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ORIGINAL ARTICLE SCIENCE & ENGINEERING

ASSESSMENT OF THERMAL COMFORT IN URBAN PUBLIC SPACE IN A TROPICAL CITY: A STUDY OF RAJSHAHI, BANGLADESH

Md. Sabbir Ahsan*; Md. Asaduzzaman; Md. Nazmul Hoda; Tamanna Sultana Swarna

Department of Architecture, Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh

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Abstract

Sustainable design approaches reduce energy consumption of urban form and the environment. Urban public space design is an efficient sustainable strategy to improve thermal and microclimatic conditions of outdoor spaces. A tropical city like Rajshahi, Bangladesh, an example of a rapid urbanization, is now dealing with the challenge of sustainable urban development, especially in the urban public space where thermal comfort makes a vital role for active to use of outdoor space in the various time. People's activities and usages of outdoor space particularly urban public place which is the most viable and sustainable features of urban design is directly affected by thermal setting and thus affect people's activities. This research aims to calculate the thermal comfort indices to find out the comfort condition of the urban public space by using a CFD based simulation software "ENVI-Met". Online sources are used to collect site specific microclimatic data for thermal comfort. Data is then synthesized to find out MRT and thermal comfort condition. The aim is to develop and recommend a checklist of comfortable urban form and potential design and materials features to investigate the scope of improvement of outdoor thermal comfort of urban public space of study area. Both the physical (height width ratio of urban form, vegetation, water features, orientation, materials) has strong impact on improving thermal comfort and activities. This research suggests some urban design options for an effective and comfortable outdoor space in the context of tropical city like Rajshahi in the end.

Keywords: Outdoor thermal comfort, urban microclimate, tropical city, ENVI-Met, Mean Radiant Temperature.

Introduction

The quality and usability of Urban open spaces is determined by many factors. Outdoor thermal comfort is one of the aspects of the urban open space which is influenced by urban microclimate. Subsequently urban microclimate is a product of local physical form of the surrounding building and landscape and interaction with the regional climate or macro climatic parameters/factors. Tropical cities have climate where heat is considered as a major problem. The problem is compounded with high humidity and low wind speed due to urban compact form. The unplanned growth of cities followed by rapid urbanization is simultaneously

*Corresponding author: <sabbirahsan@arch.ruet.ac.bd>
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replacing the natural elements transforming the urban microclimate. The building massing characteristics such as height, density, shape, orientations, and materials, comprising the street pattern, are essential components of 'urban geometry' (Carfan et al., 2012; Sharmin et al., 2015). This wide range of parameters influences the urban microclimate by contributing to the increase or decrease in temperature as well as wind speed variation in the certain context of the urban area. These microclimatic conditions determine the quality of open spaces, to which pedestrians are directly exposed. Again, the unplanned urban-built fabric causing Urban Heat Island (UHI) effect reduces the thermal comfortability greatly. Therefore, the thermal comfortability of the people affected by the local microclimate (Chen & Ng, 2012) is directly associated with urban design (Carfan et al., 2012). The rising concern of comfortable microclimate in the outdoor public space initiates the motivation of this study. A few relevant studies on understanding the outdoor climatic comfort conditions are mostly limited to the locations of the capital city, Dhaka. This indicates the importance of the need to investigate the thermal comfort concerning outdoor urban-environmental qualities in other rapidly growing cities (like Rajshahi) of tropical climates, for future urban design prospects. The findings from this study will provide a valuable reference to the strategies of thermal comfortability of outdoor public space in the context of Rajshahi and will create further scope of research with other variables. Outdoor open spaces contribute greatly to urban livability and vitality. Traditionally and historically, junctions of the roundabout of streets or nodes, the squares (Chawk) were the magnet spaces of the city that were active socially as community interaction points responding to the geo-climate (Mowla,A.2008). In the global context of climate change, a consistent rise in temperature in the urban areas along with the urban heat island (UHI) effect has the potential to negatively impact the community's lives and urban livelihood (Huq, 2001). Several studies have demonstrated that urban form, vegetation, presence of water bodies, and envelope conditions can alter urban microclimate. The study on microclimatic influence on outdoor activities by Gehl (1971) showed that people's willingness to stay in an open space significantly depends on the local sunny or shady conditions (Chen & Ng, 2012). In these circumstances, ensuring quality open spaces and urban living for the increasing urban population urges proper planning. The difference in climate and urban morphologies of the Global South results in denser urban geometry in the selected context, not similar to the Western pieces of evidence (Sharmin et al., 2015). Thus, the strategies to improve thermal comfortability in outdoor open spaces applied in the Western are not suitable for the selected site.

