SEUJA,Vol. 3, No. 2, DECEMBER. 2023, pp. 42-48

Southeast University Journal of Architecture

Journal homepage: www.seu.edu.bd/seuja

Climate Sensitive Building Geometry for Highly-dense Urban Areas

Labiba Mashiha Ta-sin [a]*, ***Md. Abdullah Al-Imran Khan*** [b]

[a] *Lecturer, Department of Architecture, Fareast International University, Dhaka, Bangladesh. . Email: labibamashiha08@gmail.com*
[b] *Lecturer, Department of Architecture, Southeast University, Dhaka, Bangladesh. Email: abdullah.khan@seu.edu.bd*

ARTICLE INFORMATION

Received: November 16, 2023
Revised: January 03, 2024
Accepted: January 24, 2024
Published online: March 20, 2024

Keywords:
Microclimate; Building geometry
Solar radiation
Residential area
Dhaka City

ABSTRACT

Dhaka, the capital of Bangladesh, expanded physically and economically twenty to thirty times between 1951 and 2001, making it the world's tenth most populous megacity. However, the city's extreme weather, which is a result of climate change, is having a negative impact on people's physical and mental well-being as well as their ability to work. According to the report, this nation has seen a rise in temperature of 0.5 degrees Celsius during the last 44 years, and it is concerning to note that a 1.4 degree Celsius increase in temperature is expected by 2050. Residents are anticipating a climate-resilient city with climate-friendly infrastructure and services as we enter the era of future resilient cities. Future city growth is determined by urban climate conditions since they have an effect on the environment as a whole, building energy performance, and outdoor human psychology. In this sense, the arrangement of the buildings might be crucial as it influences the many microclimates around the city. This paper demonstrates the role of building geometry parameters including building shapes, orientation, solid-void ratio, and room depth to absorb solar radiation as well as to improve the microclimatic condition in highly-dense residential areas. Furthermore, a questionnaire survey among city dwellers has been conducted to collect data on thermal efficiency in residential buildings along with the findings from solar radiation simulation have been compared with each other regarding the building geometry. Nonetheless, the purpose of this research is to illustrate how building forms and energy usage are related, and planners and architects may use the study's findings as a guide.

1. Introduction

A building is a functional outcome of its form, location, properties etc, which vary according to its typology. The footprint of the building designed at the initial stage determines the overall energy consumption of the mass as well as the microclimate of the surroundings. Additionally, building envelopes including roof pattern, apertures,solid-void ratio, modifies the total amount of solar radiation regarding the time of the year which can control the microclimate of a region. In this case, building geometry can be demonstrated with various indicators such as floor area, height of the mass, volume, south surface area, ceiling height, wall to window ratio etc. and considering these factors, the energy performance of a structure can be assessed to some extent. In general, the thermal efficiency of the structures is directly affected by the building geometry.

Due to the rapid growth of population and swarming urbanization, cities across the world are expanding like an asphalt jungle with buildings tumbling upon each other and having no breathing space for the city dwellers. On top of that, global warming in the last few decades has become a new concern as it has been increasing at a surprising rate which poses a threat to all life on earth. Under these circumstances, inhabitants from highly dense residential areas are suffering from various physical and psychological problems due to uncomfortable thermal conditions both indoor and outdoor. With a population density of 44,500 people per square kilometer, Dhaka, the capital of

* *Corresponding author: Labiba Mashiha Ta-sin, Lecturer, Department of Architecture, Fareast International University, Dhaka, Bangladesh.*
This article is published with open access at www.seu.edu.bd/seuja
ISSN No.: 2789-2999 (Print), ISSN No.: 2789-3006 (Online)

Bangladesh, is regarded as one of the world's most populous cities, according to UN-Habitat figures. The nation and the city both endured a scorching heat wave in recent years, with an average maximum temperature that reached a three-decade high. Furthermore, the country's total economic growth is being hampered by Dhaka's annual loss of worker productivity of USD 6 billion as a result of heat stress brought on by extremely high temperatures, in accordance to a research released by the Adrienne Arsht-Rockefeller Foundation Resilience Center. This represents more than 8% of the labor produced annually in the city. Experts and academics believe that if urgent action is not done, this percentage might increase to 10% by 2050. Dhaka is especially vulnerable because of its low rate of active cooling procedure and labor-intensive economy. The city can only get hotter as a result of the building blocks' increased carbon footprint, extensive glass facade, lack of natural ventilation, inadequate natural lighting, and frequent use of air conditioning.

