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STUDY ON LOCAL MICROCLIMATE OF OUTDOOR DOMESTIC SPACES AFTER APPLYING FLOOR AREA RATIO AND MAXIMUM GROUND COVERAGE IN DHAKA CITY

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Abstract

Introduction: Urbanization in Bangladesh is a growing phenomenon. Dhaka is the capital of Bangladesh and has become known as one of the world's megacities. This urban fabric influences the local microclimate of the respective areas. In 2023, the revised building construction rules with Floor Area Ratio and Maximum Ground Coverage introduced outdoor open spaces at ground level within the plots. Thus, various changes in the microclimate are expected, but very little research can be found on these issues. **Aim:** The purpose of this study was to analyze different configurations of outdoor domestic spaces at ground level with a view to the microclimate situation in the context of a planned residential area in Dhaka City. Furthermore, it compares the microclimate of the space configurations. Finally, it is expected to act as a guideline to help the architects and planners. **Method**: Microclimate-based computer simulation and statistical analysis were performed using ENVI-met, SPSS software. Varieties of building blocks (L, N, T, O, H, I, and U) were taken into consideration to see the impact. **Result:** Various building configurations were found to influence the local microclimate. Thus, at the end of this study, potential building configurations essential for a comfortable microclimate were suggested.

Keywords: microclimate; urbanization; outdoor domestic space; FAR; MGC.

Introduction

Urbanization is now a global phenomenon. The world's urban population reached 4.2 billion in 2018 and is expected to rise to 6.7 billion by 2030. Only 30 % of the world's population lived in urban areas in 1950; this proportion increased to 55 % by 2018 (UN, 2018). It is projected that 68 % of the population will live in urban areas by 2050 (UN, 2018). Populations are particularly concentrated worldwide in and around major cities (Yu et al., 2020). Moreover, a report by the (UN, 2018) states that 90 % of urban population growth will occur in Asia and Africa, indicating that the cities in developing countries will face significant challenges in the coming years.

Dhaka serves as the capital of Bangladesh, with an estimated population of 14 million inhabitants (Rahman et al., 2015) with an urbanization rate over 2.5 % (Sharmin et al., 2015). To accommodate this vast urban population, infrastructure in various arenas is expanding, resulting in the proliferation of multi-story buildings in residential sectors. This urban fabric influences local microclimate of these areas, and Dhaka's environmental issues are among the most severe in developing cities. Moreover, microclimate factors are important to the design of outdoor areas to effectively affect user behavior (Ravnikar et al., 2023). Ragheb et al. (2016) assert that integrating climate analysis into the design process must occur at an early stage before the obstruction of spaces by poor choices (Ravnikar et al., 2023). Outdoor spaces facilitate an active lifestyle, encompassing social and cultural activities; thus, it is a significant challenge and obligation for town planners and scholars to evaluate these places and enhance their accessibility to society (Kumar and Sharma, 2020). Therefore, this study examines how building regulations may affect the local microclimate of the domestic outdoor spaces of buildings. More specifically, it explores how two critical building regulation parameters — Floor Area Ratio (FAR) and Maximum Ground Coverage (MGC) — impact the microclimate in the outdoor spaces of residential buildings in Dhaka City. From these results, urban planners and architects can provide more insightful design solutions to the national level's intervention.

The Dhaka Metropolitan Building Regulations 2023 (MoHPW, 2023) outlines:

$$FAR = (\text{Total Floor Area}) / (\text{Total Land Area})$$
$$\text{Ground Coverage} = (\text{Built Area} \times 100) / (\text{Total Land Area})$$

Background of the study and Statement of the problem

One of the burning concerns of microclimatic change is the Urban Heat Island Effect. Moreover, it is prevalent in the most major cities and is a well-documented urban phenomenon (Abdollahzadeh and Biloria, 2021). This phenomenon in metropolitan areas are significantly influenced by the unique properties and features of the surfaces present in those regions (Maclean et al., 2021; Gapski et al., 2023). For instance, buildings and paved surfaces in urban areas absorb solar energy, which is subsequently re-radiated, raising surface temperatures by up to 5.5–10 °C (Akbari, 2009).

