THE IMPACT OF BUILDING FACADE ON COOLING EFFICIENCY AND RELATED THERMAL COMFORT FOR WEST ORIENTED OFFICES IN DHAKA CITY

by

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It is hereby declared that, this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature:

Nafisa Bari

DEDICATION

To

My Parents,

and

My Husband

For giving me unconditional support

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Abstract

Due to rapid global warming and other adverse effects generated by human activities, energy efficiency has become a major concern while designing a building. By introducing sustainable features in a building, energy costs can be reduced to a reasonable amount. According to studies, a building's energy use is hugely influenced by the climate, building function, building occupancy, building envelope, building shape and construction. Building façade being the external envelop of the structure, is constantly exposed to the outdoor environment. Therefore, it can be said that ensuring preferable thermal conditions, by appropriate facade treatment, is one of the significant aspects, that can have major contribution towards energy efficiency in commercial office spaces, specifically in warm-humid conditions. This study deals with commercial office buildings, and ensuring energy efficiency is critical in these types of buildings, due to the huge areas of glass applied to their façades. In a day-use commercial building, the cooling load can be minimized, by adopting appropriate façade design. Many studies also show the relationship of thermal comfort with energy efficiency, and how human intellectual performance and perception in general, will reach maximum potential, if human beings are in comfortable thermal conditions. For this study, Gulshan Avenue located in Dhaka, Bangladesh, was selected as the study area, as it has commercial buildings, facing maximum heat penetration through west facades, during working hours. The goal of the study was to determine whether a relationship between energy consumption and facade treatment. Among all energy needs of a building, this research focuses only on the consumption for cooling. A questionnaire survey was also carried out to investigate thermal preference of the occupants. For the investigation, computer simulations have been carried out extensively, in an existing case building and also in a typical model, generated from analysing case buildings. Energy simulation tools in architectural practice are used for conducting the simulations. The simulation results reveal that, façade treatment on the west side of commercial buildings have significant impact on energy consumption, and these attributes are indirectly related to occupants' thermal comfort. In this way the ultimate goal of the research i.e. to understand which type of façade saves more energy, making the internal environment comfortable, has been reached.

Keywords: Energy Consumption, building Façade, thermal Comfort, west oriented offices, energy efficiency, tropical climate, glass façades

Chapter 01: Introduction

1.1 Background

Buildings are one of the components of built environment, that consumes 40% of the global energy according to UNEP, and residential plus commercial buildings consume 60% of the world's electricity. In addition to that, the building sector is the largest contributor of global greenhouse gas emissions [1]. Therefore, if we can reduce the total energy consumption by these buildings, employing energy-efficient design methods, then global energy can be saved to a great extent. The design elements, that can contribute to reducing a building's energy use are, appropriate site selection, site planning, building form, layout, appropriate space organization, building envelope, choosing energy efficient building materials, energy efficient landscape design, employing passive cooling strategies, etc [2]. Building envelope includes the exterior façade of four sides, ceiling, floor and internal walls. Out of all the elements that contribute to building's energy use, the exterior façade is subjected to the major source of heat gain which ultimately leads to the need for cooling equipment. According to sources these cooling equipment add to buildings' energy consumption most [3]. Therefore, designing a building's facade carefully, is one of the important passive methods of saving building energy, and ensuring thermal comfort [4]. The building design parameters [5] interact with other parameters, and have an impact on the form and environmental performance of building. A study has found that building facade design accounted for 36% of the peak cooling loads in office buildings [6]. Another study also in the tropics [7] shows that facades are responsible for 30% of the building's total cooling loads (solar, glass and fabric). Therefore, reducing energy consumption by designing appropriate building facades, can be a potential approach towards sustainable environment.

With the growth of population in Dhaka, the demand for electricity has also increased over time. Specifically, energy consumption in commercial buildings has increased significantly, due to usage of cooling equipment. To meet the demand, and for proper distribution and maintenance of the supply, the power distribution of Dhaka is divided between two companies, named DESCO (Dhaka Electric Supply Company Limited) and DPDC (Dhaka Power Distribution Company Limited). The northern part of Dhaka is under DESCO, and the southern part is under the control of DPDC, for distribution of electricity [8]. Gulshan Avenue being a part of northern Dhaka is under DESCO for proper distribution and maintenance of electricity.

1.2 Research Problem/Question

In order to reach to the specific focus of the study a more focused research question was put forth:

Do the facade treatment in west-oriented offices of Gulshan avenue enhance cooling efficiency, and does it have impact on maintaining indoor thermal comfort conditions.

Energy consumption in commercial buildings generally, comprises consumption in three sectors, for lighting, for cooling and for other electrical appliances. Approximately one third of electricity is consumed for cooling comfort, when only electric fan and natural ventilation is considered for the purpose [9]. Studies show that, in the warm months (April-October), ventilation and air movement is vital for thermal comfort in Dhaka [10]. In tropical climates, like that in Bangladesh, natural ventilation was the principal mode of ensuring thermal comfort for residential and commercial uses. Air-conditioning was never the primary choice for cooling commercial buildings here before the 21st century, as it consumes much more energy than any means of passive cooling. But in recent times, there has been a tendency of following the western trend, of using huge amounts of glass façades, in commercial buildings, which results in massive energy consumption. These glass buildings cause the greenhouse effect, and are also responsible for enhancing global warming. This phenomenon particularly generated concepts such as sustainability, green building, LEED certification and other building rating systems. Therefore, we are in an era, where low energy buildings are considered as most successful, in terms of architectural or engineering solutions.

From recent studies, it can be said that air-conditioning increases the cost in electricity bills. Low energy and passive architecture is seen as a means to control the impact of climate on the built-forms [11]. One of the major ways through which buildings gain internal heat, is through the building façade. Using glass in the façade, further worsens it, and if it is the west façade then internal heat gain is inevitable. Hence, design and treatment of the west façade carefully, is a key factor that can minimize energy consumption, which is the research interest here.

This research began with the assumption, that building facade treatment has a relationship with energy consumption, i.e. changes in façade treatment would impact the building's cooling efficiency.

1.3 Aims and Objectives

Specific Aims:

The aim of this research is to identify the relationship of facade treatment with energy efficiency and indoor thermal preferences of the office occupants.

Objectives:

1.To gain an understanding of different types of facade treatments being employed in west facing offices in Dhaka, i.e. documenting the various approaches currently employed.

2.To investigate the energy consumption in these office spaces, due to various façade treatments, and to relate these to human thermal preferences and behavioural factors.

1.4 Possible outcome

1.A conceptual understanding of relationship between facade treatment and energy consumption.
2.An understanding of human preferences of thermal comfort and behavioural responses in selected west facing office spaces.

1.5 Significance of the study

From section 1.1, it is seen that residential and commercial building accounts for 60% of world's energy consumption. After analysing the transformation of land use in Gulshan Avenue in the capital city Dhaka (Figure-4.1, 4.2), it can be said that the growth of commercial high-rise buildings is rising in that area. Therefore, energy consumption by these buildings, should be critically analysed, in an attempt to counter the national energy crisis since, we may assume, that façade treatment of these buildings have significant impact, on the amount of energy required to maintain thermal comfort conditions. The result would guide architects to design energy efficient façades for commercial buildings, and contribute regarding saving overall amount of energy use.

1.6 Research Methodology

This section focuses on the type of research and the research method. The flow-chart diagram of research methodology is shown on Figure-1.1

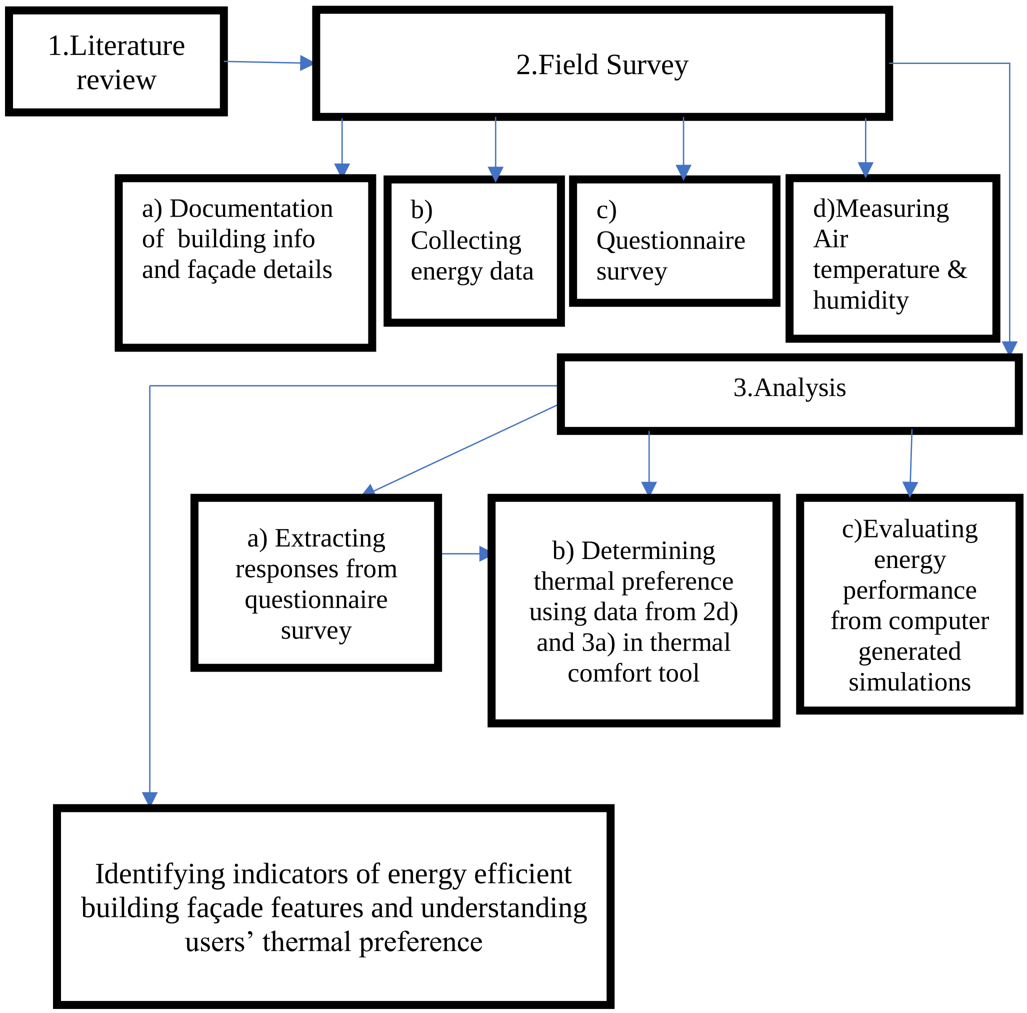


Figure-1.1: Research Methodology Flow-chart diagram

The steps followed in the research are given below-

1.Literature review, to understand the relationship, between facade treatment and space layout, with energy efficiency and other related issues of the study.

2.Field survey of Gulshan avenue buildings, which are west oriented, and their surroundings, to determine facade treatment used, and other architectural features.

Field survey will include data collection in following ways-

a) Documenting key features of some west oriented case buildings, especially highlighting specifications of glass façades and detailing of façade.

b) Collecting monthly energy consumption and electric bills to understand the existing scenario of energy consumption and also compare with the results got from simulation as mentioned in 3c.

c) Questionnaire survey to determine human response towards preferable thermal conditions.

d) Taking measurements of indoor temperature, relative humidity etc for input into the thermal comfort tool. (and match them with preferences identified from the questionnaire.) (see 3b below)

3.Analysis will be done in the following ways using the data collected through –

a) Evaluating the responses of the occupants from questionnaire survey to the presence and extent of any relationship with facade type, and to relate these to users' thermal preferences. This may not present a direct linkage – so the relationship may be estimated following indirect connections.

b) Identifying Predicted Mean Vote (PMV) and Percentage People Dissatisfied (PPD) values by using thermal comfort tool which provides occupants responses regarding thermal performance.

c) Conducting computer simulations for an existing case building and a typical model, derived from the case studies. Typical case model will emulate average material and surface combinations on three sides, and changes will be made only on the west façade, in order to evaluate the effects of different façade compositions and treatment details in terms of energy efficiency.

4.Finally checking the values generated from the simulations and analysis mentioned in 3a) and 3b) to provide design suggestions to architects.

1.7 Thesis Summary

In this section the content of each of the chapter of this research is briefly discussed. The thesis is divided into seven chapters.

In chapter 01 mainly the background of the thesis is discussed. This chapter is basically the introduction to this research. The aims and objectives, possible outcomes and research methodology is also discussed here, along with an outline of the structure of the thesis.