A number of investigations have been performed on building forms with constant floor areas and heights or with variations in floor areas and heights, taking into account building geometry and its effect on building energy in addition to functional typology. This article examines the various forms of residential structures in densely populated areas and examines how they affect the local microclimate and tenants' thermal comfort.

2. Literature review

2.1. Geometry as a design parameter for buildings

For many years, countless investigations and analyses have been carried out on automated construction space and geometry production, without any consideration of mathematical optimization or the building's external look. However, nowadays, researchers have started rethinking energy-related design variables regarding the different building shapes and forms following climate change. In architecture, buildings are viewed as three-dimensional objects with several facades that follow functions considering location, climate, and other factors into account for necessary adaptation. Unfortunately, if the shape and structure of masses are not built with climate change, and the ensuing effects in mind, the performance suffers in the end, which has been a quite typical planning error for decades. For instance, a recent study on sustainable housing has demonstrated a concise summary of the investigations that are accessible in the case of family houses in variable sizes and highlighted that the building geometry design variables are aspect ratio, geometry generation with energy evaluation, roof slope, ridge location, shading, power system etc. (BECEDO,2001) and also included wall length, depth of space, angle of horizontal wall, inclination etc. as elements of sustainable design process in their further studies (BECEDO,2002). In a second study on an oval-shaped mass, the energy performance of the building was examined and reevaluated by altering from circular to oval shapes to lower construction expenses and heating specifications. According to Kistelegdi (2022), energy conservation of up to 50% can be obtained in a multi-family residence by considering climate-related factors in the initial phases of the design procedure, whereas, the purposes of thermal and visual comfort and energy consumption could be increased by 14.2–24.6% without considering those (W Yu · 2015). Additionally, a more feasible and workable shape should be introduced for a residential unit by substituting the rectangular form with a few different alternative forms that tend to be more climate-adaptive and user-friendly (Jedrzejek,2002). To assist planners and architects in their decision-making process, further studies addressed geometry-related performance by applying an automated conversion policy and a designer preference-based improvement algorithm (B Lin, 2021). In urban planning and design, the location, orientation, and height of residential high-rise buildings have a significant impact on both internal spaces and the external environment incorporating other building details such as wall-window ratio, window position, shading devices, facade treatments, which can also be considered as community and design as a cluster (SS Wang, 2021).

2.2. Urban microclimate and thermal comfort

An urban microclimate refers to a small region of urbanized land that differs from the surrounding area in terms of atmospheric conditions yet has a greater influence on the adjacent environment. In general, metropolitan areas are often warmer than neighboring rural zones due to a phenomenon called the “urban heat island” (UHI) effect, which can give rise to discomfort for users engaging in outdoor activities and can provoke a diverse impact on low-income communities. The intensity of the UHI effect is determined by multiple factors, including urban morphology with a variety of building blocks along with the facade details, which can vary with location and orientation. Long-term effects on the users' psychological and physical well-being could arise from the circumstance, which may also have a detrimental effect on pedestrian traffic, the area between two blocks, and the building's surrounding space. Urban climatic conditions predict the growth of cities in the future due to factors such as human comfort both indoors and outdoors, as well as affects on the environment and construction energy usage overall. One of the main factors influencing the many microclimates created in an urban area is the arrangement of buildings, which also affects the region's overall thermal performance.

2.3. Microclimate in buildings and standard of daily life

The thermal effectiveness of buildings in relation to distinct places and periods has recently drawn the attention of scientists, environmentalists, planners, and architects.