Additionally, the urban microclimate is controlled by factors such as street layout, building spacing, building heights, building density, roughness length, urban permeability, surface materials, albedo, vegetation presence, and human heat generation (Oke et al., 1991). Except for the last three factors, the rest are primarily components of urban geometry. Diversity in urban geometry can result in considerable changes in microclimatic conditions (Sharmin et al., 2017). Urban planners, designers, and architects, who are responsible for determining these components, play a crucial role in reducing thermal stress and its impact on health, well-being, and productivity in both indoor and outdoor environments. However, achieving these goals in high-density tropical cities in developing nations poses significant challenges.

Urban residents cannot rely on air conditioning as an efficient remedy due to the limited availability and high cost of electricity. Additionally, air conditioning can exacerbate the issue by increasing anthropogenic heat output, further deteriorating air quality, which is already compromised by vehicle pollutants and nearby brick kilns (Begum et al., 2011). Cooling energy consumption, peak electricity demand, heat-related mortality and morbidity, urban environmental quality, local vulnerability, and comfort are all significantly affected by elevated ambient temperatures (Santamouris, 2020).

Passive ventilation techniques are insufficient to provide unpolluted and comfortable airflow within buildings, as the external environment does not support the demand for indoor environmental quality (IEQ). Dhaka's traditional outdoor spaces, including parks, gardens, squares, and narrow alleys, have historically been hubs of urban activity. The average air temperature, except on wet days, did not exceed 35 °C, making these outdoor spaces habitable. However, in recent decades, due to land scarcity and rising property prices, developers have overtaken these spaces, leading to reduced vegetation and increased air temperatures that directly impact the comfort of urban outdoor areas (Mourshed, 2011).

The spatial distribution of maximum and mean Land Surface Temperature (LST) in Dhaka city indicated increases of 4.62 °C and 6.43 °C, respectively (Imran et al., 2021). Effective urban planning and design could improve the overall microclimate and ensure a healthy living environment both indoors and outdoors. However, reducing city density is a long-term goal that depends on decentralizing the capital, a challenging task in developing nations where the capital serves as the economic hub. Urban planners and designers thus face more challenges and fewer options, necessitating the exploration of other means to achieve thermal comfort both indoors and outdoors. Dhaka's rapid urbanisation and uncontrolled expansion have led to the urban heat island (UHI) effect and increased air pollution (Azad and Kitada, 1998). In recent decades, the city has seen an unprecedented increase in its urban population. Inadequate planning controls and poor construction laws have resulted in substandard building standards with diminished thermal and ventilation performance. The current construction codes set minimal requirements for space, light, and airflow to maximize the use of existing space (World Bank, 2007). Moreover, Floor Area Ratio significantly impacts the microclimate of urban domestic spaces, influencing the comfort and well-being of residents. High FAR often translates to taller buildings and denser urban forms, creating urban canyons that trap heat and limit air circulation (Jamei et al., 2016; Yu et al., 2020). This tradeoff is particularly pronounced in dense, rapidly urbanizing cities like Dhaka (Sharmin et al., 2015).

To ensure practical interior and outdoor thermal comfort, the Government of Bangladesh (GoB) implemented the Dhaka Imarate Nirman Bidhimala 2008 building regulation acts. Two key regulations, the Floor Area Ratio (FAR) and Maximum Ground Coverage (MGC), are mandatory to obtain permits for architectural building plans. These regulations are responsible for different building shapes and creation of various outdoor spaces for residential buildings in Dhaka City (MoHPW, 2023).

Rationale of the study

Scopes were increased in the design of buildings by architects after applying the Floor Area Ratio (FAR) and Maximum Ground Coverage (MGC) in Dhaka's building construction rules. Applying FAR and MGC resulted in design variations within the structures designed by architects. Recently, this can be observed in building design by designing different types of outdoor domestic open space configurations at ground levels in buildings, but the question remains: what impact do the outdoor domestic spaces have, considering microclimate (at the local level)? Thus, various changes in microclimate are expected, but very little research can be found on these issues. The setting of each city is distinct; thus, conducting field studies in many cities is essential to enhance our current understanding of creating healthy urban environments (Sharmin et al., 2019).Therefore, this research focuses on multiple shapes of outdoor domestic spaces created at the ground level of buildings after applying FAR and MGC based building construction rules and investigates the various outcomes of the local microclimate effect due to different building forms through microclimate-based computer simulation. It is expected to act as a guideline to help the architects and planners. Additionally, when designing buildings, after applying the **FAR** and **MGC** based building construction rules of Dhaka City for a desired microclimate-based outcome, it is expected that the readers, architects, microclimate environment researchers, environmentalists, and building regulation authorities would be very interested and would like to go through this study.