In chapter 02 the climatic context of Bangladesh, with special focus on Dhaka is presented. Here the climate is analysed in the context of tall buildings, as the research deals with climate responsive high-rise buildings. As per recent trends, corporate offices are housed in tall buildings, which are considered as landmarks. For showcasing, the landmark features most of these buildings are treated principally with glazed surfaces, which raises the issue of the buildings' energy consumption levels. One of the main concerns of this research has been to analyse thermal comfort preferences of the users of the commercial buildings in the study area. Therefore, chapter 02 also deals with a brief introduction towards thermal comfort and highlights on thermal comfort indices, mainly reviewing published sources related to it. The PMV-PPD model (thermal comfort tool), which is the method used to determine thermal preference in this research, is also elaborated in this chapter. Thermal comfort is discussed with climate as it is an effect of climatic factors.

In chapter 03, ways of treating different types of commercial building façades is elaborated, and how façade treatment can enhance energy efficiency is also mentioned, i.e. characteristics of different types of exterior solar control devices, have been described. The application of these shading devices are shown in form of examples.

Documenting some of the landmark buildings in the study area, in order to find out features of the building façades, and analysing their energy efficient features, has been part of the methodology of this research. Therefore chapter 04 focuses on data collection from the buildings in the investigative area through field visit, interviewing concerned people, and taking a questionnaire survey of the occupants. The contents of the questionnaire is also discussed here. The summary of the design features of the case buildings is also presented here.

Chapter 05 deals with the analysis and findings of the research. In the first phase, the data obtained from questionnaires is analysed, through charts and graphs, and comparisons are made. Then the extracted data, related to thermal comfort indices, are put into a thermal comfort tool, to determine thermal preference of users. In the third phase, computer generated simulations are conducted in an existing case building, and on another typical model generated after analysing case buildings. The results of the simulation reveal options towards energy efficient façade treatments.

Finally in chapter 06, the research narrative is concluded, by mentioning the major findings, and recommendations are provided for ensuring energy efficiency in commercial buildings, under the context examined. The scope for further research, based on this study, is also discussed, while mentioning the limitations of the study.

References

[1] United Nations Environment Program, 2009; *"Buildings and climate change-summary for decision makers"*, UNEP DTIE, Sustainable Consumption & Production Branch, France.

[2] Izzet Yüksek and Tülay Tikansak Karadayi, 2017; "*Energy-Efficient Building Design in the Context of Building Life Cycle, Energy Efficient Buildings*," Eng Hwa Yap, IntechOpen , DOI: 10.5772/66670. Available from: https://www.intechopen.com/chapters/53557 (January 18th 2017).

[3] Ahsan, T., 2009; "*Passive Design Features for Energy-Efficient Residential Buildings in Tropical Climates: The Context of Dhaka, Bangladesh"*, Unpublished M. Arch Thesis, KTH, Department of Urban Planning and Environment Division of Environmental Strategies Research.

[4] M.A.Alghoul, 2011; *"Perspectives of double skin façade systems in buildings and energy saving"*, Renewable and Sustainable Energy Reviews, Vol.15, Issue 3, pp. 1468-1475.

[5] Izzet Yüksek and Tülay Tikansak Karadayi, 2017; op. cit.

[6]Haase .M.Amato, 2006; *"A Sustainable Facade Design for Zero Energy Buildings in the Tropics"*, presented at 23rd Conference on Passive and Low Energy Architecture(PLEA) , Geneva, Switzerland.

[7] Syma.H . Trisha, ZN Ahmed, 2016; *"Light Zones vs. HVAC Loads: evaluating energy efficiency for shading devices in commercial buildings"*, in 32nd International Conference on Passive and Low Energy Architecture (PLEA) Los An.geles, Cities , Buildings , People: Towards Regenerative Environments, Vol. 1

[8] Tariq, S.H., 2016; Investigation on energy consumption for thermal comfort with respect to plan layout of residential apartment buildings in Dhaka, lib.buet.ac.bd.

[9] Ahsan, T., 2009; op. cit.

[10] Ahmed, Z. N., "*Assessment of Residential sites in Dhaka with respect to Solar Radiation Gains"*, unpublished PhD Thesis, De Montfort University, UK, p: 95-96, 1994.

[11] Ahmed, Z. N., *"Sustainability in the Built Environment of Bangladesh: Participation of Architects; Environmental Sustainability Concerns"*, Eds. M.M. Rahman, M.J.B. Alam, M.M.Ali, A.B.M.Badruzzaman and I.Smout; EEM BUET, CERM-BUET, ITN-BUET, WEDC; September 2006; pp133-144, 2006

Chapter 02: Climatic Context in designing Tall Buildings and related Thermal Comfort issues

2.1 Introduction

In Chapter-01, the background, objective and methodology of the research was discussed. The content of each chapter is mentioned in Section 1.7. In this Chapter, the climatic context of Bangladesh with special focus on Dhaka, is elaborated. The chapter also includes climate responsiveness of tall commercial buildings, as the research focuses on commercial high-rise office buildings in Dhaka. Finally the thermal comfort related issues along with the tool used for determining users' thermal preference is discussed here.

2.2 Climate

2.2.1 Climate of Bangladesh

The climate of Bangladesh is categorized as composite monsoon [1].
Here the climate displays three distinct seasons: a long warm-humid season from end-May to end-October, a short hot-dry season from mid-March to end-May and a short cool-dry winter of two months. One of the major constrains for the Architects while designing a building here would be environmental factors. If a building is designed without climatic considerations, then extra energy needs to be involved for operating the building, which puts a massive pressure on the energy sector of a developing country like Bangladesh [2].

Figure-2.1 Location of Dhaka Division highlighted in map of Bangladesh
(Source: Wikipedia)

Dhaka is located in central Bangladesh at 23°42′0″N 90°22′30″E (Figure-2.1). According to meteorological data, the climate of Dhaka can be categorized as tropical monsoon type, with an annual average temperature of 25 °C, and monthly means varying between 18.5 °C in January and 29 °C in April [3].
The urban climate of Dhaka city is discussed in the following section, as this information is relevant to determine adequate design solutions for commercial high-rise buildings under warm-humid conditions.

2.2.2 Causes of Climate Change and impact on the energy sector

The Human race is continuously influencing climate change, by industrial activity (discharge of poisonous gas and waste into air, water and cultivable land), emissions from motor vehicles, burning fossil fuels, cutting down forests, farming livestock, etc. Due to such adverse activities, the earth undergoes severe environmental crisis, in the form of raised temperatures and release of greenhouse gases into the atmosphere. The concentration of carbon dioxide (CO_2) in the atmosphere, has increased from about 280 parts per million in the 1800s, to more than 415 parts per million today, and is still increasing rapidly [4].

Climate change is an environmental crisis, because humans evolved and societies grew, during a long cool era in Earth's history, that has ended, because our industrial emissions drove average global temperatures higher. Humans, not nature, must change their behaviour, to restore the atmosphere, to the state in which we developed as a species. Our survival is at risk. This increased concentration has intensified the natural greenhouse effect of the earth's atmosphere. It has raised the global average surface temperature by 2℃ and is causing a cascade of complex shifts to climate patterns. These disruptions result in more frequent and more extreme weather events, redistribution and destruction of wildlife populations, and many other harmful changes [5].

In western countries more precisely in cold climates, tall commercial buildings are designed having glass façades, which create greenhouse effects. This is positive in their case, as the greenhouse effect enables maintaining warmth inside those buildings. This condition is not applicable in tropical climates, specifically in warm-humid conditions, as the trapped heat becomes a cause of thermal discomfort for the occupants in such conditions. Due to following western trends in commercial high-rise buildings of tropical climates like Dhaka, Bangladesh, huge support of mechanical appliances is required, to minimize excessive incoming heat. Therefore, the climate change caused by human intervention, in the form of building façade treatment, results in higher energy consumption. This is the interest of this research as mentioned in Section 1.2. For cities like Dhaka climate change causes energy crisis, as demand is higher than supply over here.

2.2.3 Urban Climate of Dhaka

The micro-climate of each city in a country is different from other cities, depending on population density and location. Again, within the same city, these characteristics are further modified in different locations [6]. This micro-climatic condition occurs due to some specific factors, such as quantity of hard or soft surface, density of built environment, building height, orientation, proximity between buildings, materials used for construction, dependence on mechanical and electrical appliances [7]. The variation of climatic conditions of different zones in a city is also evident from T. R. Oke's study on local climatic zones [8].Therefore, the climate of Dhaka city, and more specifically of the study area, Gulshan avenue, needs to be judged in an analytical way, to see it's impact on the built environment.

In this research, monthly energy consumption data of an existing building in the year 2019 i.e. pre-Covid time (Table-4.12), around the year, is collected. The results are also achieved from simulations (Table-5.2-5.6). But energy consumption of the month of August is highlighted in each case, and compared to identify which condition provides most energy efficient results, as August is considered to be the most humid month in Bangladesh (Figure-2.2).

Average humidity in Dhaka

On average, August is the most humid, while March is the least humid month. The average annual percentage of humidity is: 74.0% (Figure-2.2)

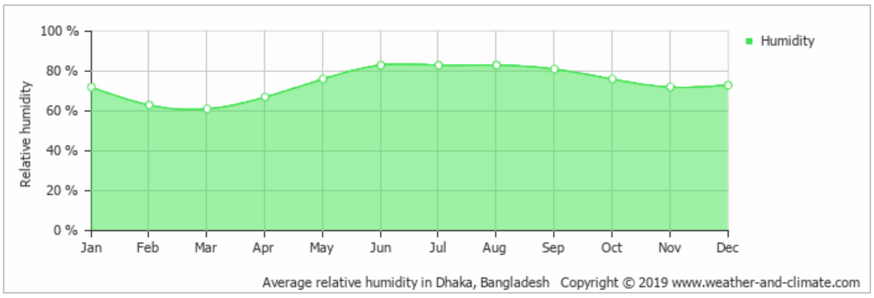


Figure-2.2: Average Humidity in Dhaka, 2019 (Source: Bangladesh Meteorological Department) [9]

It is essential to conduct the study during the most humid period where the users find the weather condition to be thermally most uncomfortable, as the research focuses on related energy efficiency driven by thermal comfort needs. From Figure-2.2 it is seen in Bangladesh the month of August shows highest humidity round the year.

According to Figure-2.3 The average annual maximum temperature is: 34.0° C and the average annual minimum temperature is: 26.0° C

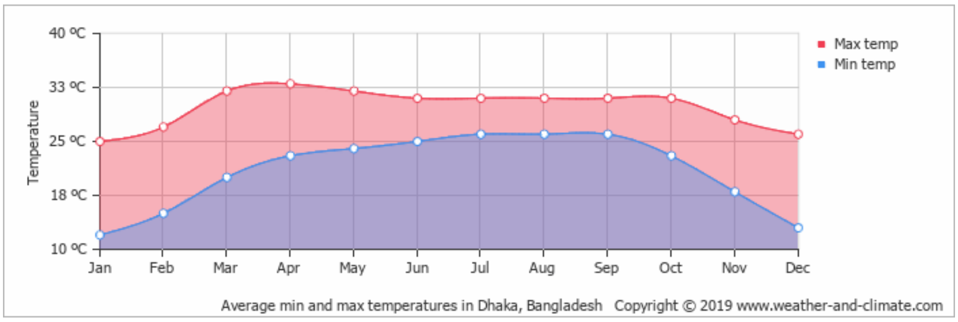


Figure-2.3: The monthly mean minimum and maximum temperature in Bangladesh, 2019 (Source: Bangladesh Meteorological Department) [10]

From Figure-2.3 it is seen that maximum temperature in Bangladesh occurs between the month of March-May. But from Figure-2.2 it can be seen that the capital city, Dhaka faces maximum humidity during the month of August though the temperature is not highest. Therefore, August can be felt as the warmest month to the users, in terms of perception. The reason is discussed broadly in Section-2.4, while featuring Thermal comfort issues which is also a focus of this research.

2.3 Tall buildings

According to the Council for Tall Buildings and Urban Habitat (CTBUH), a tall building is not strictly defined by the number of stories, or it's height. It also depends upon the context in which it stands. Tall buildings are treated as landmarks in a city. It is unique in character, as special engineering systems need to be adopted, in order to resolve its HVAC and structural systems [11]. Tall buildings need to be functionally flawless, rather than being merely aesthetic, as they work like machines. This research deals with energy efficiency in commercial high-rise buildings in Gulshan Avenue, Dhaka, and also relates to the thermal comfort factors associated with it.