This interest basically focuses on two main aspects, energy consumption of the structure and thermal comfort for both indoor and outdoor. With rising standards of living in modern times, contemporary architecture attempts to provide people with comfortable living spaces considering the issue of urban heat islands and global climate change. It is assumed that the execution of rational design solutions sought to lower energy consumption while maintaining the acquisition of details required in residential spaces to preserve conventional functionality. This leads to certain problems with energy use, temperature control, and microclimate. The ideas of sustainable and climate-friendly buildings and structures take into account the impact on the environment when assessing the location and orientation of buildings in relation to other important factors, such as the use of traditional building materials that incorporate cutting-edge technological systems, infrastructure, and user needs adaptation because modern technology makes it possible to achieve any comfort level in a room, in terms of investment and running costs. In addition, materials that a human being comes into contact with in his daily life are light, sound, radiation, air, vibration, plants, animals, and other humans, etc., and all these together determine the condition and development of microclimate in buildings. Although the human body may adapt to its surroundings, planners and architects nevertheless want individuals to have a pleasant, functional place for their everyday needs. As it may boost their usability and functioning, the built-in microclimate should offer its users a safe and comfortable environment.

2.4. Urban Heat Island (UHI) impact on Dhaka city

Bangladesh has become one of the most susceptible and vulnerable countries to climate change due to its high population density, crowded infrastructure, and frequent natural disasters. The country has recently experienced massive heatwaves, which have caused numerous health problems and economic losses for its citizens. Many causes for this concerning issue have been found by means of numerous assessments carried out throughout the years.

Policymakers have been forced to look into heat-related hazards due to the growing concern over the health of both present and projected populations. Research on urban vulnerability has been developed regarding the recent state of the city regarding land surface temperature, which has the quickest correlation to the microclimate of that particular area and the living standards of the dwellers. The temperature difference between the city center and nearby suburbs tends to be more noticeable when breezes are mild and are greater at night than during the day, which is prominent during summer and winter. Urban heat islands are not being exacerbated by climate change, but also rendering heat waves more frequent and intense, which in turn amplifies the urban heat island impact. In response to a variety of factors, including the materials commonly used for paving and roofing in urban areas, such as concrete and asphalt, which have significantly different thermal properties (heat capacity and thermal conductivity) and surface radiative properties, urban areas with compact building blocks, concentrated roads, and maximum hard surfaces heat up more during the day than suburban and rural areas. As a result, the metropolitan area typically experiences higher temperatures than the surrounding rural area and uses more energy overall.

Though the general situation varies from locality to locality, for illustration, some zones in the Dhaka metropolitan area were found to have a very low capacity for adaptation due to high population concentration, while others with sufficient amenities, numerous health institutions, a large population of literate residents, adequate electricity, pucca structures, etc. In summary, properly maintained and developed infrastructure serves to mitigate any harm, deal with the effects, and allow for a stable and sustainable environment for the upcoming years. In this regard, the geometric impacts of building envelopes are one of the main causes of an urban heat island since high-density urban regions with massive structures, particularly residential clusters, offer numerous negative surfaces for exposure to sunlight and solar radiation absorption and reflection, causing excessive use of mechanical solution and urban heat release.

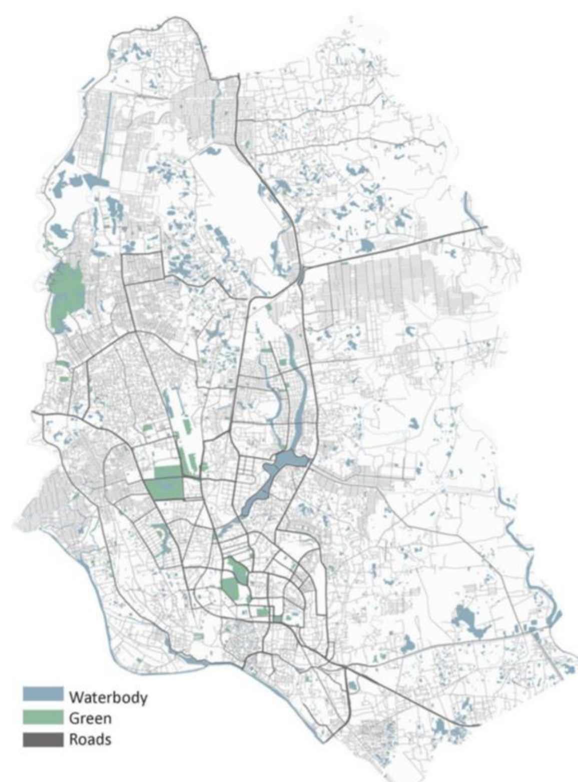

Figure 1: Dhaka Metropolitan Area as study area.