Objectives of the study

General Objective

The objective of the study is to investigate whether microclimate variations can be observed at ground-level domestic open spaces created after applying **FAR** and **MGC** in residential areas considering adjacent building blocks.

Specific Objectives

I. To investigate the interrelationships of considered parameters MRT (Mean Radiant Temperature), DBT (Dry Bulb Temperature), RH (Relative Humidity) and WS (Wind Speed) due to various domestic space configurations within plot areas.

II. To find out possible outdoor spaces within plots after applying FAR & MGC in residential areas in Dhaka city.

III. To investigate the impact of outer façade of a built structure orientation on local microclimate of domestic spaces within plot areas.

IV. To simulate the microclimate situation of outdoor domestic spaces through ENVI-met (software) for analysis.

V. Statistical analysis of the microclimate data from simulation to find out which configuration/s are best fit considering microclimate conditions in residential urban blocks of domestic outdoor spaces after applying FAR and MGC of building construction rules practiced in Dhaka city.

Methods

First of all, relevant published materials and previously done research on street morphology, urban canyons, urban microclimate, outdoor thermal comfort, and FAR regulations was thoroughly analyzed. Initially, eight planned residential neighborhoods in Dhaka, including Gulshan, Dhanmondi, Banani, Uttara, and Baridhara, was observed visually. The "Uttara residential region" was chosen for reconnaissance based on the availability of residential structures in such areas. As there is no sector in those residential neighborhoods where all buildings have been created in accordance with FAR regulation, a reconnaissance study was done to identify two sectors where at least **fifty per cent** of structures have been constructed in accordance with FAR & MGC rules, 2008. In the reconnaissance study, all orthogonal routes in the residential area of Uttara were thoroughly explored.

The research was conducted through microclimate simulation software **ENVI-met** version 3.1, beta 5, an established and authenticated software vastly used for urban outdoor microclimate analysis. A planned residential block (sector-14, Uttara) was considered in the research. As varieties of building blocks are possible in an urban block, selected varieties of building block shapes were taken into consideration to see the impact on the urban microclimate environment and closely observed the changes achieved. Besides, the simulation field survey was conducted in planned residential area/s to compare and justify the study. Various points were selected within the domestic spaces selected in the research, in a view to having equal distances for having true scenario as much as possible for collecting the measurements of microclimatic data, such as **DBT** (Dry Bulb Temperature), **MRT** (Mean Radiant Temperature), **RH** (Relative Humidity) and **WS** (Wind Speed) and analysis was done through statistical software **SPSS** version 23.

Research quality consideration

Research quality considerations were as follows:

- *Independent variables:*
  - Orientation
  - Domestic shape configuration due to Form layout/building shape
- *Dependent variables:* [Microclimate parameters]
  - Temperature
    - MRT (Mean radiant temperature) (K)
    - DBT (Dry bulb temperature) (K)
    - DBT diff. (K)
    - DBT change (K/h)
  - Wind speed
    - Wind speed (m/s)
    - Wind speed change (%)
  - *Unit of assignment*
    - Domestic outdoor spaces
    - Outdoor activity areas
- *Control group* [Groups to which no treatment is applied]
  - Surrounding surface materials
  - Different plot sizes
  - Vegetation
  - Other FARs and MGCs
  - Impact of vehicular movements
- *Focus on Causality*
  - The focus on causality was "the effect of outdoor domestic space configuration on local microclimate considering "on-ground" and "elevated" structures".