Therefore, the main objectives of the study are as follow:

- To identify the impact of urban morphology, envelop condition, and orientation on the urban microclimate (i.e. Temperature, relative humidity, radiation, wind speed, and mean radiant temperature) in relation to outdoor thermal comfort.
- To explore methods of using simulation study to evaluate outdoor thermal comfort and its relationship with microclimatic parameters in urban open space.

Climate Profile of Rajshahi

Rajshahi is located in the north western part of Bangladesh within the Barind track at an elevation of 23 meter above sea level. The city is situated on the Padma River's alluvial plains, which flows through the southern part of the city. According to the Bangladesh Bureau of Statistics (2011), the city has a population of more than 7,63,952 people (Wikipedia, Bangladesh bureau of statistics). According to the Köppen climatic classification Rajshahi has a tropical wet and dry climate (http://www.meteotemplate.com/template/plugins/climate Classification/koppen.php). The climate is characterized by monsoons, high temperatures, high humidity, and moderate rainfall. Early in March, the hot season begins and lasts until the middle of July. During the pre-monsoon (hot-dry or summer) period i.e. March, April, May the highest mean temperature is around 33 °C to 35 °C, while the minimum mean temperature in winter season (cool-dry) i.e. December, January, February is around 11 °C to 13 °C. The monsoon months get the highest rainfall. The district receives roughly 1,448 mm of rain each year. The following table (Table 1) summarizes climate data obtained from Bangladesh's Meteorological Department.

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Table 1. Summary of climatic information of Rajshahi

Type	Season	Month	Mean max. DBT: °C	Mean min. DBT: °C	Monthly mean temp.: °C	RH min.: %	RH max: %	Monthly mean wind speed m/s	Precipi -tation mm/ month	Monthly global radiation (MJ/m²)
Cool dry	Winter	Dec	25.8	12.6	19.2	58	98	0.82	10.6	14.19
		Jan	24.5	11	17.75	57	99	0.45	11.3	18.72
		Feb	27.7	13.1	20.4	47	95	0.45	17.5	20.4
Hot dry	Pre Monsoon (Summer)	Mar	33.1	17.8	25.45	34	92	0.82	24.8	22.01
		Apr	35.7	22.7	29.2	41	89	1.34	63.7	21.43
		May	34.5	24.3	29.4	59	91	1.30	136.4	17.32
Hot wet	Monsoon	Jun	33.4	25.8	29.6	73	93	1.27	264.6	15.96
		Jul	32.1	26	29.05	77	97	1.15	320.7	17.07
		Aug	32.3	26.1	29.2	76	96	1.16	273.9	15.06
		Sep	32.2	25.6	28.9	76	96	0.69	295.9	13.64
	Post Monsoon	Oct	31.7	23.2	27.45	69	97	0.55	106.4	16.77
		Nov	29.3	17.9	23.6	60	96	0.36	16.3	14.78

According to Köppen climate classification, which is probably the most widely used climate classification systems and is based on mean temperatures and precipitation and their seasonality, Rajshahi has a humid subtropical climate with dry winter. It is denoted as Cwa in this climate classification system.

Table 2. Temperature profile of June 21 in Rajshahi

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Temperature	26.7	26.4	26.2	26	25.8	26	26.5	27.8	29.2	30.5	31.7	32.4	33	33.4	33.4	32.9	32.3	31.6	30.4	29.6	28.9	28.2	27.7	27.2

The area chosen as a case study for outdoor thermal comfort is 'Shaheb Bazar Zero Point' which is situated at the center of CBD in Rajshahi city. It is located at the junction point on the south side of the main road that runs along the east-west direction. The branch road which goes to new market from this junction point in northward direction has an extension to the south side of the main road. This extension is used as an outdoor public place, which is surrounded on three sides by buildings. On the south side there is a three storied large mosque. This mosque has narrow road on three sides. East and west edges of this open space have commercial developments. On the west side there is a five storied shopping mall and on the east side there are two storied buildings. This public open space is stayed partially shaded throughout the day due to the building on three sides.

Materials and Methods

To attain the aforementioned objectives, the study combined multiple strategies (Figure 1). At first phase, a literature review was conducted to find out the variables that are related to the outdoor thermal comfort in urban open space. This also provided a theoretical framework for the study.

Rajshahi, a tropical city of Bangladesh, located on the north-western part of the country was chosen as case study. An urban open space, Zero point, Shaheb bazar, which is at the heart of the city's CBD area was selected for simulation study of the microclimatic variables. Meteorological data of Rajshahi was collected from published data in website by Bangladesh Meteorological Department. For the purpose of simulation, June 21 was selected as it observes the longest day of the year (Table 2).

Figure 1. Google map of the site.

Figure 2. Site drawing of and building height information.