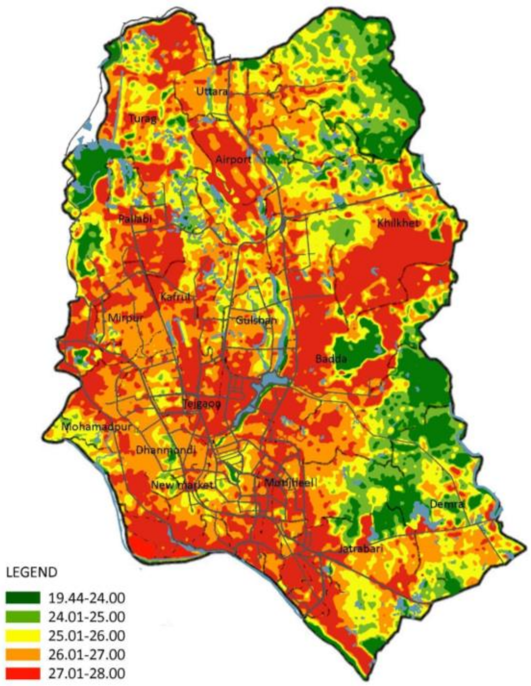

Figure 2 : Land surface temperature (Degree Celsius unit).

3. Methodology

3.1. Study Area

To conduct the study rationally, Dhaka city, one of the densely populated residential areas of the modern world with a lot of issues regarding excessive heat, is chosen for a thorough study. The methodological order involves different survey techniques; the existing context of Dhaka city in terms of residential zone density and land surface temperature in order to investigate the problem arising due to extreme heat in urban areas and collecting information in the context of Dhaka city to address the issue appropriately.

3.2. Data Collection

To analyze the issues regarding extreme heat wave, field survey, data has been collected from newspaper and scholarly articles featuring articles on these related fields, questionnaire survey, and one-to-one interviews with the city dwellers. In addition, data of opinion and perception of the city dwellers have been collected through questionnaire surveys and interviews regarding the perception of climate change and impact on their daily life issues due to excessive heat.

3.3. Modelling Process

In order to comprehend the consequences of building geometry on both indoor and outdoor thermal comfort in terms of solar radiation, four different types of building forms are chosen in this study. In this research, the analysis and simulations are conducted using H, L, T, U shaped building blocks since most common residential blocks in Dhaka city usually belong to these forms. In addition, most of the residentials zones are located quite highly populated and dense with physical infrastructures and to conduct a rational analysis, the study site has been chosen in such a context. Along with context, all of the blocks are designed with a height of six storeys and ceiling height of 3.05 meter incorporating bricks as building materials which is usually in the context of Dhaka city. The blocks have been modeled with Rhinoceros 3D including the site context.

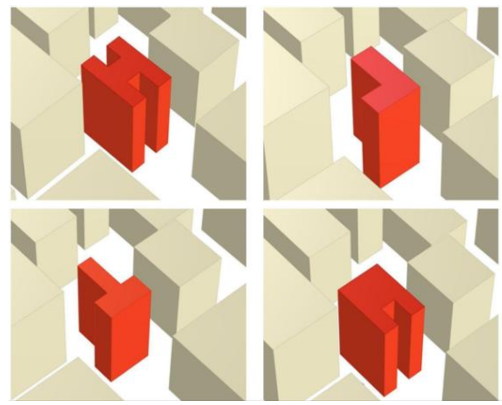

Figure 3: Different building geometry used for simulation.

Physical attributes of the building	H-Shaped	L-Shaped	T-Shaped	U-Shaped
Floor area (squaremeter)	91.3	79	66	102
Volume (cubic meter)	1808.8	1565.2	1307.6	2019.6
No of storeys	6	6	6	6
Ceiling height	3.05	3.05	3.05	3.05
South wall area	181.2	181.2	181.2	181.2
Total wall area (square meter)	1187.6	865.55	865.55	1046.7

Table 1 : Physical attributes of the building forms for simulation.

3.4. Simulation

After determining and fixing a site in a highly dense residential area for modeling with some predetermined range of variants such floor area, volume, ceiling height, number of storeys etc., experiments on solar radiation on the surface of each type of building geometry with mentioned features with the assistance of Rhinoceros 3D, Grasshopper, Ladybug Tools etc. have been conducted in order to compare the solar radiation variation among the four type building forms and determines the impact on indoor thermal comfort as well as outdoor environment.