Sampling for the simulation

Different possible building shapes were considered to have outdoor domestic spaces after applying FAR and MGC. The simulation was done on a hot summer day (March to June). 33 decimal plots in the residential area were considered during the simulation. Simulation in the evening time is considered to be 5 pm and 6 pm (considering outdoor activities). Different possible building shapes were considered, such as ‘L’, ‘N’, ‘T’, ‘O’, ‘H’, ‘I’, and ‘U’ shaped blocks at different positions having outdoor domestic spaces (Fig. 1), and data were collected at different points of the domestic spaces (Fig. 2). In this case, the “on-ground” and “elevated” building structures were taken into consideration for separate the simulation. Residential buildings classified as “on-ground” are those whose ground floors are designed for family living. In contrast, there are no residential arrangements, and the ground floors of the “elevated” residential building are left to be used for parking or security facilities only.

Results

Simulation result outputs are shown on Figs. 3–4.

Data analyses for "On-ground" structures

In the above table (Table 1), data that were statistically significant are marked "yellow", and the shape of the corresponding building patterns are shown, where it can be seen that considering various building shapes impacts microclimate data in various ways. Having open domestic spaces at different locations thus impacts significantly considering different times also. As for a tropical climate, a lower temperature and higher wind speed are desirable for better microclimatic comfort. Keeping these two factors in mind, from this data set we can state that the inverted ‘T’ shape building is more suitable.

Data analyses for "Elevated" Structures

Similarly, in the above table (Table 2), data which were statistically significant are marked "yellow", and

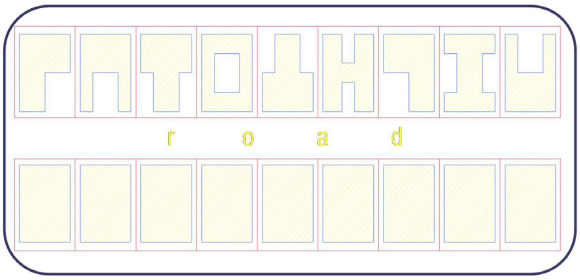


Fig. 1. Considered different shapes of buildings within the plots

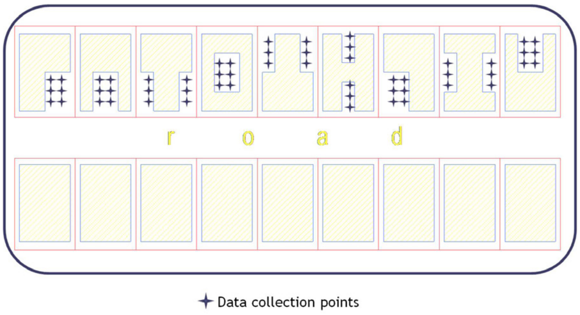


Fig. 2. Considered points of data extraction considering domestic spaces of different building shapes

the shape of the corresponding building patterns are shown where it can be seen that considering various building shapes impacts microclimate data in various ways. Having open domestic spaces at different locations thus impacts significantly considering different times also. As was previously mentioned,