In second phase, field measurement was performed to produce drawing of the urban open space with surrounding urban form. Also field observation of envelop material and urban open space edge condition were recorded. Photographs were also taken for survey. To investigate relationship among microclimatic variables ENVI-met 4.4 were used. ENVI-met is a robust program which can perform multi-physics simulation in urban scale. The model is based on the work of Bruse and Fleer (1998) and Bruse (2004). This software can simulate microclimatic model of three dimensional space based on Cartesian coordinates. It can calculate interaction of surface-plant-atmosphere in the urban environment. The simulation software operates with two physical systems. The Land surface comprised of two separate layer – soil and vegetation. For the sake of simplicity, the equation of Fourier and Richards are used to calculate the heat and moisture exchange. The study of Clapp and Hornberger (1978) are used for the classification of soil based on soil hydraulic parameters. Bruse (2004) used formula of Pielke (1984) and Tjernström (1989) to calculate thermal conductivity and diffusivity. Vegetation are assumed to be a multilayered system which exchange energy and moisture with the surrounding atmosphere.

To compute the complex interaction between wind speed, air temperature and humidity in atmosphere Reynolds and Navier-Stokes equation averages are used. Here the turbulence model is based on turbulent kinetic energy (E) and its dissipation rate (ε) by Launder, Spalding (1974). According to the information provided in ENVI-met website (http://www.envi-met.com) numerical model does not work properly at the edge of the simulation are due the limitation of computation. As these edge is missing at least one neighboring grid. Therefore, the best way to avoid this limitation is to set the model as far as possible form the border.

The whole process of simulation can be divided into three steps (Figure 2). In ENVI-met 'Workspace' tool is used to set up the material properties according to the field survey data. Then 'Spaces' tool is used to produce three dimensional model of the site. Finally, 'ENVI-guide' is used to input climate information and prepare the file for simulation.

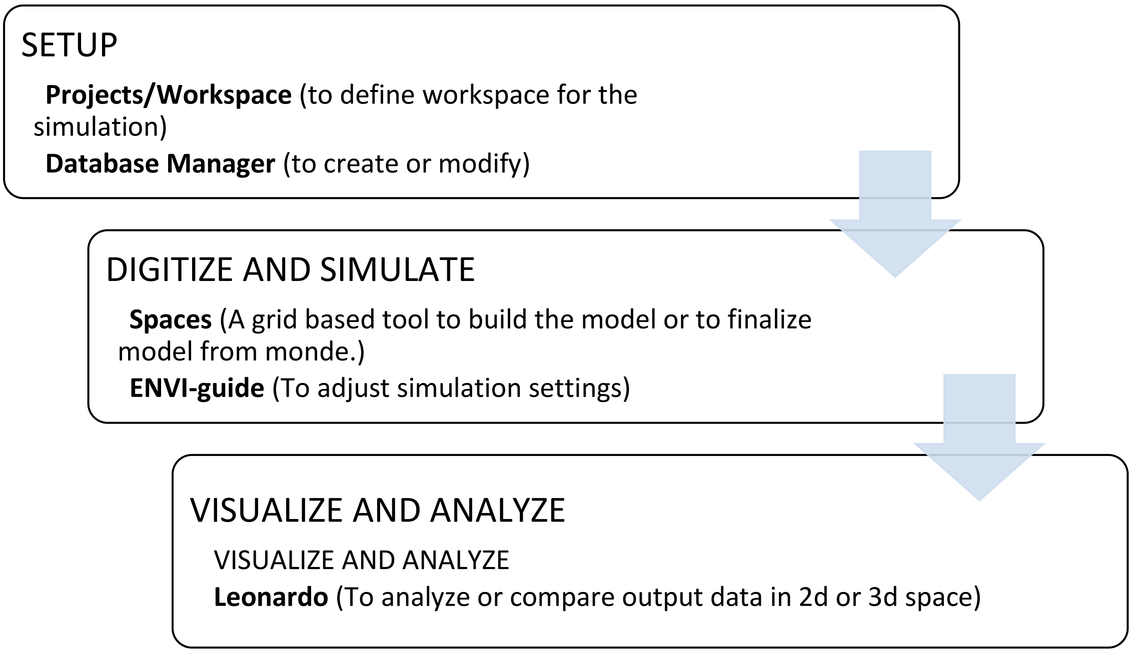

Figure 3. ENVI-met simulation process.

To investigate the impact of urban morphology, envelop condition, and orientation on the urban microclimate three points has been chosen in the urban open space for parametric study. The first point 'Point A' is located near the main road having Cartesian coordination of (22, 27) (Figure 5) in ENVI-met 'Spaces'. It has building surfaces on either sides of east and west and exposed to direct and diffuse radiation throughout the day. The second point 'Point B' is located at the middle of the open space having Cartesian coordination of (25, 20) (Figure 5) in ENVI-met 'Spaces'. It is surrounded on three sides and partially shaded. The third point 'Point C' is located under the shade of the building with a coordination of (30, 17) (Figure 5) in ENVI-met 'Spaces'. This point stays shaded thought out the day. To assess the influence of envelop material on MRT and subsequently on outdoor comfort condition four materials are used in ENVI-met simulation. The thermal properties of these materials are shown in the following table.