3.5. Data collection from dwellers

A questionnaire survey and one-to-one interviews have been conducted with the residents of highly populated areas of Dhaka city such as Badda, Banasree, Dhanmondi, Mirpur, Mohammadpur, Motijheel, Rampura etc. to perceive the overall condition of the inhabitants and to understand the circumstances of their daily life in terms of thermal discomfort in their living areas due to extreme heat. People residing in these mentioned areas are asked five questions connected to their residences which they face in their regular life and the complete observation as well as opinion of 58 respondents are illustrated below.

Opinion of the inhabitants	Strongly agree	Agree	Neutral	Disagree	Totally disagree
Discomfort inside the building during summer	16	34	6	2	0
Excessive electric bills due to extreme heat	14	28	10	4	2
Natural light required inside the building	20	32	2	4	2
Air conditioner required for residential buildings	12	16	14	8	10
Workability decreases due to thermal discomfort	18	26	8	6	0

Table 2 : Opinion and observation of the inhabitants.

4. Result

The experiments have been conducted with the climatic data of Dhaka city in terms of incident solar radiation on building envelopes. Previous research indicates that the key element influencing thermal comfort is not the radiation's specific wavelength but rather the rise in the overall intensity of simulated solar radiation. The findings of thermal sensation polls indicated that the detrimental impact of ultraviolet radiation on the thermal conditions could be determined, with a sensation scale rise of 1 scale unit for every increase in direct radiation of around 200 Wm(-2) (SG Hodder, 2007). Experiment results on different building forms have been shown bellow.

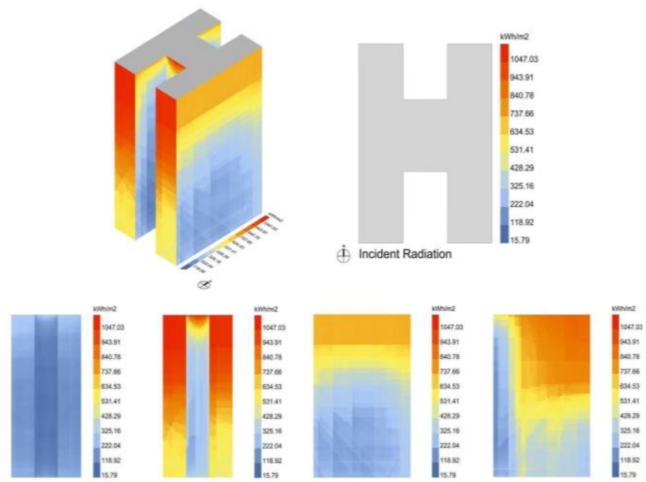

Figure 4: Solar radiation on the facade of an H-shaped structure (North, south, east, west elevation respectively).

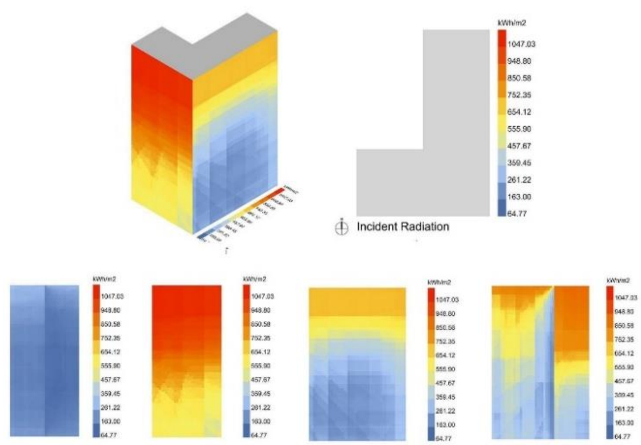

Figure 5: Solar radiation on the facade of an L-shaped structure (North, south, east, west elevation respectively).