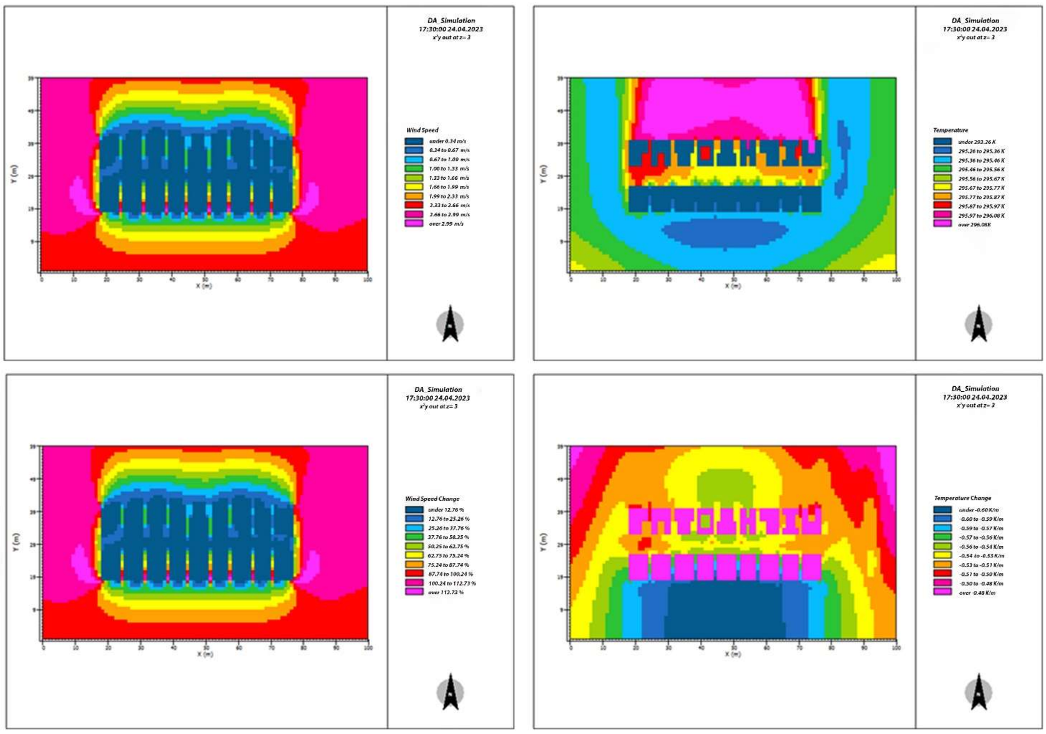


Fig. 3. Simulation outputs considering "On-ground" structures

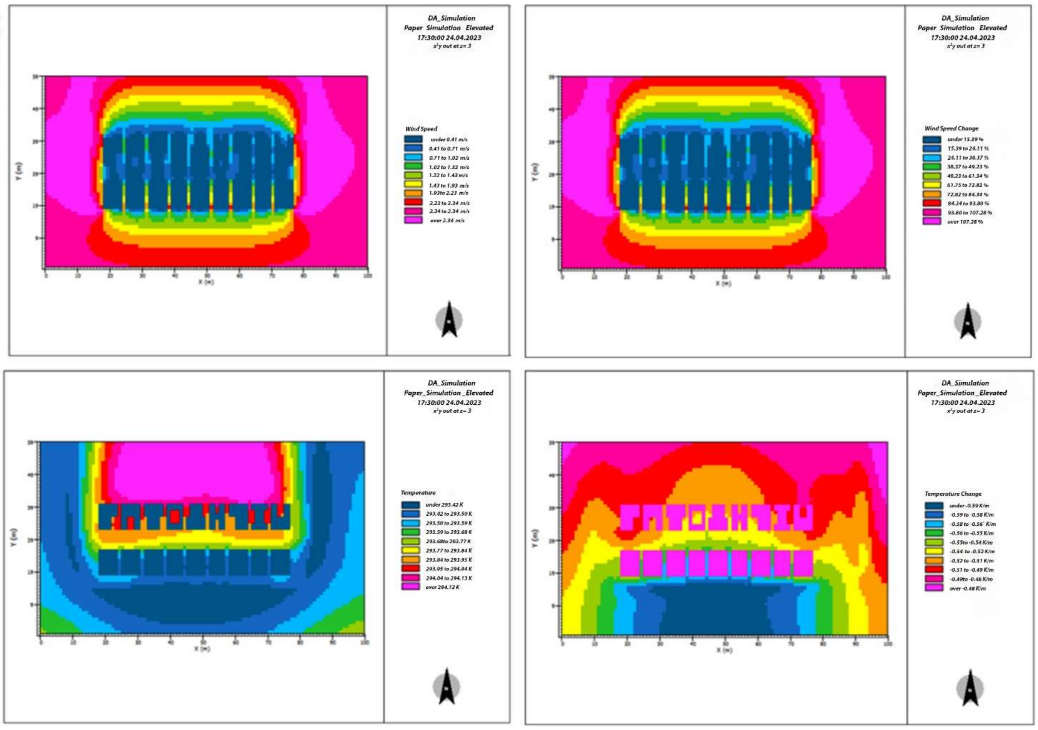


Fig. 4. Simulation outputs considering "Elevated" structures

Table 1. **Micro–climate data considering "On–ground" structures at 5 pm and 6 pm**