Analysis part of the study contains the examination of the data obtained from field survey and simulation. Atmospheric data generated by the simulation shows the impact of urban sites and how it modifies

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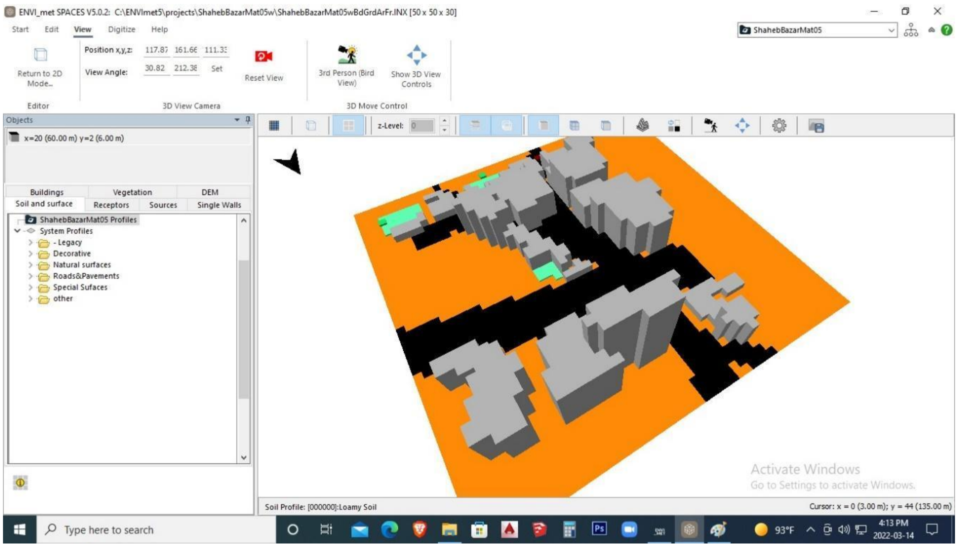


Figure 4. 3D model of the site in 'Spaces' of ENVI-met.

air temperature, humidity, radiation, air flow and mean-radiant temperature subsequently influences outdoor thermal comfort. After statistical analysis of the data, inferences are made of the relationship between outdoor thermal comfort and climatic elements.

Table 3. Material properties used in simulation for parametric study

	Wall 5" Brick (SI unit)	Wall 10" Brick (SI unit)	Wall 10" Concrete (SI unit)	Glass wall (SI unit)
Layer	3	3	3	1
Thickness	0.127	0.254	0.254	0.02
Absorption	0.60	0.60	0.50	0.50
Transmittance	0	0	0	0.90
Reflection	0.40	0.40	0.50	0.50
Emissivity	0.90	0.90	0.90	0.90
Specific heat	1200	1200	850	750
Thermal conductivity	0.44	0.44	1.60	1.05
Density	1500	1500	2220	2500