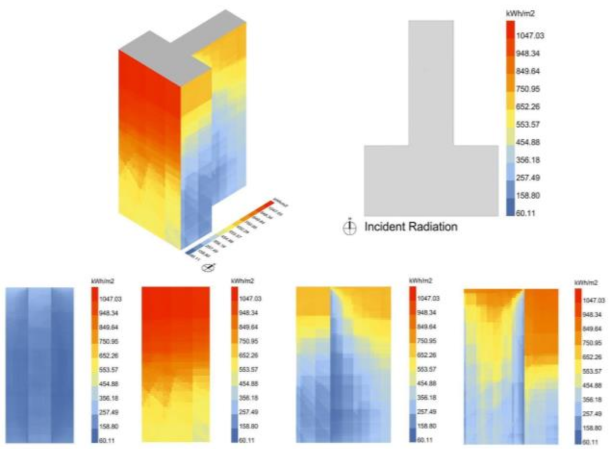

Figure 6: Solar radiation on the facade of an T-shaped structure (North, south, east, west elevation respectively)

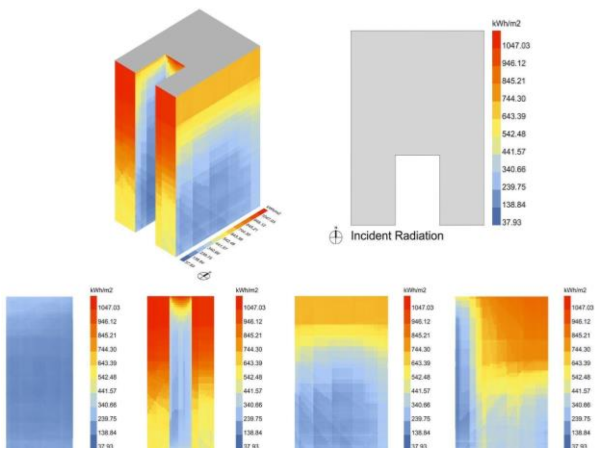

Figure 7: Solar radiation on the facade of an U-shaped structure (North, south, east, west elevation respectively) .

5. Discussion

After simulating and analyzing the mentioned building forms, it is observed that solar radiation can fluctuate with the variation of building geometry as well as other physical attributes and the energy performance can depend on the building location as the amount of solar radiation varies with altitudes and latitude of earth. .

The major recommendations are demonstrated below:

- Variation in building forms and shapes can influence both indoor and outdoor thermal comfort as solar radiation on building envelop changes with the variation of building geometry in a particular area

- Having less solar radiation on building envelopes can promote thermal comfort as it warms the building surface resulting in both indoor and outdoor thermal discomfort.

- In the context of Dhaka city, both H and U shaped buildings can perform better since both of them have probability to gain less solar radiation on their south facade with appropriate and logical orientation.

- Residential blocks in a similar climate context can be designed with the mentioned shapes as well as planning a residential or housing cluster forming H and U shape as a whole for better thermal environment.

6. Conclusion

This paper's research highlights the essential influence of building geometry on urban residential areas' thermal environments. It demonstrates how building forms including height, wall to window ratio, orientation, materials etc are connected to the incidents of solar radiation on the structure surface. Though the study demonstrated the thermal issues in terms of residentials buildings, the analysis process can be helpful for the further studies of the thermal environment of any building block by figuring out how much solar radiation strikes the façade of buildings. Understanding and experimenting the building performance in specific site context as well as particular physical features of the structure, planners and architects can be benefited while designing space for human beings as they can presume the impact and consequences of the design development along with the structures' overall energy efficiency.

In summary, people around the whole world have been suffering due to rapid temperature fluctuations and swarming urbanization which have turned out to be a threat to humankind. To cope up with the circumstances, several innovative solutions and methods have been introduced to mitigate the alarming situation of global warming. In order to contribute to the crisis, this study has addressed a futuristic solution on urban scale which can make housing planning or building design more economic, ecological and user friendly.

Acknowledgement

Special thanks to the students of the Architecture department, Fareast International University (FIU) for their assistance to conduct the interviews and questionnaire survey in crowded residential zones of Dhaka.