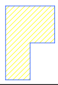
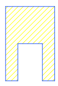
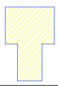
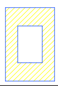
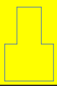
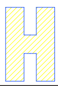
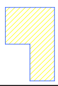
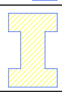
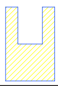
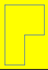
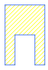
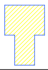
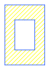
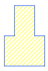
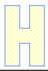
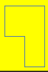
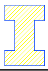
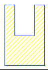
5 pm						*On-ground structures*	6 pm					
Wind speed (m/s)	Wind speed change (%)	MRT (K)	DBT (K)	DBT temp. diff. (K)	DBT temp. change (K/h)	Building shapes	Wind speed (m/s)	Wind speed change (%)	MRT (K)	DBT (K)	DBT temp. diff. (K)	DBT temp. change (K/h)
0.34–0.67	12.84–25.26	Under 293.57	296.26–296.36	0.29–0.39	2–3.7		0.34–0.67	12.73–25.23	287.69–288.17	295.54–295.66	0.26–0.37	–0.69–0.66
Under 0.34	Under 12.84	Under 293.57	296.31–296.42	0.34–0.44	1.16–2.85		Under 0.34	Under 12.73	287.93–288.42	295.54–295.66	0.26–0.37	–0.69–0.66
0.34–0.67	12.84–25.26	293.57–297.10	296.16–296.26	0.18–0.29	0.31–2.00		0.34–0.67	12.73–25.23	287.45–287.93	295.32–295.43	0.04–0.15	–0.71–0.68
5 pm						*On-ground structures*	6 pm					
Under 0.34	Under 12.84	Under 293.57	296.36–296.47	0.39–0.49	0.31–2.00		Under 0.34	Under 12.73	288.17–288.66	295.54–295.66	0.26–0.37	–0.66–0.62
0.67–1.00	25.26–37.69	Under 293.57	296.16–296.26	0.18–0.29	2.00–3.70		0.67–1.00	25.23–37.73	287.20–287.69	295.38–295.49	0.095–0.21	–0.71–0.68
Under 0.34	Under 12.84	293.57	296.26–296.36	0.29–0.39	1.38–0.31		Under 0.34	Under 12.73	288.17–288.66	295.54–295.66	0.26–0.37	–0.69–0.66
0.34	12.84–25.26	293.57–297.10	296.16–296.26	0.18–0.29	0.31–2.00		0.34	12.73–25.23	287.69–288.17	295.32–295.43	0.04–0.15	–0.69–0.66
Under 0.34	12.84–25.26	293.57–297.10	296.21–296.31	0.24–0.34	2.00–3.70		Under 0.34	Under 12.73	288.17–288.66	295.43–295.54	0.15–0.26	–0.68–0.64
Under 0.34	Under 12.84	Under 293.57	296.36–296.47	0.39–0.49	2.85–4.55		Under 0.34	Under 12.73	287.45–287.93	295.66–295.77	0.37–0.49	–0.66–0.62

Table 2. **Micro-climate data considering 'Elevated' structures at 5 pm and 6 pm**