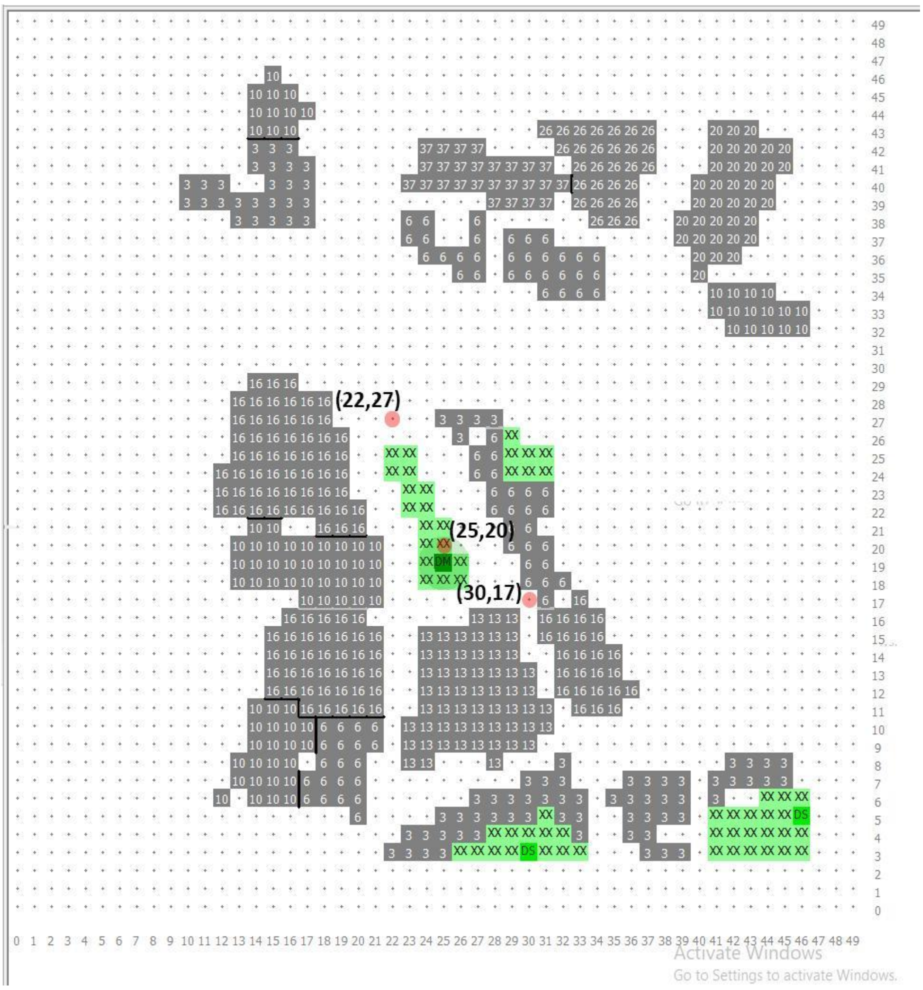


Figure 5. Location of three points for parametric study. (Grey areas are building, Red circles are point for simulation and green areas are greeneries)

Results

Figure 6 shows the simulation output of potential air temperature for four different building envelop materials including 5 inch brick wall, 10 inch brick wall, 10 Inch concrete wall, Glass Wall, respectively at 12:00 pm when sun position was directly above the public space and at 16:00 pm when sun position is angular with the outdoor open space.

The Table 4 shows that air temperature of out-door space remains almost unchanged due to variation of the different building envelop materials. But, the air temperature difference between 12:00 pm and 16:00 pm is largest at point C (30, 17) which remains in shade than other two points A (22, 27) which is partially shaded and B (25, 20) which is in open space.

Figure 7 shows the mean radiant temperature of point A in the urban open space simulated for four different building envelop materials from 8:00 am to 20:00 pm. Maximum MRT found at 14:00 pm for point A, at 15:00 pm for point B and at 16:00 pm for point C. On the other hand, air temperature of point A, B and

C for those different materials remains almost unchanged due to variation of the different building surface materials. The temperature rises gradually in the morning and reaches peak at 16:00 pm and then falls in the evening.