2.3.1 Justification of designing climate responsive tall buildings

As previously discussed in Section-2.2.3 due to micro-climate, temperatures in certain areas of a city, tend to increase above the surrounding areas. Greenhouse effect is a driving force behind this increase. The phenomenon such as greenhouse effect, traps the principal amount of heat that is penetrating through the glass façade of a building, along with the heat discharged by the occupants, and other electrical equipment. The effect, which is also known as 'Urban Heat Island Effect', is found in the dense commercial areas of Dhaka city. Studies show that, densely built high-rise commercial areas of Dhaka, display higher temperatures than areas with other types of buildings [12] .

The reason behind designing climate responsive high-rise buildings is explained very well in Ken Yeang's research. The principal explanation is supposed to be reducing operation cost of a building, as a result of reducing energy use, as much as 40% of the overall life cycle cost of the building. Climate sensitive design can turn out to be beneficial, in terms of energy efficiency, even though the initial construction costs were higher [13].

Another reasoning would be ensuring thermal comfort of the occupants of the tall buildings. Environment-conscious Buildings could enhance users' satisfaction in their workplace, and they would get an increased experience of the external environment. When the building is climate sensitive, it would be able to provide the users' the experience of outdoor climate, rather than limiting them to the indoor controlled environment, to which they are confined for approximately half of their day. Finally, climate responsive buildings would also be ecological, by deducting the total energy consumption of the building. This also has the added benefit of reducing the operation cost of the building [14].

2.3.2 Challenges with designing west oriented buildings in the tropics

Tropical climate like Bangladesh is subjected to characteristics such as high temperature, high humidity and heavy rainfall in certain period of the year. The principal cause of discomfort in the summer months here is the humidity present in air, for which continuous movement of air becomes vital in indoor environments [15]. Design challenges also remain in order to prevent solar radiation penetration and affect provision of air for sweat evaporation.

Under the above-mentioned circumstances, it is obligatory to design buildings by ensuring less penetration of external heat, extraction of excess heat by mechanical or passive cooling [16].

Among all the building façades, the west becomes the most challenging, in the sense that it gets sun exposure for the longest time, during the hottest part of the day. Another reason behind the challenge is west is struck by the low angle of sun in the afternoons. That’s why it’s necessary to control solar radiation in office buildings, which are busy during the afternoons, particularly in west facing office spaces, to ensure energy efficiency. This notion generated the basis of selecting west facing buildings for this investigation. Moreover, when the front façade is west facing, then the treatment becomes more challenging, as it requires an increased percentage of glass façade, to ensure a decent view to the exterior. The study area of this research, Gulshan avenue, runs in the north-south direction. Therefore, the commercial high-rise buildings on this road, are either east or west facing, which makes the task of the designers challenging in terms of façade treatment. From these buildings some of the west facing buildings are studied in Chapter-04 elaborately.

2.3.3 Façade design of tall buildings in tropical climates

Tall buildings in general, have more external surfaces than low-rise building. Therefore, façades can be designed to work as filters, from the external heat. This will also lead to minimizing the operation cost of the building. The façade needs to have certain qualities, like being able to restrict the amount of heat penetrating the surface. It can work as an element that provides insulation from sound and heat, can be a source of fresh air if having ventilation options, and it also can add to the external beauty of the building.

The façades of tall buildings are subjected to direct sunlight more than others. It is a major source of heat gain in tropical climates. The amount of heat penetrating a tall building façade can be minimized by using shading devices. This will also allow designers to use huge amounts of glass façades, which enables more daylight inside, and reduces load on artificial lighting [17]. In tropical climates designing building façade or more specifically designing building openings should be given utmost importance as windows have a large-scale impact on thermal comfort considering it's size, orientation and shading configuration. It also has effect on the total energy consumption of the building. It is thus necessary to optimize facade design for maximum benefit regarding energy saving and occupants' thermal comfort [18].

2.3.4 Tall building regulations in context of Dhaka

RAJUK (Rajdhani Unnayan Kartipokkha) is the organization responsible for development and control of built-forms in Dhaka city. It formulated a rule known as set-back rule, which regulates the minimum open space on the different sides of a building. This set-back restriction depends on a number of factors, like plot-size, width of adjacent road, height of building, etc. [19] .

In Figure-2.4, the setback guidelines for 10 storey or above buildings are shown. From Table-4.12 it is observed that the commercial buildings in Gulshan avenue are more than 10 storey. Therefore, the setback guideline shown in Figure-2.4 is applicable for the commercial buildings (F1 type building) of Gulshan avenue.

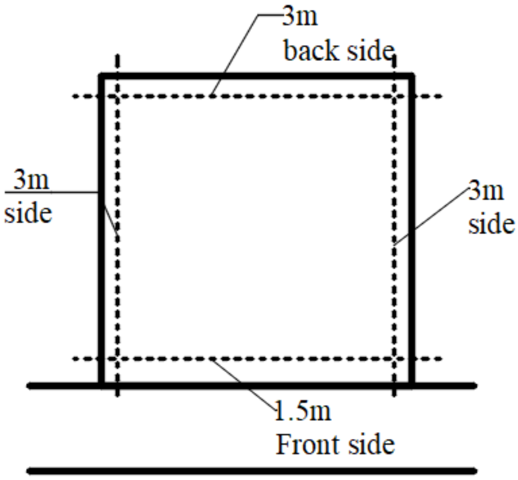


Figure-2.4: Diagram showing Setback in a commercial plot having 10 storied or above (as per Building Construction Act, 2008)

Just like set-back rules, there are rules for limiting the building footprint, the total built area on a site, the maximum number of floors, and FAR (Floor area ratio) rules.

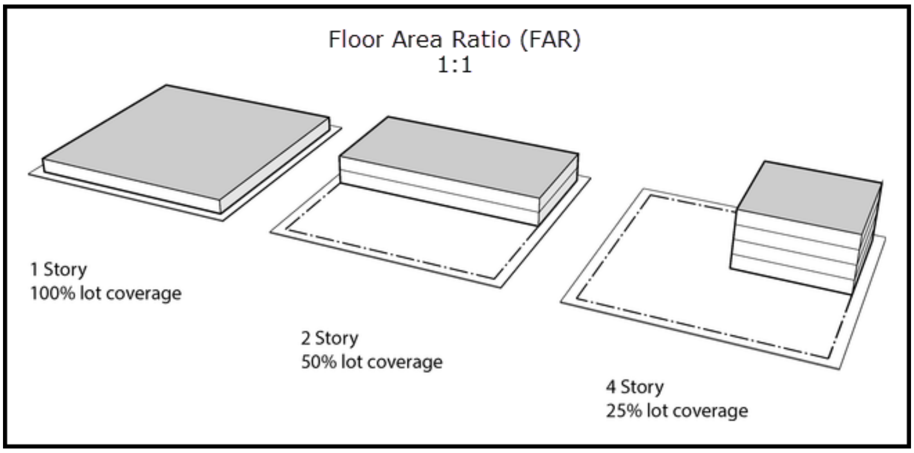


Figure-2.5: Concept of FAR (Source: Sarah Kobos; 2018)

Apart from FAR, the height limits established by Civil Aviation Authority of Bangladesh is also a determinant factor for fixing the allowable number of floors. Other important regulations are MGC i.e Maximum Ground Coverage, Mandatory open space etc. All these rules work as a guideline to express the urban fabric of Dhaka.

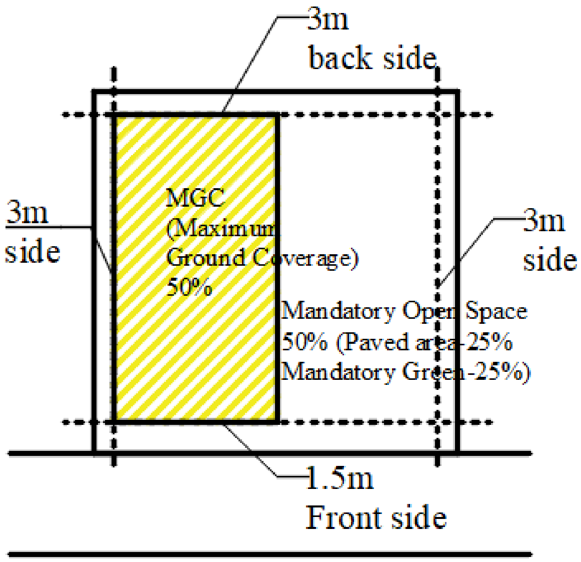


Figure-2.6: Diagram showing Maximum Ground Coverage and Mandatory Open Space

Figure-2.6 shows a condition when the maximum ground coverage (MGC) is 50% of the total land. Therefore, the mandatory open space becomes 50% for this case comprising of 25% paved area and 25% mandatory green.

2.4 Thermal Comfort and occupant's preference in commercial buildings

In this section the thermal comfort related issues associated with occupants of commercial buildings are presented. The issue of thermal comfort is connected to climatic factors as well as it might have connection to energy efficiency.

A significant part of this research, is to understand the impact of the internal environment of a commercial office space, on the thermal comfort sensations of the office occupants. Section-2.2 mentions that energy consumption can vary, according to changes in building façade treatment, resulting in increase or decrease in total cooling load. Further, it is mentioned that the changes in internal environment driven by cooling equipment, can effect users' perception of thermal comfort. This section deals with attributes of thermal comfort, and how they relate to the achievement of energy efficiency in commercial

buildings. As assessment of thermal comfort is done through questionnaires, another major part of this section is related to questionnaire surveys, and how they can help to understand users' take on indoor thermal comfort conditions.
Thermal comfort is the condition of mind that expresses satisfaction with the environment, and is assessed by subjective evaluation [20]. Generally, the criteria of total comfort depends upon each of the human senses. Human responses to the thermal environment, depends not only on air temperature, but also on humidity, radiation and air movement [21].

Humidity conditions in the warm-humid rainy season, necessitates wide openings, to let the breeze in, and these must be shaded properly, to keep out direct solar radiation and rain.

Contrary to expectations, in view of the high levels of temperature and humidity experienced in Bangladesh, the acclimatized population feels thermal discomfort, in only a small proportion of the year. Studies in Bangladesh have been conducted, to identify the truly uncomfortable periods of the yearly cycle. It is identified that March-April is uncomfortably hot, while May-September, the rainy season has lower temperatures but high humidity, and the heat feels tolerable, but not pleasant. Again, from September-October, with a rise in temperature, uncomfortable heat is felt again [22]. Conditions are pleasant during the cool winter season, November-February. Moreover, from figure-2.2 it can be seen, that June-October is the most humid period in Bangladesh, while in terms of temperature, March-October faces the highest values (Figure-2.3). Therefore, during the period of March-October, some mechanical means are needed in high-rise office buildings, to discharge the uncomfortable heat impact, and to ensure thermal comfort for the occupants.

The notion of thermal comfort is subjective. Under the same conditions, different people may have different experiences regarding thermal comfort. Studies to judge and evaluate thermal comfort, and conditions that lead to it, have been undertaken in the Western World since the eighteenth century [23]. The most common factors, known to affect human perception of thermal comfort, have been divided into two groups: environmental variables, which include air temperature, mean radiant temperature, relative humidity of the surrounding air, air velocity; and personal variables consisting mainly of activity level and clothing thermal resistance, the 'clo' value [24]. Along with these factors affecting human thermal comfort, there are indices of thermal comfort, of which PMV (Predicted mean vote) and PPD (Predicted percentage of dissatisfied) are further elaborated in Section-2.5

The reason for creating thermal comfort is, first and foremost, to satisfy man's desire to feel comfortable, in line with the desire for comfort in other directions [25]. Comfort is sensed by the body and perceived by the brain. That is why the science of indoor climate engineering comes before HVAC (Heating , Ventilation and Air conditioning) engineering. It is well known that poor thermal comfort forces users to look for high energy alternatives, to achieve thermal comfort [26], thus draining energy resources.

2.5 PMV-PPD

This section deals with explaining PMV (Predicted Mean Vote) and **PPD** (Predicted Percentage Dissatisfied) which are very popular thermal comfort index. PMV and PPD helps to predict users' perception of thermal comfort in a particular condition.

By investigating the thermal comfort attributes in commercial spaces, the indicators of thermal problems can be determined. Here, to predict thermal comfort conditions the **PMV** (Predicted Mean Vote) and **PPD** (Predicted Percentage Dissatisfied) models are used as tools.

PMV *(Predicted Mean Vote)* is a tool by which thermal comfort can be assessed according to human perception. This index helps individuals to determine their impression, regarding thermal comfort in an indoor climate, which holds the amalgamation of thermal comfort factors.

The PMV index predicts the mean response of a larger group of people according the ASHRAE thermal sensation scale [27]:

Table-2.1. ASHRAE 7 point thermal sensation scale

PMV	-3	-2	-1	0	+1	+2	+3
Thermal Sensation	cold	cool	Slightly cool	neutral	Slightly warm	warm	hot

Table-2.2. Criteria for PMV, PPD for typical spaces [28].