5 pm						*Elevated structures*	6 pm					
Wind speed (m/s)	Wind speed change (%)	MRT (K)	DBT (K)	DBT temp. diff. (K)	DBT temp. change (K/h)	Building shapes	Wind speed (m/s)	Wind speed change (%)	MRT (K)	DBT (K)	DBT temp. diff. (K)	DBT temp. change (K/h)
0.72–1.02	38.59–50.11	Under 293.57	296.24–296.33	0.22–0.31	0.29–1.33		0.56–0.87	15.4–26.86	288.14–288.62	295.56–295.66	0.22–0.32	–0.78––0.30
5 pm						*Elevated structures*	6pm					
0.41–0.72	15.55–27.07	Under 293.57	296.33–296.42	0.31–0.41	0.29–1.33		0.41–0.71	15.4–26.86	287.18–287.66	295.56–295.66	0.22–0.32	–0.78––0.30
0.72–1.02	15.55–27.07	293.57–297.11	296.33–296.42	0.31–0.41	Over 1.33		0.41–0.71	21.13–32.59	287.42–287.90	295.56–295.66	0.22–0.32	–1.25––0.78
Under 0.41	Under 15.55	293.57–297.11	296.38–296.47	0.36–0.46	0.29–1.33		Under 0.41	Under 15.40	287.66–288.14	295.66–295.76	0.32–0.42	Over –0.3
0.71–1.02	27.07–38.59	293.57–297.11	296.38–296.47	0.36–0.46	Over 1.33		0.56–0.87	21.13–32.59	286.94–287.42	295.56–295.66	0.27–0.37	–1.72––2.2
0.41–0.72	15.55–27.07	293.57–297.11	296.33–296.42	0.31–0.41	0.29–1.33		0.41–0.71	15.4–26.86	287.66–288.14	295.61–295.71	0.27–0.37	–1.25––0.30
0.72–1.02	38.59–50.11	293.57–297.11	296.29–296.38	0.27–0.36	0.29–1.33		0.41–0.71	15.4–26.86	286.94–287.42	295.56–295.66	0.22–0.32	–0.78––0.30
0.41–0.72	15.55–27.07	293.57–297.11	296.33–296.42	0.31–0.41	Over 1.33		0.56–0.87	21.13–32.59	287.66–288.14	295.61–295.76	0.27–0.42	–1.72––0.78
0.41–0.72	27.07–38.59	Under 293.57	296.33–296.38	0.31–0.36	0.29–1.33		0.56–0.87	21.13–32.59	286.94–287.42	295.66–295.76	0.32–0.42	–0.78––0.30

for better microclimatic comfort, lower temperatures and higher wind speeds are preferred. Considering these two factors, we can state that the two inverted '**L**' shapes facing each other are the most suitable placement for the elevated structures.

Discussion

After analyzing the corresponding data of the simulation outputs, desirable building shapes considering favourable microclimate conditions for 'on-ground' and 'elevated' structures can be divided in the following ways (Fig. 5 and Fig. 6).

Limitations of the study & Further scope of work

Although the study yielded useful insights, it also revealed many shortcomings that indicate possible areas for further research. Initially, the presence of *vegetations* was not taken into account, which could have a substantial influence on the outcomes, particularly in investigations of urban microclimates. The simulation was carried out during a *24-hour period*, which restricted the study's temporal range and may have disregarded any *seasonal fluctuations*. Additionally, the study solely simulated wind blowing towards the *south*, disregarding the impacts of breezes coming from *other directions (i. e. north, east and west),* which could produce contrasting outcomes in an actual situation.

Furthermore, the research failed to consider the diversity in *road widths* that could affect environmental factors such as heat retention and wind flow, and it only accounted for a single road width. It also presumed that all building materials were the same. Additionally, irregular building forms, which may have a significant impact on how airflow and temperature are distributed in cities, were not taken into account and the study only looked at 33 decimal plots. Finally, the study disregarded the influence of traffic movements, so neglecting a crucial factor that could potentially effect air quality and noise levels in urban settings.

These constraints indicate that future research should encompass a wider array of factors, such as diverse construction materials, multiple wind orientations, varying road widths, different plot dimensions, irregular building shapes, and the influence of vegetation and vehicular movements. This will yield a more comprehensive comprehension of the topic.

Conclusion

The study aimed to examine if there are observable microclimate changes in ground-level domestic open spaces that are generated after implementing FAR (Floor Area Ratio) and MGC (Maximum Ground Coverage) in residential areas, taking into account the nearby building blocks. From the study above, it can clearly be stated that there is a significant relationship in terms of

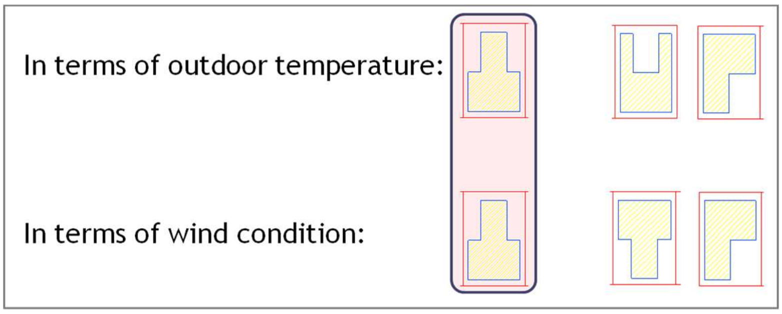


Fig. 5. Graphical presentation of favorable results considering "On-ground" structures [In the left, shaded part denotes most suitable building shape regarding temperature and wind condition]