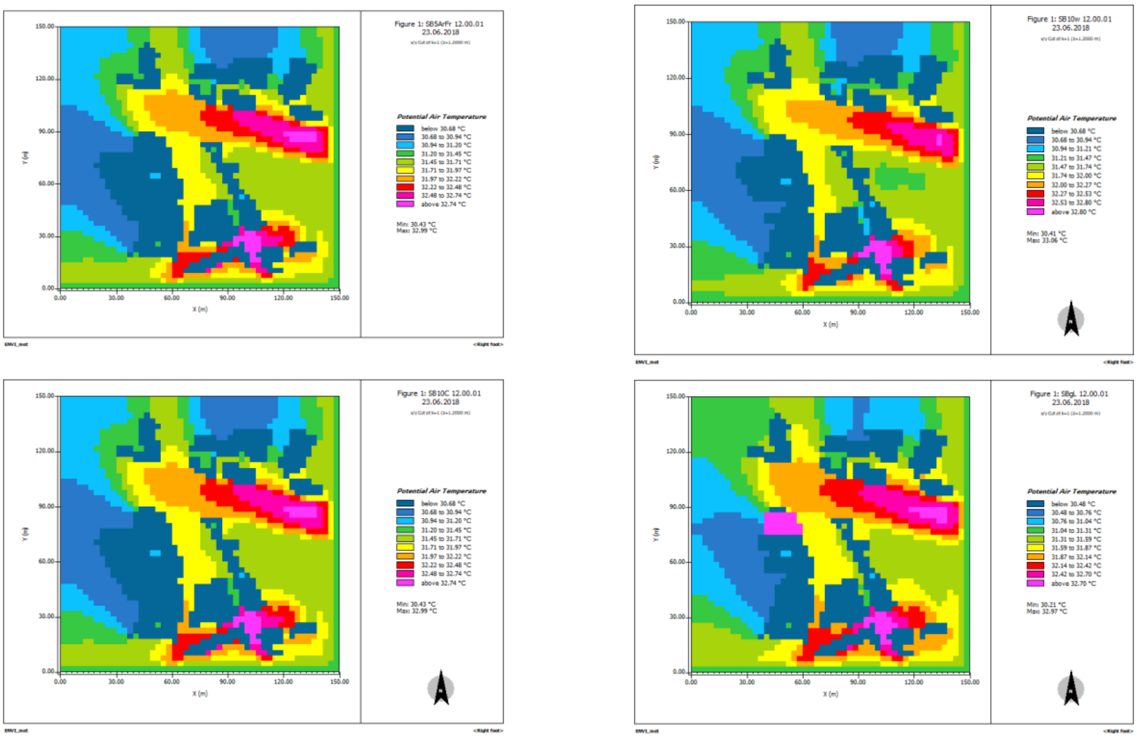
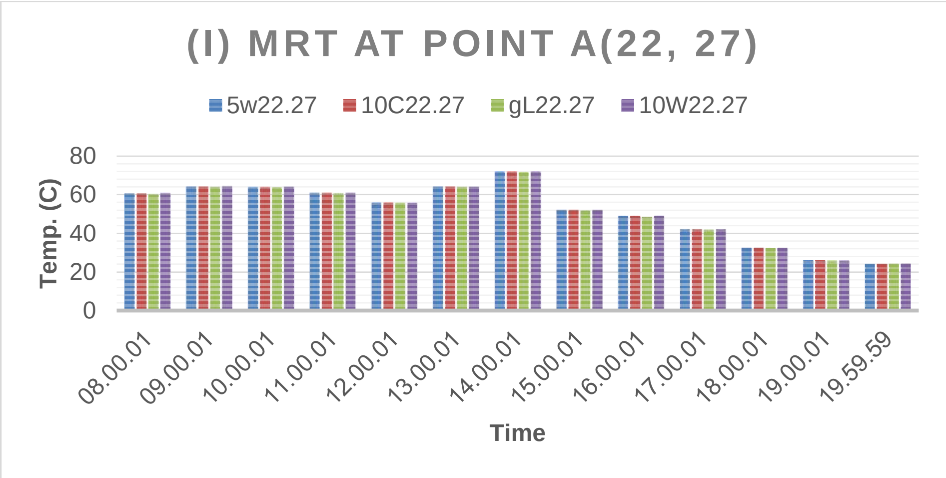
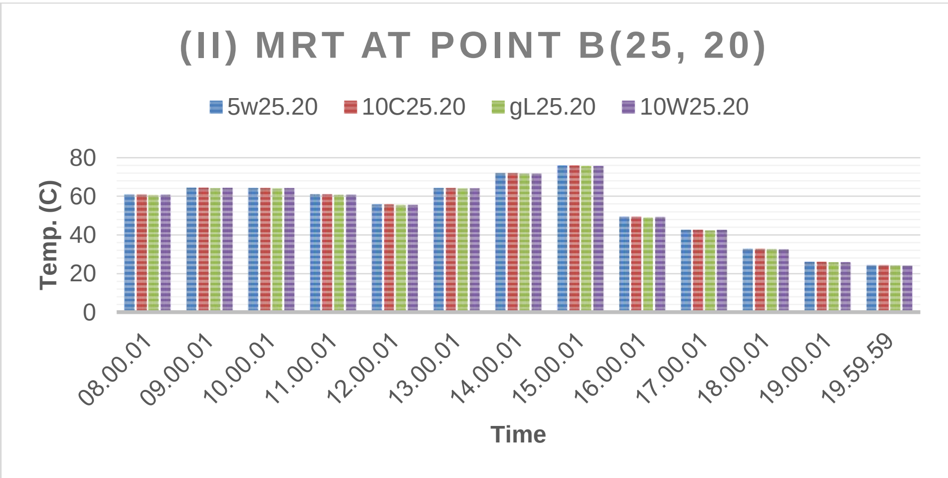


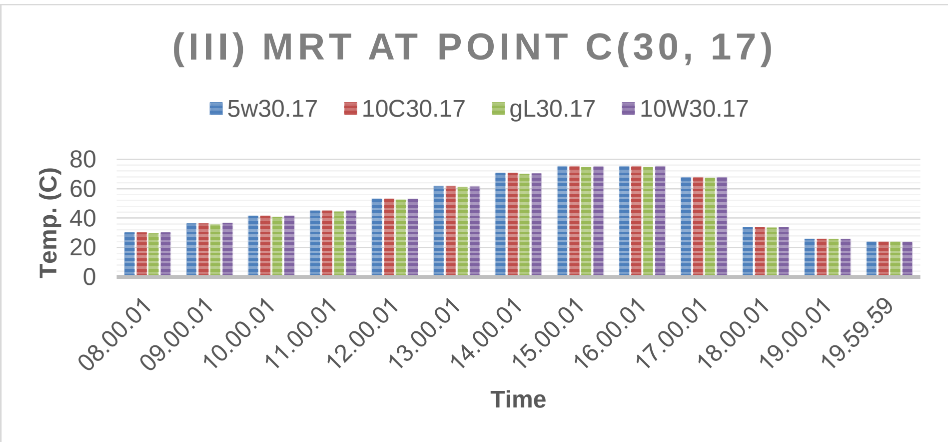
Figure 6. ENVI-met simulation (Air Temperature: 5 Inch brick wall, 10 Inch Brick Wall, 10 Inch Con. Wall, Glass Wall)

Table 4. Air Temperature profile of the three different positions with five different materials at 12:00 pm and 16:00 pm respectively.

