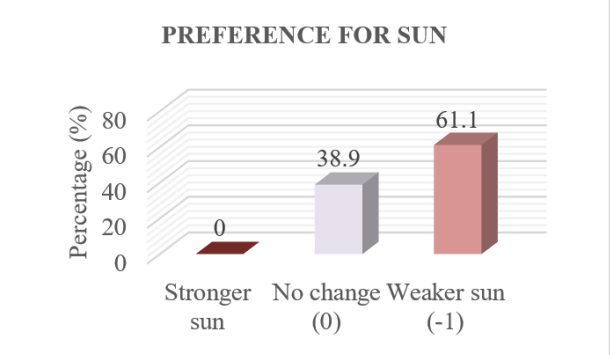

Figure 15: Preference for Sun

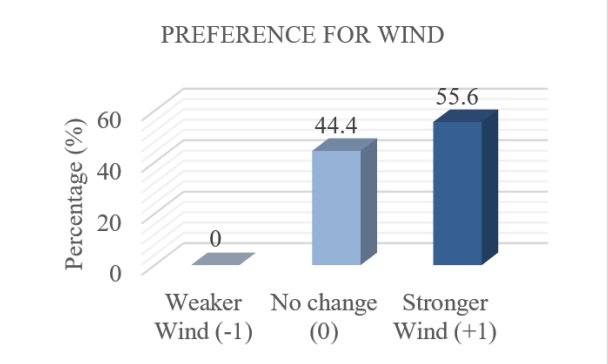

Figure 16: Preference for Wind

percent of respondents wanted no change in air temperature. Similarly, 61.1 percent of respondents preferred weaker solar radiation, while the remaining 38.9 percent of respondents wanted no change in solar radiation. For wind, 55.6 percent of respondents preferred stronger wind, while the remaining 44.4 percent of respondents wanted no change in wind.

6. Conclusion and Recommendation

In this study, the thermal comfort of pedestrians was investigated using one of Kathmandu's busiest streets

as an example. Durbarmarg. The results of the study are consistent with the literature review. The physical characteristics of the sidewalks such as the shade of buildings, the presence of vegetation (trees), and the pavement materials affect the thermal environment of the sidewalks. Since a majority of the people (66.7 percent) felt either the hot ,warm or very hot sensation and most of the people preferred the cooler temperature (66.7percent), weaker sun (61.1 percent) and stronger wind (55.6 percent), it can be concluded that the sidewalks of Durbarmarg was not thermally comfortable for pedestrians during summer.

The study concludes that activity mapping and thermal sensation study are of utmost importance especially in the climatic conditions of Kathmandu. In temperate climatic regions like Kathmandu, the study is also important in winter. However, the study was conducted only in summer. Therefore, further research is needed as the study was conducted in a typical street section and only during the few summer days. A random sample was drawn for the questionnaire survey and the sample size was small (total number of respondents: 18), so the results of the survey cannot be generalized to a larger population. Similar studies can be conducted in different street segments and in summer and winter if the sample is large enough. The study also shows that further studies can be conducted considering parameters such as the aspect ratio of the street, vegetation, and paving materials using the simulation research method.

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