Category	**Explanation**	**General comfort**	
		PPD [%]	Predicted Mean Vote [-]
A	Hospital, Elementary School, Old age home, Space for differently abled	<6	-0.2<PMV<+0.2
B	New Buildings and Renovations	<10	-0.5<PMV<+0.5
C	Existing Buildings	<15	-0.7<PMV<+0.7

Developed by P.O. Fanger [29], the predicted percent dissatisfied (PPD) is an index, that predicts the percentage of thermally dissatisfied people, who feel too cool or too warm, and is calculated from the predicted mean vote (PMV). The PMV and PPD form are therefore closely related, and both indices take the form of a U-shaped relationship, where percentage dissatisfied increases for PMV values above and below zero (thermally neutral). At the neutral temperature, as defined by the PMV index, PPD indicates that 5 % of occupants will still be dissatisfied with the thermal environment. The standard BS EN ISO 7730:2005 (British Standards Institution 2006) uses both the PPD and PMV.

The PMV index is expressed by P.O. Fanger as

$$PMV = (0.303\, e^{-0.036M} + 0.028)\, L$$

where

PMV = Predicted Mean Vote Index

M = metabolic rate

L = thermal load - defined as the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level

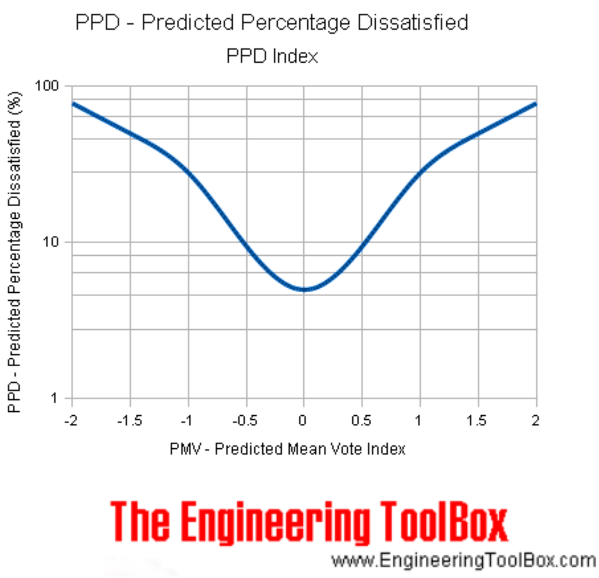


Figure 2.7: PMV-PPD Index (Engineering ToolBox,2010) [30]

Table-2.3. Validity intervals for PMV input parameters, taken and adapted from ISO- 7730 [31]

Parameter	ISO 7730	Humphreys and Nicol	
		PMV free from bias if:	Comment
Clothing insulation [I_{cl}]	0-2 clo (0- 0.310 $m^2\ KW^{-1}$)	$0.3<I_{cl}$	Overestimation of warmth of people in lighter and heavier clothing, serious bias

			when clothing is heavy. Little information exists for conditions when I_{cl}<0.2 clo
Activity level [M]	0.8-4 met (46-232 Wm^{-2})	M<1.4 met	Bias larger with increased activity. At 1.8 met overestimation sensation of warmth by 1 scale unit
Air temperature [ta]	10-30 °C		
Mean radiant temperature [t_r]	10°-40°C		
Air velocity [v_a]	0-1 ms^{-1}	va<0.2 ms^{-1}	

PMV-PPD is an effective method to understand occupants' response to thermal comfort in internal office environment, which is a significant part of this research. The data (thermal comfort indices in existing office space that helps to extract the value of PMV and PPD) collected from the questionnaire (Chapter-4.3) are inserted in thermal comfort model (Chapter-5) and in this way, peoples perception regarding thermal comfort in offices spaces are determined. The data related to thermal comfort indices in existing office conditions, is also collected from field survey.

2.6 Thermal comfort model used for PMV-PPD analysis

One of the aims of analysis to calculate the PMV-PPD values, was to understand the users thermal comfort preference in the west oriented office spaces. Before analysis the terms PMV-PPD need to be discussed. Therefore, a short description of PMV-PPD is provided in Section-2.5, and here in Section-2.6 thermal comfort model used for the analysis is introduced.

Here in this research the CBE Thermal Comfort Tool (ASHRAE-55) has been used to determine the PMV-PPD values. The CBE Thermal Comfort Tool is a free and open-source web based tool, to calculate and visualize thermal comfort indices. It is intended to be used by users with different backgrounds, including engineers, architects, researchers, educators, facility managers and policymakers [32]. A sample of the CBE tool is given in Figure-2.8, along with a psychometric chart generated from the calculator (Figure-2.9).

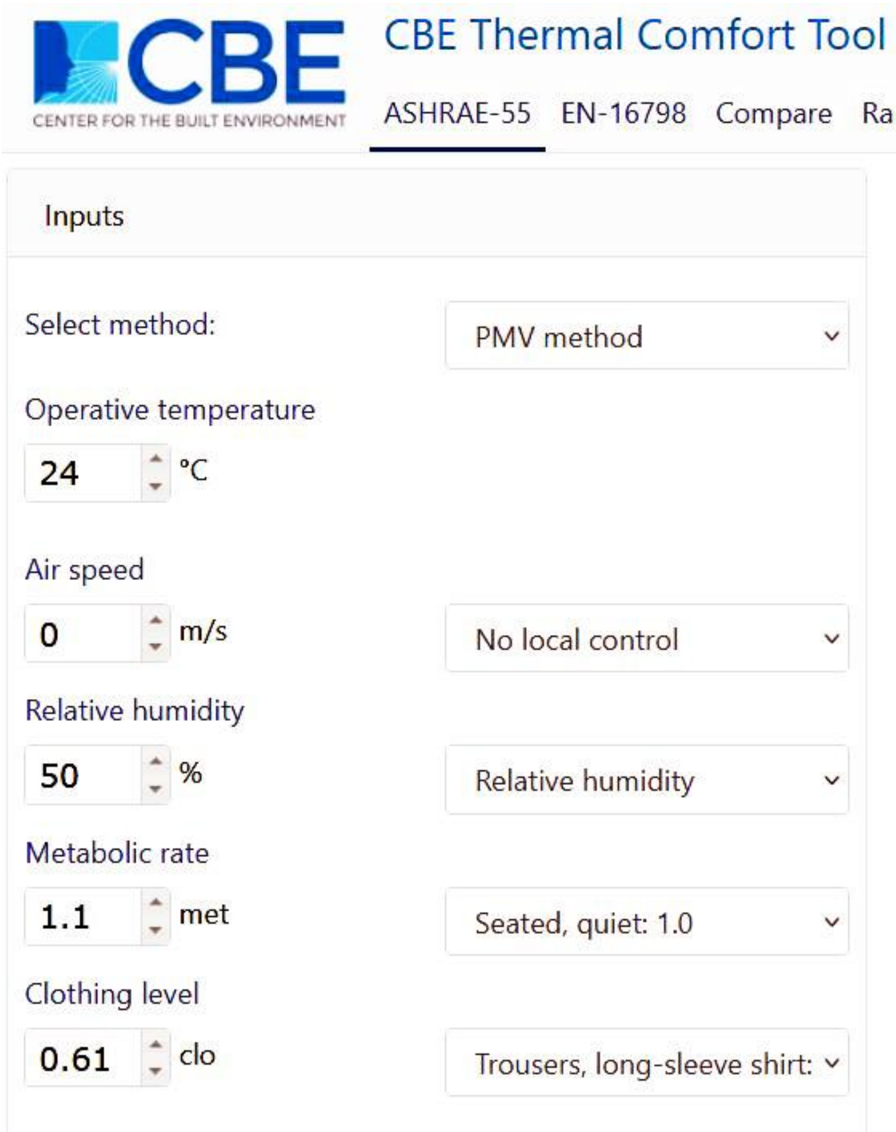


Figure 2.8: CBE thermal comfort tool (Source: Tartarini, F., Schiavon, S., Cheung, T., Hoyt, T., 2020) [33]

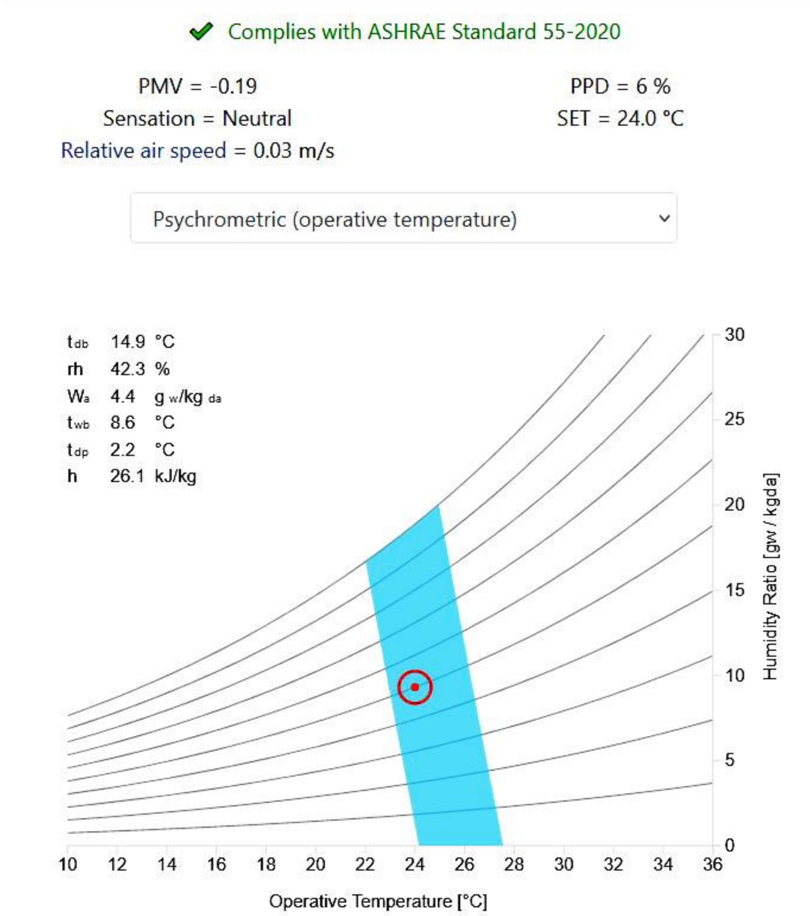


Figure 2.9: Psychometric Chart (Source: Tartarini, F., Schiavon, S., Cheung, T., Hoyt, T., 2020) [34]

In keeping with the assessment tool, the questionnaire includes questions like clothing level, activity level, air temperature, for input into the comfort calculator. Values inserted in the comfort calculator, are the answers, converted into values marked by the majority of the respondents. Standard clo values and met values, used for this study, are given below (Table-2.4 and 2.5).

Table-2.4. Clo value look-up table (modified after ASHRAE 55-2010) [35]

	clo	check		clo	check
Underwear			**Dress and Skirts**		
Bra	0.01	☐	Skirt (thin)	0.14	☐
Panties	0.03	☐	Skirt (thick)	0.23	☐
Men's briefs	0.04	☐	Sleeveless, scoop neck (thin)	0.23	☐
T-shirt	0.08	☐	Sleeveless, scoop neck (thick)	0.27	☐
Half-slip	0.14	☐	Short-sleeve shirtdress (thin)	0.29	☐
Long underwear bottoms	0.15	☐	Long-sleeve shirtdress (thin)	0.33	☐
Long underwear top	0.20	☐	Long-sleeve shirtdress (thick)	0.47	☐
Footwear			**Trousers and Coveralls**		
Ankle-length athletic socks	0.02	☐	Short shorts	0.06	☐
Pantyhose/stockings	0.02	☐	Walking shorts	0.08	☐
Sandals/thongs	0.02	☐	Straight trousers (thin)	0.15	☐
Shoes	0.02	☐	Straight trousers (thick)	0.24	☐
Calf-length socks	0.03	☐	Sweatpants	0.28	☐
Knee socks (thick)	0.06	☐	Overalls	0.30	☐
Boots	0.10	☐	Coveralls	0.49	☐
Shirts and Blouses			**Suit Jackets and Vests**		
Sleeveless/scoop-neck blouse	0.12	☐	Sleeveless vest (thin)	0.10	☐
Short-sleeve knit sport shirt	0.17	☐	Sleeveless vest (thick)	0.17	☐
Short-sleeve dress shirt	0.19	☐	Single-breasted (thin)	0.36	☐
Long-sleeve dress shirt	0.25	☐	Single-breasted (thick)	0.44	☐
Long-sleeve flannel shirt	0.34	☐	Double-breasted (thin)	0.42	☐
Long-sleeve sweatshirt	0.34	☐	Double-breasted (thick)	0.48	☐
Sweaters					
Sleeveless vest (thin)	0.13	☐			
Sleeveless vest (thick)	0.22	☐	**Clo value** (sum of individual values) =		_____
Long-sleeve (thin)	0.25	☐			
Long-sleeve (thick)	0.36	☐			

Heat exchange, between the body surface of an individual, and the environment, can be controlled by the clothes they wear. For calculating transmission through clothing the *clo* unit has been devised, to simplify the handling of the insulating cover. As far as MET is concerned, it has a relationship with metabolism of human body, i.e. the amount of work it is doing. Metabolism is the term describing the biological processes within the body, that lead to the production of heat, and the unit for calculating activity level of human body which influences metabolism, is known as MET [36]

Table-2.5. Typical metabolic heat generation for various activities (after ASHRAE, 2005) [37]

Activities	W/m^2	met
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking(on level surface)		
3.2 km/h (0.9 m s^{-1})	115	2.0
4.3 km/h (1.2 m s^{-1})	150	2.6
6.4 km/h (1.8 m s^{-1})	220	3.8
Office Activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1

The comfort calculator also requires data such as air velocity and relative humidity. As this study is about mechanically controlled offices, the air velocity is considered 0 m/s. In case of putting the value of relative humidity, the average humidity data collected during field survey in the case buildings, was considered, for the most humid month i.e. August (Figure-2.1)

Apart from the extracted data that are used in calculating PMV-PPD values, the data from the questionnaire are analysed using different charts in Section-5.2. In addition to that, some data from the responses were also compared, to get an idea of the diversified preferences of the users.