	5 Inch brick wall			10 Inch Brick Wall			10 Inch Con. Wall			Glass Wall		
POINT TIME	A (22,27)	B (25,20)	C (30,17)	A (22,27)	B (25,20)	C (30,17)	A (22,27)	B (25,20)	C (30,17)	A (22,27)	B (25,20)	C (30,17)
12:00 PM	31.835	31.757	31.505	31.813	31.707	31.291	31.835	31.757	31.505	31.793	31.712	31.485
16:00 PM	33.9	33.925	34.159	33.861	33.889	34.11	33.9	33.925	34.159	33.855	33.861	34.149


(I) MRT AT POINT A(22, 27)
5w22.27
10C22.27
gL22.27
10W22.27
Temp. (C)
0
20
40
60
80
08.00.01
09.00.01
10.00.01
11.00.01
12.00.01
13.00.01
14.00.01
15.00.01
16.00.01
17.00.01
18.00.01
19.00.01
19.59.59
Time


(II) MRT AT POINT B(25, 20)
5w25.20
10C25.20
gL25.20
10W25.20
Temp. (C)
0
20
40
60
80
08.00.01
09.00.01
10.00.01
11.00.01
12.00.01
13.00.01
14.00.01
15.00.01
16.00.01
17.00.01
18.00.01
19.00.01
19.59.59
Time


(III) MRT AT POINT C(30, 17)
5w30.17
10C30.17
gL30.17
10W30.17
Temp. (C)
0
20
40
60
80
08.00.01
09.00.01
10.00.01
11.00.01
12.00.01
13.00.01
14.00.01
15.00.01
16.00.01
17.00.01
18.00.01
19.00.01
19.59.59
Time

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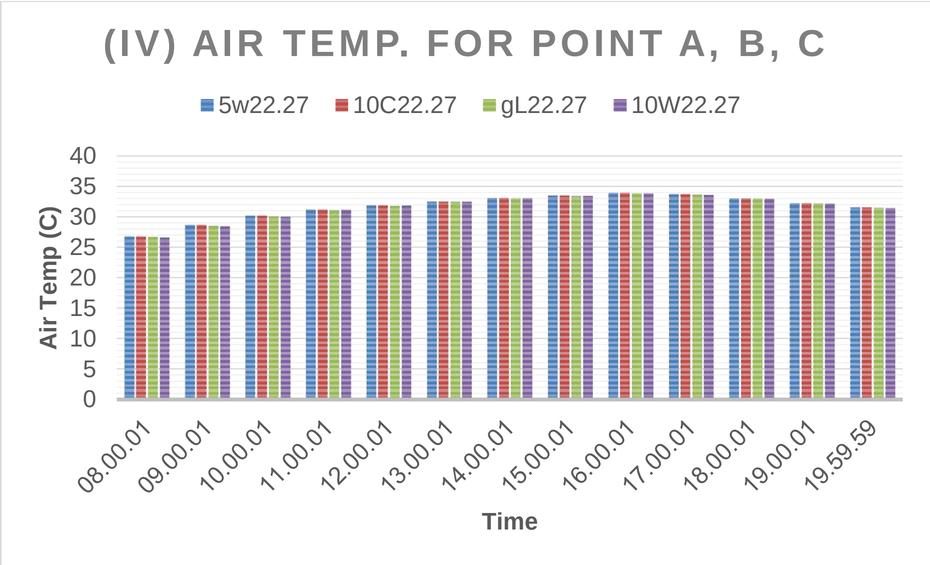

Figure 7. (i) MRT at points A (22, 27) for four different materials shown in colored bar. (ii) MRT at points B (25, 20) for four different materials shown in colored bar. (iii) MRT at points C (30, 17) for four different materials shown in colored bar. (iv) Air temperature at points A, B and C for four different materials shown in colored bar.