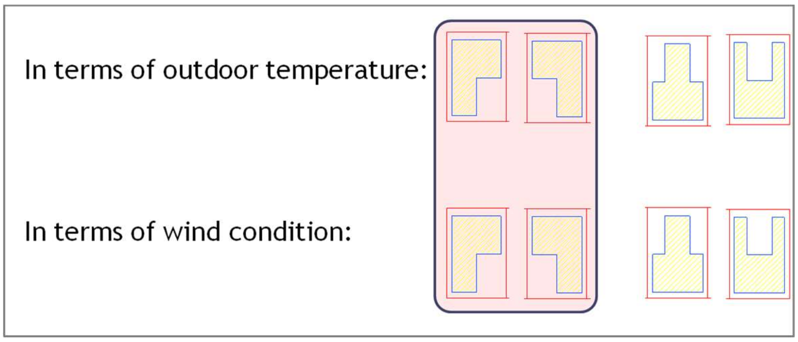


Fig. 6. Graphical presentation of a favorable result considering "Elevated" structures [In the left, shaded part denotes most suitable building shape regarding temperature and wind condition]

building shape and outdoor domestic spaces used, considering the local microclimate. In the case of a tropical climate, achieving a lower temperature and higher wind speed is preferable in order to enhance microclimatic comfort. By considering these two factors, it is evident from the study that the inverted '**T**' shape building is more appropriate for on-ground structures, while the two inverted '**L**' shapes that face each other are the most suitable positioning for elevated structures. Apart from the limitations of the study and considering the future aspects of further work in this regard, it is necessary to examine such relationships, which will eventually help in future domestic space design for residential buildings to improve the outdoor environment and thus influence urban microclimate.

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ИССЛЕДОВАНИЕ МЕСТНОГО МИКРОКЛИМАТА НАРУЖНЫХ БЫТОВЫХ ПОМЕЩЕНИЙ ПОСЛЕ ПРИМЕНЕНИЯ КОЭФФИЦИЕНТА ПОЛЕЗНОЙ ПЛОЩАДИ И МАКСИМАЛЬНОГО ПОКРЫТИЯ ЗЕМЕЛЬНЫХ УЧАСТКОВ В ГОРОДЕ ДАККА

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Аннотация
Введение. Процесс урбанизации в Бангладеш приобретает все больший размах. Дакка — столица Бангладеш, которая стала известна как один из мегаполисов мира. Городская структура влияет на микроклимат прилегающих районов. В 2023 году в соответствии с измененными правилами строительства зданий с учетом коэффициента полезной площади и максимального покрытия территории введены правила строительства открытых пространств на уровне первого этажа в пределах земельных участков. В связи с этим ожидаются различные изменения микроклимата, однако исследований по этим вопросам очень мало. **Цель исследования:** анализ различных конфигураций открытых пространств жилых домов на уровне первого этажа с точки зрения микроклимата на примере проектируемого жилого района в городе Дакка. Помимо этого, в исследовании проводится сравнение микроклимата при различных конфигурациях пространств. Мы предполагаем, что этот документ станет хорошим подспорьем для архитекторов и проектировщиков. **Методы.** Компьютерное моделирование микроклимата и статистический анализ проводились с использованием программ ENVI-met, SPSS. Для определения воздействия были приняты во внимание различные варианты строительных блоков («L», «N», «T», «O», «H», «I» и «U»). **Результаты.** Было установлено, что различные конфигурации конструкций зданий оказывают воздействие на местный микроклимат. Поэтому по результатам проведенного исследования были предложены потенциальные конструкции зданий, обеспечивающие комфортный микроклимат.

Ключевые слова: микроклимат; урбанизация; открытое пространство жилого дома; коэффициент полезной площади (FAR); коэффициент максимального покрытия земельных участков (MGC).