2.7 Summary

This Chapter dealt with the climatic context of Dhaka region and it's impact on commercial tall buildings. It is mentioned here why energy saving is a burning issue in the context of our country and how tall buildings are responsible for a significant amount of energy consumption globally as mentioned in the previous chapter. Basically, the justification of designing climate responsive buildings is discussed in this chapter. Another significant aspect of the research which is application of energy efficient building façade is raised in Section 2.3.3. The climatic data of Dhaka provided in Section 2.2.3 creates the basis for the simulations provided in chapter-05. Apart from climate the issue of thermal comfort is also discussed in this chapter as thermal comfort is an effect of climatic factors. In addition to that thermal comfort model from where the PMV and PPD values ae determined are also discussed in this chapter. In the next chapter , different ways of treatment of west façade of commercial building for energy efficiency have been discussed.

References

[1] Ahmed, Z.N.1987; The Effects of Climate on the design and Location of Windows for Buildings in Bangladesh, unpublished MPhil thesis, Sheffield City Polytechnic, Chapter 2, October 1987.

[2] Rahman, A. 2007*; Performance evaluation of shading devices used in tall buildings of Dhaka city*, M.Arch thesis, Department of Architecture, BUET, *p. 9.*

[3] Climate maps; Available at: http://www. Climatemaps.com, retrieved on 20.06.2016.

[4] Change, N. G. C. (2020). Causes of Climate Change

[5] Ibid.

[6] Ahmed, K S.1995, *Approaches to Bioclimatic Urban Design for the Tropics with special Reference to Dhaka, Bangladesh,* Phd. Thesis, (unpublished), Architectural Association, School of Architecture, London, UK. *p. 15,32,47*

[7] Climate maps ; op. cit.

[8] Stewart, I.D. and Oke, T.R., 2012. Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, *93*(12), pp.1879-1900.

[9] *"Average Humidity in Dhaka, Bangladesh ".* Bangladesh Meteorological Department. *Retrieved on 2019*

[10]*"Maximum and Minimum temperature in Dhaka, Bangladesh ".* Bangladesh Meteorological Department. *Retrieved on 2019*

[11] Yeang, K., 1997; "*Designing the Green Skyscraper";* In Proceedings of the Third International Conference on Conquest of Vertical Space in the 21st Century, London *p. 12-18*

[12] Ahmed, Z. N., 1994; *"Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gains",* Ph.D. thesis, De Montfort University, UK.

[13] Yeang, K. , 1990; *"Designing the Green Skyscraper",* In Proceedings of the Fourth World Congress on Tall Buildings: 2000 and Beyond, Council for Tall Buildings and Urban Habitat, Hong Kong. *p. 113-115*

[14] Rahman, A., 2007; op. cit. *p.19*

[15] Koenigsberger, O.H., Ingersoll, TG.; Mayhew, A., Szokolay, S.V.,1973; *Manual of Tropical Housing and Building Design*, Part 1, Orient Long man. *p. 23*

[16] Rahman, A., 2007; op. cit. *p.15*

[17] Yeang, K., 1997; op. cit.

[18] Aman, J., 2017. Impact of windows for daylighting on thermal comfort in architecture design studios in Dhaka (M.Arch. Thesis). Bangladesh University of Engineering and Technology, Dhaka.
http://lib.buet.ac.bd:8080/xmlui/handle/123456789/4835.

[19] Ministry of Housing and Public Works, Government of Bangladesh. Building Construction Act, 2008

[20] Zain, Z.M., Taib, M.N. & Baki, S.M.S , 2007, "*Hot and Humid Climate: Prospect for Thermal Comfort in Residential Building", Desalination,*
209(1-3): 261-268.

[21]Staiger, H., Laschewski, G. and Grätz, A., 2012. The perceived temperature–a versatile index for the assessment of the human thermal environment. Part A: scientific basics. *International journal of biometeorology*, *56*(1), pp.165-176.

[22] Ahmed, Z.N.; Howarth, A.T. and Zunde, J.M,1990, "*Thermal comfort studies and applications for Dhaka",* Building Services Engineering Research and Technology, 11(3), pp.105-108.

[23] Markus T A and Morris E N, 1980, "*Buildings, climate and energy* (Pitman)"p 37.

[24] Ahmed, Z.N.;op. cit.

[25] De Dear, R. and Brager, G.S., 1998. Developing an adaptive model of thermal comfort and preference.

[26] P.O. Fanger.,1970; *"Thermal Comfort: Analysis and Applications in Environmental Engineering."* Newyork: McGraw-Hill Book Company.

[27] Beizaee, A., Firth, S., Vadodaria, K. and Loveday, D., 2012, "*Assessing the ability of PMV model in predicting thermal sensation in naturally ventilated buildings in UK"*.

[28] Nikolaou, T., Kolokotsa, D., Stavrakakis, G., Apostolou, A. and Munteanu, C., 2015 ; "*Managing indoor environments and energy in buildings with integrated intelligent systems."* Springer International Publishing.

[29] P.O. Fanger.,1970;op. cit.

[30] Engineering ToolBox, 2010; "*Predicted Mean Vote Index (PMV)*." [online] Available at: https://www.engineeringtoolbox.com/predicted-mean-vote-index-PMV-d_1631.html [Accessed Day Mo. Year]

[31] M. A. Humphreys and J. F. Nicol, 2002; "*The validity of ISOPMV for predicting comfort votes in every-day thermal environments."* Energy and Buildings 34(6), 667-684

[32] Tartarini, F., Schiavon, S., Cheung, T. and Hoyt, T., 2020. CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX*, *12*, p.100563.
Available at: https://doi.org/10.1016/j.softx.2020.100563

[33] Ibid

[34] Ibid

[35] Parkinson, T. and de Dear, R., 2017. Thermal pleasure in built environments: spatial alliesthesia from air movement. *Building Research & Information*, *45*(3), pp.320-335.

[36] Hasan, M.H., Alsaleem, F. and Rafaie, M., 2016. Sensitivity study for the PMV thermal comfort model and the use of wearable devices biometric data for metabolic rate estimation. *Building and Environment*, *110*, pp.173-183.

[37] Kim, E.B. and Park, J.K., 2014. Proposal for a heat balance model tailored to the Korean Peninsula. *Asia-Pacific Journal of Atmospheric Sciences*, *50*(1), pp.657-667.

Chapter 03: Building Façade and it's treatment for energy efficiency

3.1 Introduction

In the previous chapter, is discussed why it's necessary to design climate responsive tall buildings and it is mentioned that designing energy efficient façades can be a key factor, that makes the building sustainable. Here in this chapter, details of building façades, and how they can be treated for ensuring energy efficiency, is discussed. Another important aspect associated with building façades are shading or solar control devices, which are also discussed in this chapter, which can be treated as an element that reduces the amount of sunlight entering through the façade.

The word facade originally comes from the Italian word "facciata", and is defined as the outside, or all of the external faces, of a building. It is one of the most important elements of a building**,** along with the roof, since it acts as the primary barrier, protecting against external weather elements that could damage the health of the structure, such as sun, wind, rain, etc. Hence selection of facade system is important, in that protection against these risks, whilst helping to achieve lower energy consumption, reduces maintenance costs and improves comfort for the inhabitants [1].

The facade is a building component that combines attributes of both appearance, as well as superior performance in a manner, unlike any other building system. It protects the indoor from adverse effects of the nature, and also is a factor for creating indoor thermal comfort conditions. In recent times it is the most effective means of controlling building's energy consumption [2], and can thus be considered a key passive architectural element.

3.2 Treatment of commercial building facades for energy efficiency

Façades need to be designed, incorporating modern technologies, that would help the buildings to be considered sustainable, in terms of energy use. Solar radiation is a factor, and its penetration is influenced by the building façade, as detailing of the façade denotes how much heat and light is entering a building.

Solar radiation affects the temperature and density of air, thus affecting the wind velocity, direction and humidity [3]. Adjustment of solar radiation entering into a building is a major step to ensure energy efficiency, as well as ensuring thermal comfort conditions. The amount of heat entering into a building can be adjusted, by means of orientation, aperture geometry; shading devices; properties of opaque and transparent surfaces [4]. Therefore, in this chapter, the ways of treating commercial building façades that characterize solar control is elaborated.

3.2.1 Treatment of façade by building or facade orientation:

Building orientation helps the architect to determine which areas of the building are exposed to direct sunlight. Proper orientation can be estimated through consideration of the path of the sun, and it can be used to define which side can provide the maximum advantage to the building. The air-conditioning or heating energy requirements also get affected, making way for energy conservation, if the building is properly oriented [5].

To propose better orientation for a building, first of all the true north has to be identified. Then sun angles in different seasons can be known, which will allow designing optimum openings and shading devices. This will control maximum solar radiation, and capture the incoming heat for the appropriate climates [6].

Tilting the plans

How the principles of orientation can be applied are shown below, relevant for the northern hemisphere –

Figure-3.1: Plan at north

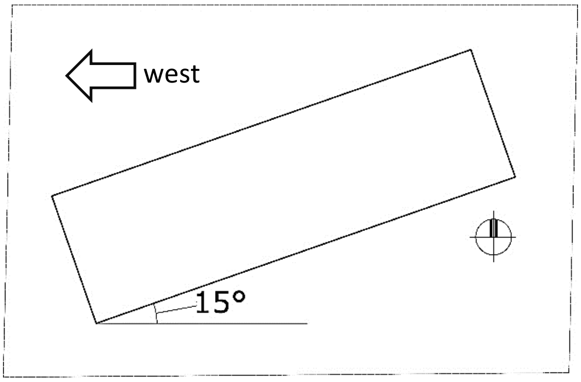


Figure 3.2: Plan 15° tilted from normal (up to 15° west of solar north)

This orientation maximizes late afternoon solar gains and allows morning sun in winter. Therefore, it is suitable for cold climates. This configuration can also be useful in warmer climates in naturally ventilated spaces, where cooling breezes are from the south-east. Slightly increased overhangs for northern eaves reduces solar gains in spring and autumn in these climates, and breeze filtering plants to the east provide shade from morning sun in summer .

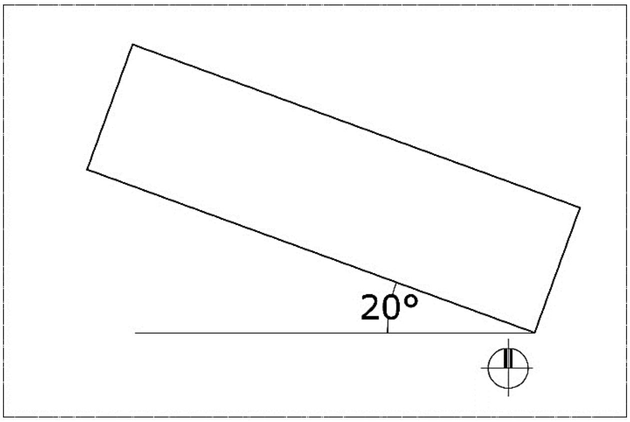


Figure-3.3: Plan up to 20° east of north

The areas where warm-humid conditions are critical, the orientation shown in Figure 3.3 maximizes exposure to cooling breezes, but reduces solar heat gains. Therefore, in case of west facing buildings, these techniques can be applied to reduce the effect of incoming sun. This consideration is further explored in chapter-05 while running simulations.