References

Adamski, M. (2007, April 1). *Optimization of the form of a building on an oval base.* Building and Environment. https://doi.org/10.1016/j.buildenv.2006.02.004

Yu, W., Li, B., Jia, H., Zhang, M., & Wang, D. (2015, February 1). *Application of multi-objective genetic algorithm to optimize energy efficiency and thermal comfort in building design.* Energy and Buildings. https://doi.org/10.1016/j.enbuild.2014.11.063

Jędrzejuk, H., & Marks, W. (2002, December 1). *Optimization of shape and functional structure of buildings as well as heat source utilization. Basic theory.* Building and Environment. https://doi.org/10.1016/s0360-1323(01)00101-9

Lin, B., Chen, H., Yu, Q., Zhou, X., Lv, S., He, Q., & Li, Z. (2021, August 1). *MOOSAS – A systematic solution for multiple objective building performance optimization in the early design stage.* Building and Environment. https://doi.org/10.1016/j.buildenv.2021.107929

Wang, S. S., Yi, Y. K., & Liu, N. X. (2021, November 1). *Multi-objective optimization (MOO) for high-rise residential buildings' layout centered on daylight, visual, and outdoor thermal metrics in China.* Building and Environment. https://doi.org/10.1016/j.buildenv.2021.108263

Stone, B., Vargo, J., & Habeeb, D. (2012, September 1). *Managing climate change in cities: Will climate action plans work?* Landscape and Urban Planning. https://doi.org/10.1016/j.landurbplan.2012.05.014

Dewan, A., Kiselev, G., Botje, D., Mahmud, G. I., Bhuian, M. H., & Hassan, Q. K. (2021, August 1). *Surface urban heat island intensity in five major cities of Bangladesh: Patterns, drivers and trends.* Sustainable Cities and Society. https://doi.org/10.1016/j.scs.2021.102926

Abrar, R., Sarkar, S. K., Nishtha, K. T., Talukdar, S., S., Rahman, A., Islam, A. R. M. T., & Mosavi, A. (2022, April 20). *Assessing the Spatial Mapping of Heat Vulnerability under Urban Heat Island (UHI) Effect in the Dhaka Metropolitan Area.* Sustainability. https://doi.org/10.3390/su14094945

Kistelegdi, I., Horváth, K. R., Storcz, T., & Ercsey, Z. (2022, January 12). *Building Geometry as a Variable in Energy, Comfort, and Environmental Design Optimization—A Review from the Perspective of Architects.* Buildings. https://doi.org/10.3390/buildings12010069

Majerska-Palubicka, B., & Cibis, J. (2019, February 24). Microclimate in Buildings and the Quality of Life in the Context of Architectural Design. *IOP Conference Series: Materials Science and Engineering, 471*, 092013. https://doi.org/10.1088/1757-899x/471/9/092013

Salihi, M., Fiti, M. E., Harmen, Y., Chhiti, Y., Chebak, A., Alaoui, F. E. M., Achak, M., Bentiss, F., & Jama, C. (2022, June 1). *Evaluation of global energy performance of building walls integrating PCM: Numerical study in semi-arid climate in Morocco.* Case Studies in Construction Materials. https://doi.org/10.1016/j.cscm.2022.e00979

Abdollahzadeh, N., & Biloria, N. (2021, June 1). *Outdoor thermal comfort: Analyzing the impact of urban configurations on the thermal performance of street canyons in the humid subtropical climate of Sydney.* Frontiers of Architectural Research. https://doi.org/10.1016/j.foar.2020.11.006

Othmer, F. J., Schmitt, J. P., & Greiving, S. (2020, August 1). *Numerical modelling of the urban climate as an integrated part of environmental assessments.* Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2020.138774

Keskas, I., Bourbia, F., Mohammadi, M., & Calautit, J. K. (2022, November 1). *Geo-solar segmentation mechanism: An early design stage method for building solar morphing.* Solar Energy. https://doi.org/10.1016/j.solener.2022.09.028

K. (n.d.). *Dhaka map detailed of city vector image.* VectorStock. https://www.vectorstock.com/royalty-free-vector/dhaka-map-detailed-of-city-vector-40741833

The Daily Star – Leading English Daily among Bangladesh Newspapers. (n.d.). The Daily Star. https://www.thedailystar.net/

AEEE | Annals of Electrical and Electronic Engineering. (n.d.). http://www.aeeej.org/

CESB22 – Central Europe towards Sustainable Buildings 2022 – International Scientific Conference of iiSBE series. (n.d.). https://cesb.cz/