Figure 8 shows that MRT value at three different point A, B, and C are significantly changed. For point A which remain under direct radiation from 08:00 am to 14:00 pm exhibit higher MRT (61℃ – 72℃) value. After this time when the point is under shade due to the building mass the MRT decreases to 25℃ at 20:00 pm. Point B shows similar pattern of MRT. However, highest MRT delayed one hour to 15:00 pm. On the other hand, Point C which remains under shade throughout the day reflect the influence of diffuse and reflected radiation on MRT value. MRT at 8:00 am is 30℃ in contrast Point A and B has a MRT of 61℃ at the same time. MRT gradually rises to a value of 75℃ at 16:00 pm then gradually drops to a value of 24℃.

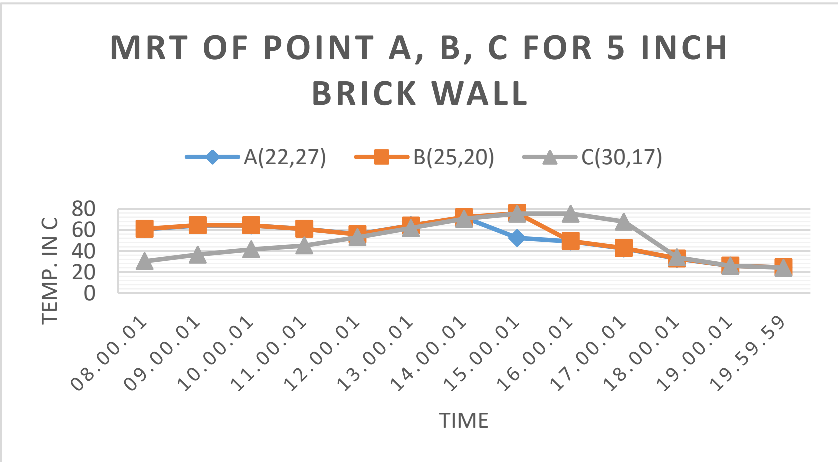

Figure 8. MRT comparison at three different points A, B, and C.

MRT value has strong correlation with all radiation type i.e. Direct, diffuse and reflected radiation. However, MRT value in Point C has weak correlation with diffuse and reflected radiation. This can be explained by the location of point C which is in shade and it has minimum exposure to outside sky hemisphere.

Table 5. Scattered plot analysis for correlation between MRT and Direct radiation, diffuse radiation and reflected radiation of point A, B, C.

	R^2		
MRT	Point A (22, 27)	Point B (25, 20)	Point C (30, 17)
Direct Radiation (W/m²)	0.7063	0.7697	0.7663
Diffuse Radiation (W/m²)	0.8774	0.8404	0.3163
Reflected Radiation (W/m²)	0.7095	0.7526	0.5477

Discussion

Outdoor thermal comfort of a public space is very essential factors in the tropical city like Rajshahi. MRT value shows the effect of radiation (i.e. direct, diffuse and reflected radiation) and air temperature reveals the effect of convection heat flow. Both of this climatic parameters has a substantial role on out-door thermal comfort. Envelop material of the surrounding building has no effect on the air temperature. Since solar radiation is absorbed by the air and diffused by convection, temperature stays uniform for all locations. Air temperature in the morning is low and stays within the comfort range. Then it rises along with the altitude angle of the sun. Temperature reaches its peak of 34℃ in the late afternoon. Which is above the comfort range. Then the temperature drops again to 31.5℃. In this study we found that MRT values remains almost same due to change of building materials. Therefore according to this study building material has very little effect on air temperature and MRT. However, MRT changes throughout the day and the time series data shows that the change pattern depends on the exposure of the location to the direct, diffuse and reflected radiation. Solar radiation directly reaching in the open spaces affected by the shape, orientation and size of urban form surrounding urban open spaces. Places in urban open space that is directly exposed to direct radiation and has no shade show high MRT from early morning to early afternoon. However, when sun descend to lower altitude angle and the location is shielded from direct radiation by urban form, the MRT falls rapidly from 75℃ to 24℃. On the contrary, shaded zone shows the effect of diffuse and reflected radiation and the results shows that during the late afternoon the MRT keep rising. MRT in shaded zone decreases after sunset and coincided with the MRT of the exposed zone. The results of this study shows the effects of building material, solar radiation on the air temperature and MRT. Careful planning and strategical placement of urban form can reduce MRT of urban open space. Using principle of orientation, appropriate height width ratio, sufficient plantations to provide shade can significantly improve thermal comfort condition of urban open space, which in turn will greatly contribute to the urban livability and vitality.

Conclusion

This paper only investigates the MRT and air temperature in relation with different building surface materials, where PMV or PPD are not considered. For further study influence of water body, vegetation of different scale in horizontal surface as well as vertical surface can be considered to improve thermal comfort. In this case ENVI-met simulation can be used to compute PMV-PPD value for determining outdoor thermal comfort. In conclusion, the orientation, urban form has more impact on out-door thermal comfort than building surface materials like concrete, brick, glass etc. to creating comfortable public spaces.

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