This simple configuration allows for ambient light during the day, in cooler contexts. In warmer regions, passively shaded clerestory windows along the facade, would allow hot air to escape in summer while allowing in a small amount of winter sun [7]. Positioning the building in north-south orientation would allow more day light. Again, if the east-west façade has shorter length it would minimize the effect of low angle of sun, which makes the indoor environment warmer.

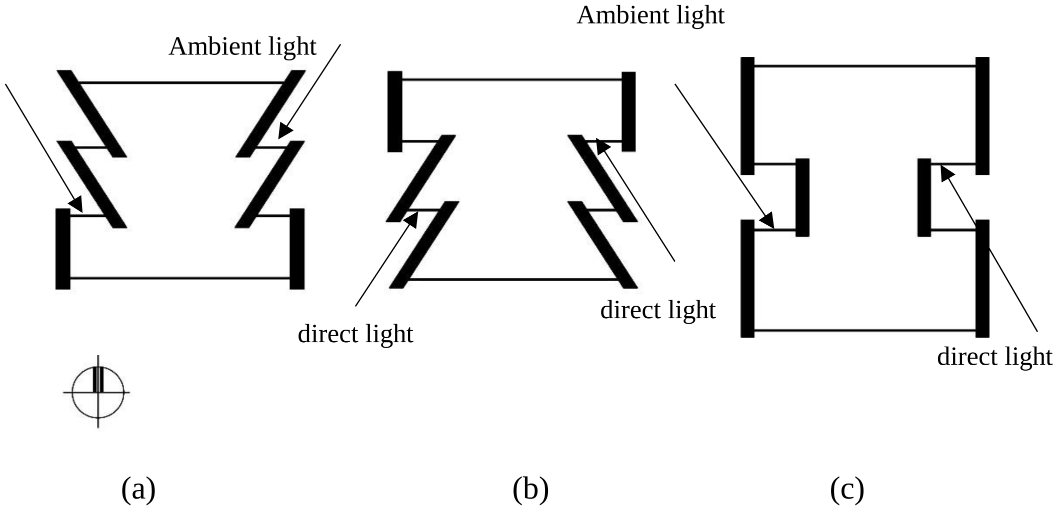


Figure 3.4: Ways of treating east or west façade to reduce the effect of direct radiation (Source:The Carbon Neutral Design Project, 2012) [8].

(a)Allows ambient north light from the marked direction

(b)Allows direct sun light from the marked direction

(c) Allows the combination of both (a) and (b) from the marked direction

Figure 3.4 shows three different configurations that reduces direct sun exposure through east and west façades, by shifting the openings to face north and south. This results in less heat gain through east or west facades [9].

3.2.2 Treatment of façade with glass

The use of glass façade in commercial buildings is increasing globally for principally two reasons. The first reason may be to ensure enough view of the outdoor from individual workstations, and second reason is to provide sufficient day light indoors. Another aspect of glass façade is that it traps a percentage of incoming sun, which can be an advantage in cold climates. Moreover, due to advancement in the industrial sector, the manufacture and installation of glass curtain walls and other types of glass, is of relative ease in present times. Additionally, the Architect uses such facades often for aesthetic intentions also.

Since commercial buildings use principally glass façade therefore, architects need to have a clear indication regarding the properties of glass. The properties of glass that indicates the amount of heat penetration are- visible light transmittance , U-Value , reflectance, solar heat gain co-efficient, shading co-efficient. These properties of glass either control the amount of heat entering the glass façade or works as an insulator or reflect a certain amount of light incident upon the glass. Therefore the value of these properties are an indicator of glass performance in terms of heat penetration. The properties of glass are briefly discussed in Appendix A.

Glass façades of a commercial building can be treated in several ways. Some are briefly discussed below-

Tilted Façade

Tilting the building façade in upward or downward direction can be a way of treating the glass façade (Figure 3.5). In Figure-3.5 an example of a section of tilted glass façade is given .The details are explained below.

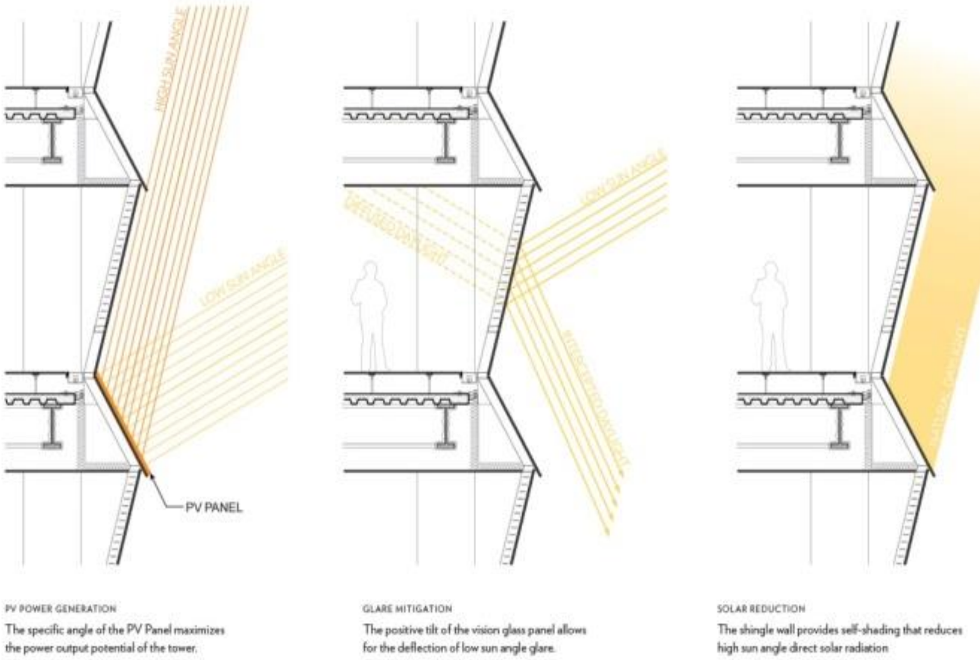


Figure 3.5: FKI Tower Exterior Wall, Seoul, North Korea
(Source:Oh, S.H., 2020) [10]

Figure-3.5 shows the section of an innovative exterior wall of a 50-storey, 240m high building named FKI Tower, Seoul, North Korea which reduces internal heating and cooling loads, while collecting energy through photovoltaic panels. These panels are integrated into the spandrel areas of the southwest and northwest facades. By angling the spandrel panels 30 degrees toward the sun, the amount of energy collected by the panels is maximized. Below the spandrels, the vision panels are angled 15 degrees toward the ground, minimizing the amount of direct sun radiation and glare. The building is able to use the geometry of the exterior wall to self-shade the perimeter spaces. The tower's exterior wall clearly illustrates the advancement in building facades, from simple wall systems, to high-performance, integrated design solutions [11]. The reason for putting this example in this research is that the glass façade of this building resembles with one of the case studies in Gulshan avenue elaborated in Section-4.4.3 named Navana Pristine Pavillion. The integration of photovoltaic cells and angled vision glass towards the ground, have resulted in net energy cost reduction of 36.6% from the baseline building [12].

Double skin façade

The double-skin façade, or DSF, is an envelope construction, composed of two transparent "skins", separated by an air corridor. The DSF is a form of active façade, because it employs equipment, like fans or solar/thermal sensors. It also integrates passive design strategies, such as natural ventilation, daylighting, and solar energy. The DSF is a hybrid of these two, as it uses some mechanical energy, in addition to the natural and renewable energy resources [13]. The foremost benefit of double-skin facades cited by design engineers of European Union (EU) is in acoustics. A second layer of glass placed in front of a conventional façade, reduces sound levels at particularly loud locations, such as high traffic urban areas. The second layer of glass, provides opportunities for heat extraction during the summer, which may be beneficial for Dhaka in warm-humid conditions. DSF is tested for efficiency for this study, in chapter-05. Shading systems, placed within the cavity, are protected from the weather. Studies show that thermal comfort improves with this buffer space, compared to conventional window systems. The complexities and design variations of double-skin facades are large. EU engineers caution their clients, that energy-efficiency is not the foremost benefit of double-skin facades. They also suggest that such benefits derived may be small depending upon circumstances [14].

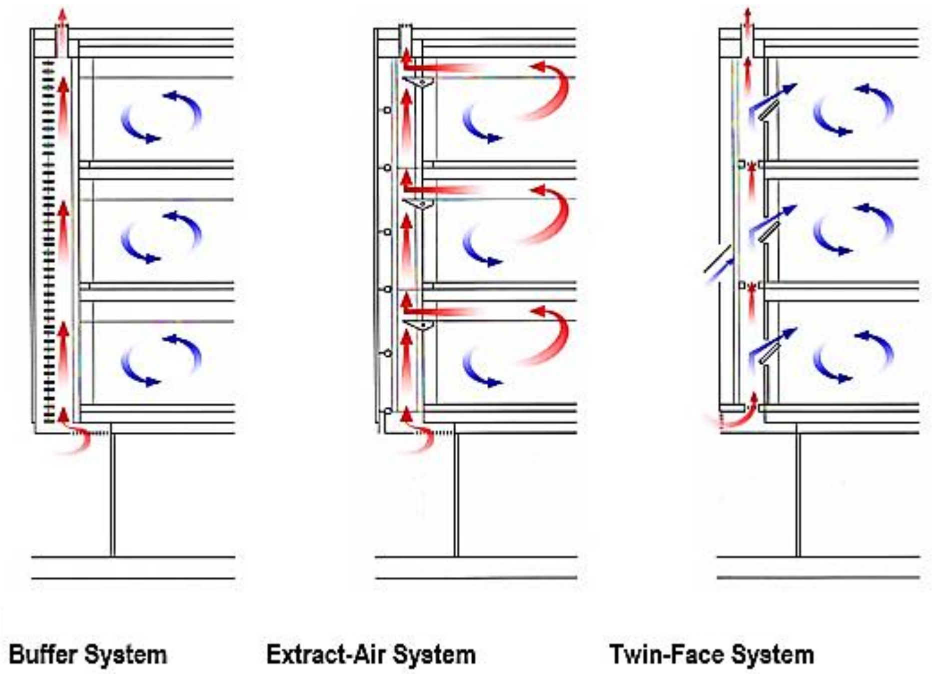
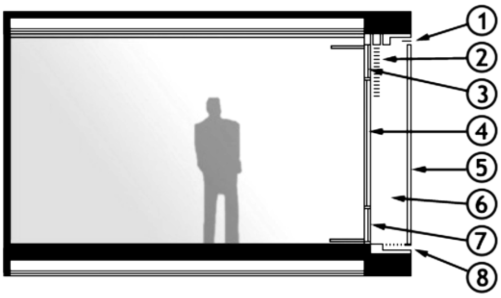


Figure 3.6: Types of double skin façade (Source:Oesterle, Lieb, Lutz, Heusler,2001)

Heat extraction double-skin facades

Heat extraction double-skin facades, rely on sun shading located in the intermediate space, between the exterior glass façade and interior façade, to control solar loads. The concept is similar to exterior shading systems, that reduces the amount of solar radiation entering the building, except that heat absorbed by the between-pane shading system is released within the intermediate space (Figure-3.6), then drawn off through the exterior skin, by natural or mechanical ventilation means. Cooling load demands on the mechanical plant are diminished with this strategy [15].



1.Exterior upper air outlet
2. Controllable solar control device
3. Interior upper operable window (air inlet)
4. Interior operable or fixed view window
5. Exterior glazing layer
6. Air cavity
7. Interior lower operable window (air inlet)
8. Exterior lower air inlet

Figure 3.7: Heat extraction double-skin facades (Source: Oesterle, Lieb, Lutz, Heusler. 2001)

3.2.3 Available glasses in the market for construction

The following table shows basic information of glass types used in commercial building of Dhaka, extracted from the website of CHB building technologies Ltd.

Table 3.1: Basic information of Glass types used in commercial building facade (Source: CHB Building Technologies Ltd. Website)

Glass Name	Glass Type	Shape	Usage	Colour	Size	Thickness (mm)	Features
a)Building Glass	Laminated Glass	Flat	Door	Clear	Max size 2440x3660 mm Min size	3-19	1.High safety 2. sound insulation

					300x500 mm		3.Anti-ultraviolet ray 4.bullet resistant
b)Construction Glass	Tempered Glass	Flat	Door	Clear	Max Size 2500-3600mm Min size 200x400 mm	3-12	1.Float 2.insulating glass
c)Double Glazing Glass	Laminated Glass	Flat	Door	Clear	Max size 2440x3660mm Min size 300x500 mm	3-19	1.High safety 2. sound insulation 3.Anti-ultraviolet ray 4.bullet resistant
d)White Milk Laminated Glass	Laminated Glass	Flat	Building	White Milk	Max size 2440x3660mm Min size 300x500 mm	3-19	1.High safety 2. sound insulation 3.Anti-ultraviolet ray 4.bullet resistant
e)Reflective Glass	Laminated Glass	Flat	Door	Clear	Max size 2440x3660mm Min size 300x500 mm	3-19	1.High safety 2. sound insulation 3.Anti-ultraviolet ray 4.bullet resistant

f)Low-E-Insulated Glass	Laminated Glass	Flat	Door	Clear	Max size 2440x3660mm Min size 300x500 mm	3-19	1.High safety 2. sound insulation 3.Anti-ultraviolet ray 4.bullet resistant
g)Laminated Safety Glass	Laminated Safety Glass	Flat	Door	Clear	Max size 2440x3660mm Min size 300x500 mm	3-19	1.High safety 2. sound insulation 3.Anti-ultraviolet ray 4.bullet resistant

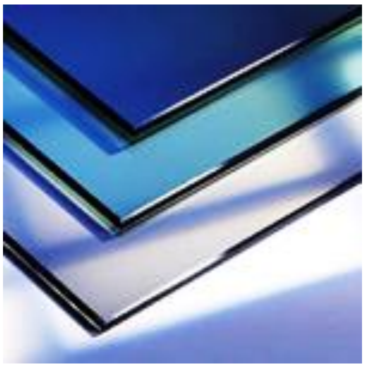
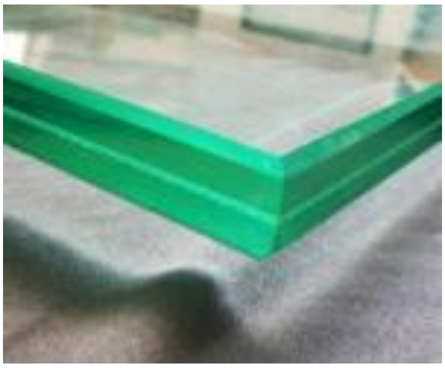
a) Building Glass

b) Construction Glass

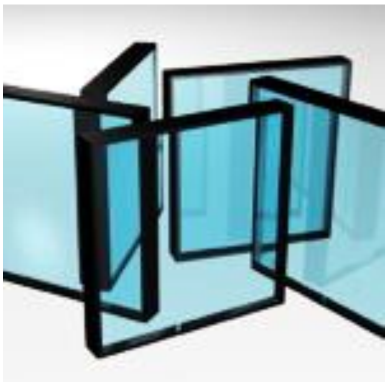
c) Double Glazing Glass

d) White Milk Laminated Glass


e) Reflective Glass f) Low-E insulating Glass

g) Laminated Safety Glass h)Laminated Glass



i) Insulated Glass

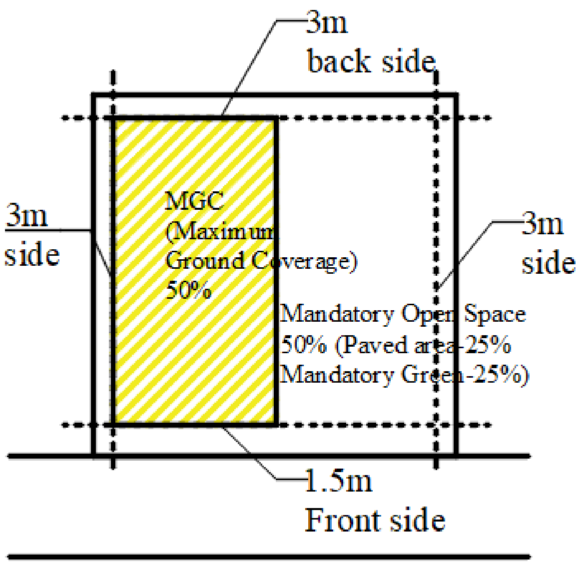
Figure 3.8: Different types of glass available in market for construction (Source: CHB building technologies Ltd.)

3.3 Treatment of façade with shading Device

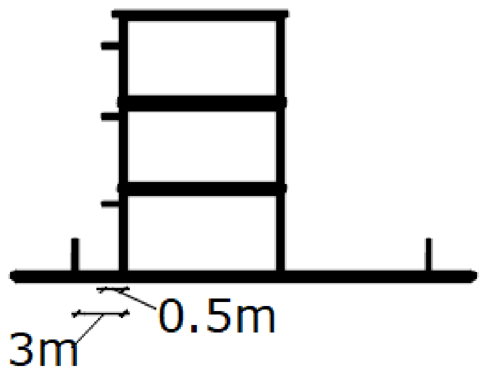
The amount of heat and light penetrating through a building façade, can be controlled by installing different shading devices, or exterior solar control devices i.e. horizontal or vertical overhangs, fins, or full window screen geometries. The architectural character of a building is thereby defined by the shape and material of these shading devices [16].

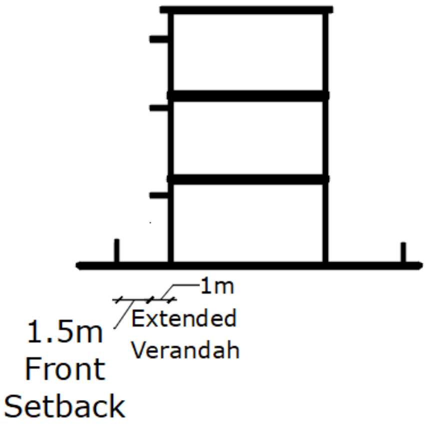
External shading devices can be utilized to block the solar radiation before it reaches the indoor environment. The greatest source of heat gain, can be the solar radiation, entering through glazed openings. This could, in fact, increase the indoor temperature, far above the outdoor temperature, even in moderate climates, due to greenhouse effects though it only happens through glazed openings in sealed buildings. Window glass is particularly transparent for short wave infra-red radiation by the sun, but almost opaque to long wave radiation emitted by objects in the room. As a result, the heat, once it has entered through a window, is trapped inside the building. As the west façade gets maximum sun exposure during the warmest part of the day, the openings in this façade require properly designed shading devices, to minimize the solar heat gain. Studies show, that horizontal shading devices are appropriate, to protect the windows from solar heat gain, in south orientations, while vertical shading devices are beneficial for west facades [17]. Studies also indicate that, horizontal louvered shading gives better protection against heat gain, due to the gaps between the device and built-up surfaces [18]. For this research, computer simulations have been performed later in chapter-05, to investigate the impact of these west façade shading devices, on energy efficiency.

According to Dhaka Building Construction Act 2008, shading devices or sunshades, can be extended into setback spaces up to 0.5m (Figure-3.9-b). It can be extended up to 1.5m without compromising maximum ground coverage, if the setback area is kept more than the minimum requirement, specified for different land sizes. Front balconies, up to 1m in depth, can be exempt from calculations of maximum ground coverage, provided they do not project beyond the minimum front setback, which is specified as 1.5m (Figure-3.9-c) [19].



(a)





(b) (c)

Figure-3.9:(a)Diagram showing Setback in a commercial plot (Source:Building Construction Act, 2008)

(b)Section showing allowable depth of shading device on setback area.

(c)Section showing allowable depth of extended verandah on front side.

A Study conducted in the context of Egypt showed that, the application of combined shading, which is the combination of both horizontal and vertical shading, reduced the indoor temperature up to 1.5^{0}C [20].

Another study was conducted in the context of Singapore, where climate is much like that of Dhaka in the humid months. The study found that, with suitable façade designs and shading devices, indoor temperature could be reduced by 2 to 3°, compared to the outdoor temperature [21].

An overview of types of external shading device best for different orientation is shown in Figure-3.10.

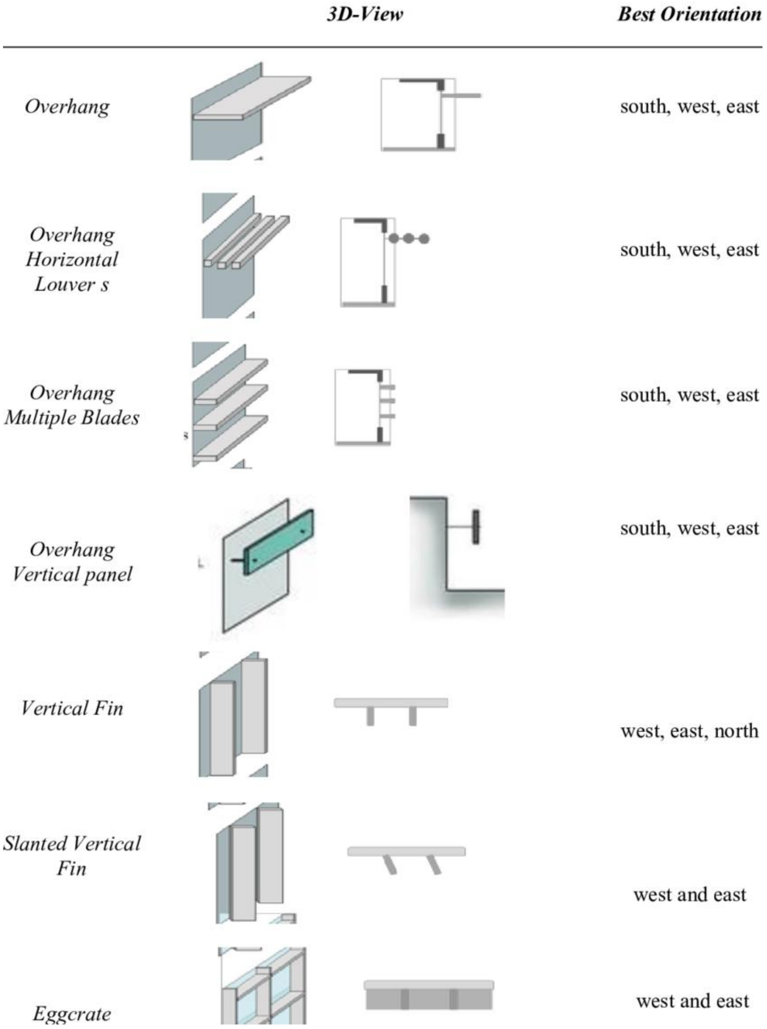


Figure 3.10: External Shading Device (Source: Faisal, G., & Aldy, P, 2016) [22]

The details of louvers and blinds are briefly discussed here, as these are the most common types of shading devices, used in the study area of this research (Chapter-04). Generally, louvers and blinds are composed of multiple horizontal or vertical slats. Exterior blinds are more durable, and usually made of galvanized steel, anodized or painted aluminium or PVC, for low maintenance [23]. Size, shape and angle of the slats vary. Slats can be either flat or curved. With different shapes and reflectivity, louvers and blinds are used, not only for solar shading, but also for redirecting daylight. There are two types of louvers: fixed systems and adjustable systems. Fixed systems are designed mainly for solar shading, adjustable systems can be used to control thermal gain, reduce glare, and redirect sunlight [24].

In Dhaka city operable systems are still not popular, and fixed systems are widely used in contemporary designs (Chapter-04) [25]. Horizontal shading devices are appropriate, to protect windows from solar heat gain in the south orientation. It works efficiently from 10 A.M. to 2 P.M. when the sun is opposite to the window pane and at a high altitude [26]. Studies also indicate that, horizontal louvered shading gives better protection against heat gain, due to the gaps between the device and built-up surfaces [27]. In the study area of this research these horizontal louvers are implement in western façade also (Section-4.4.1).Here in figures-3.9 and 3.10, details of horizontal louvers of different size, shape and angle are shown [28].

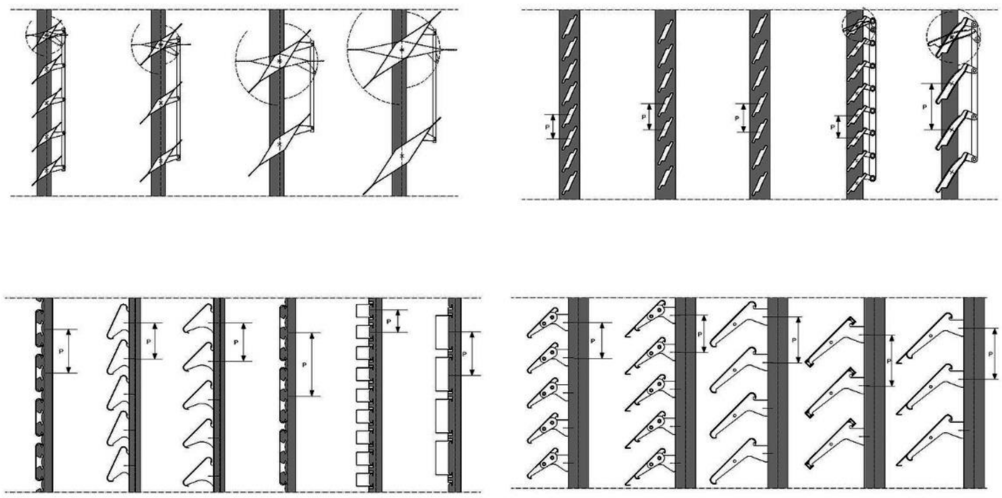


Figure 3.11: Horizontal angular shading device (Source: ArchDaily)

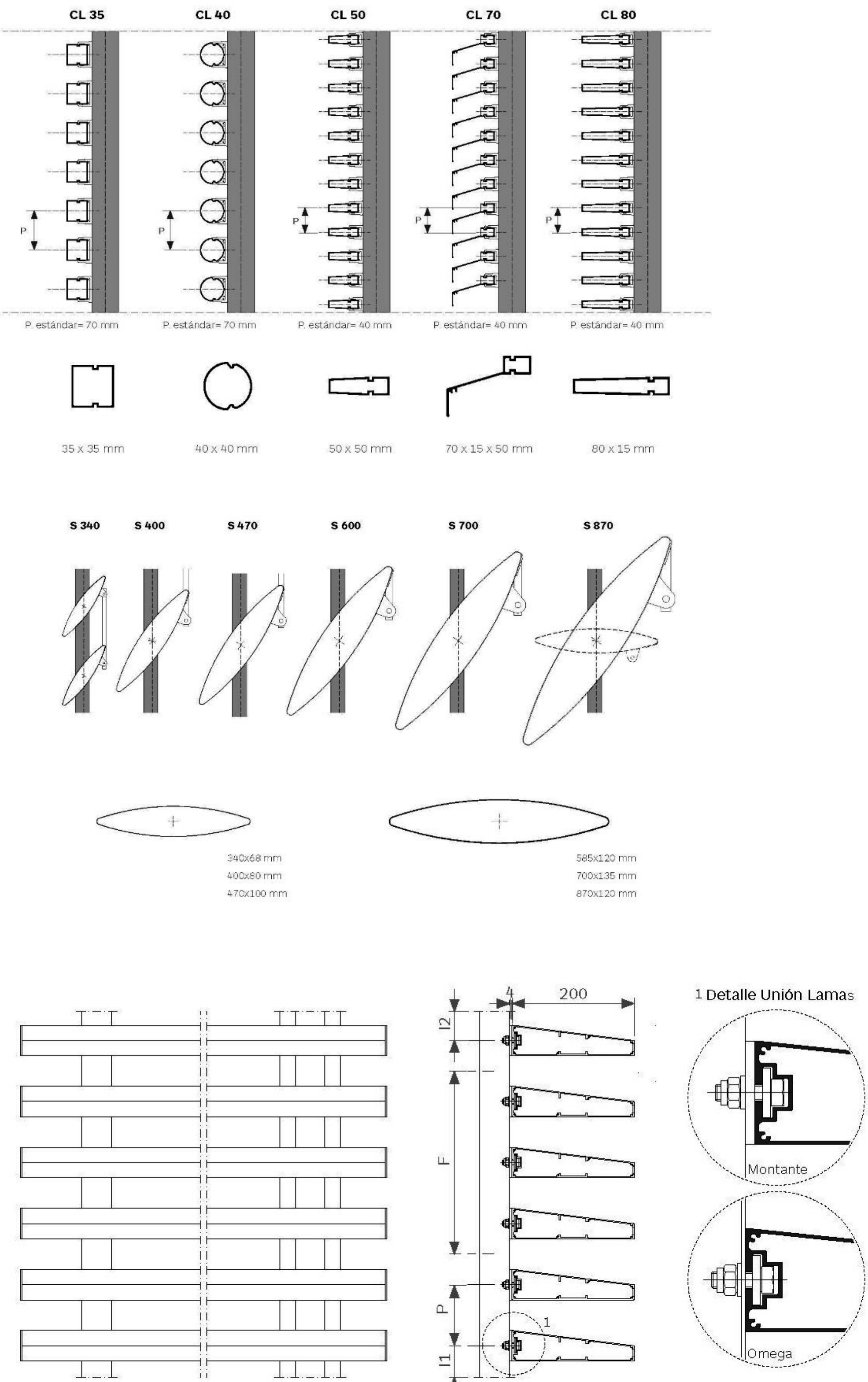


Figure 3.12: Sections of horizontal louvers having different shapes (Source: ArchDaily)

Vertical fins protect window facades, from east and west low-angle sun. Overhang and fins combined, can be applied to buildings in hot climates.

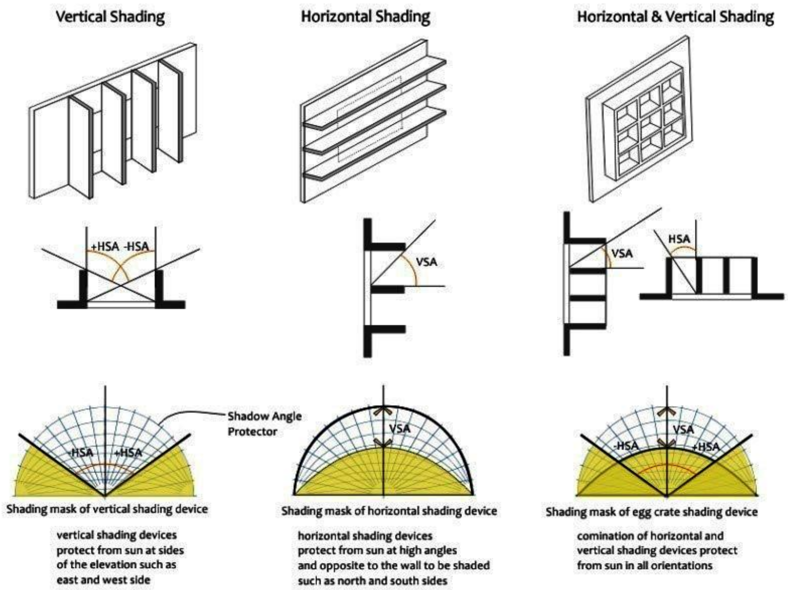


Figure-3.13: Different types of shading (Source:Energy Conservation Building Code, 2017) [29]

3.4 Summary

Chapter-03 focused on different ways of treating commercial building façades, which would lead to save a certain amount of building's total energy use. The chapter elaborates on various treatment of building façades, such as by building orientation, by tilting the glass façades, by using double skin facades, or by using external solar control devices. Later, in chapter-05 it is verified through computer simulations that which of these façade treatment is more energy efficient. Therefore, the literature discussed in chapter-03 formulated the basis of analysis for chapter-05. In the next Chapter another significant aspect of this research i.e the analysis part (both extraction from questionnaire and computer simulations) is discussed.

References

[1] Cupapizarras, September 2019; "*Types of facades for buildings".*

Available at: https://www.cupapizarras.com/int/news/types-of-facades/

[2] Constro Facilitator , March 23, 2021; *"Different types of facades for commercial building*."

Available at: https://www.constrofacilitator.com/different-types-of-facades-for-commercial-building/

[3] Ahmed, Z. N. 1994; *"Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gains",* Ph.D. thesis, De Montfort University, UK.

[4] Santamouris, M, dan Asimakopoulos, D. 1996; "*Passive Cooling of Buildings*", James & James, Universitas Michigan

[5] Amin, A. 2019,*"Façade design for energy-efficient buildings: analysis of architectural façades through functionality and simplified forms approach",* The Architectural Science Association (ANZAScA).

[6] [https://www.yourhome.gov.au/passive-design/orientation]

[7] Ibid

[8] 2012; *Carbon Neutral Design Strategies: Reduce Loads/Demand-Shading*, Society of Building Science Educators, American Institute of Architects.

[9] [https://www.aiachicago.org/dea_archive/2015/fki-tower-exterior-wall/]

[10] Oh, S.H., 2020; "*Curtain wall facades on the new generation of supertall buildings present and future directions*", International Journal of High-Rise Buildings, 9(2), pp.124

[11] Ibid

[12] Betancur, J, 2017; "*Multitasking façade: how to combine BIPV with passive solar mitigation strategies in a high-rise curtain wall system"* International Journal of High-Rise Buildings, 6(4), pp.307-313.

[13] Double-Skin Façade System: Materials, Advantages & Examples. (2017, November 9). Retrieved from https://study.com/academy/lesson/double-skin-fa-ade-system-materials-advantages-examples.html.

[14] Oesterle, Lieb, Lutz, Heusler. 2001, *Double-Skin Facades:Integrated planning* , Munich: Prestal Verlag.

[15] Ibid

[16] Lee, E., Selkowitz, S., Bazjanac, V., Inkarojrit, V. and Kohler, C., 2002. *High-performance commercial building façades*.

[17] Rahman, A. 2007*; Performance evaluation of shading devices used in tall buildings of Dhaka city,* M.Arch thesis, Department of Architecture, BUET.

[18] Trisha, S. H. 2015, *"Assessment of HVAC load in light zones to determine energy efficient shading for tall office buildings of Dhaka"*, M. Arch. Thesis,

(unpublished), Department of Architecture, Bangladesh University of Engineering and Technology, Dhaka.

[19] *Dhaka Building Construction Act, 2008*, Government of Bangladesh, Ministry of Housing and public works, Dhaka

[20] Ahmed, A. M. Ali, Tarek, M. F. Ahmed 2012, "*Evaluating the Impact of Shading Devices on the Indoor Thermal Comfort of Residential Buildings in Egypt",* Fifth National Conference of IBPSA-USA, Madison, Wisconsin, August 1-3

[21] Feriadi, H. 2003, *"Thermal comfort for natural ventilated residential buildings in the tropical climate"*, Unpublished PhD Dissertation, National University of Singapore.

[22] Faisal, G., & Aldy, P, 2016, April; Typology of building shading elements on Jalan Sudirman corridor in Pekanbaru. In *IOP Conference Series: Materials Science and Engineering* (Vol. 128, No. 1, p. 012029). IOP Publishing.

[23] Leung, T.C., Rajagopalan, P. and Fuller, R., 2013. Performance of a daylight guiding system in an office building. *Solar Energy*, *94*, pp.253-265.

[24] Al-Masrani, S.M., Al-Obaidi, K.M., Zalin, N.A. and Isma, M.A., 2018; Design optimization of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, *170*, pp.849-872.

[25] Ahmed, Z. N. 1994; op. cit.

[26] Rahman, A. 2007;op. cit.

[27] Trisha, S. H. 2015,op. cit.

[28] Franco, José Tomás. " 6 Spanish Projects That Creatively Use Louvers and Shutters in Their Facades" [Detalles de celosías y su aplicación en 6 edificios en España] 29 Aug 2018. ArchDaily. Accessed 21 Jun 2022.

[29]Bhavik M, Suhas T; "*An approach towards solar passive methods in Architecture"*, Surfaces reporter magazine.

Chapter 04: Field Investigation

4.1 Introduction

Data collection for this research have been conducted following three ways. Firstly, data from case buildings have been collected from field survey. It needs to be mentioned here, that most of the study part of this research was conducted during the period of COVID-19 outbreak, which limited the extent of the field survey. Along with field survey, the data related to case buildings were also collected from secondary sources, such as interviewing concerned building architects, engineers.In addition to that data was also collected through written notes published on the website and magazines, and from data base of the existing building management offices. Another significant part of data collection was through questionnaire survey. The questionnaire was provided, to people working on a west facing building on Gulshan avenue, to collect data related to their thermal preferences and behavioural responses. The overall data, collected following the above mentioned methods, is presented in this Chapter.

4.2 Brief description of the study area (Gulshan avenue)

Dhaka is the capital city and a major business hub of Bangladesh. Previously, Motijheel and Karwan Bazar used to be the centre of commercial activity in Dhaka. The land use of Dhaka city has gone through rapid alteration, along with economic development, in the last few decades. Although the major commercial buildings in the 1980s were still concentrated in the Motijheel area (Figure-4.1), the activities of the CBD became defused [1]. A study suggested that the administrative buildings and commercial areas of Dhaka [2] have extended from the historic core northwards. New business centers towards the north, near the New Market area, Elephant Road, Mag Bazaar, Mouchak, Farmgate, Gulshan and Uttara started to flourish being located close to the planned residential areas [3]The detail area plan of Dhaka dated 2010 is given in Figure-4.2

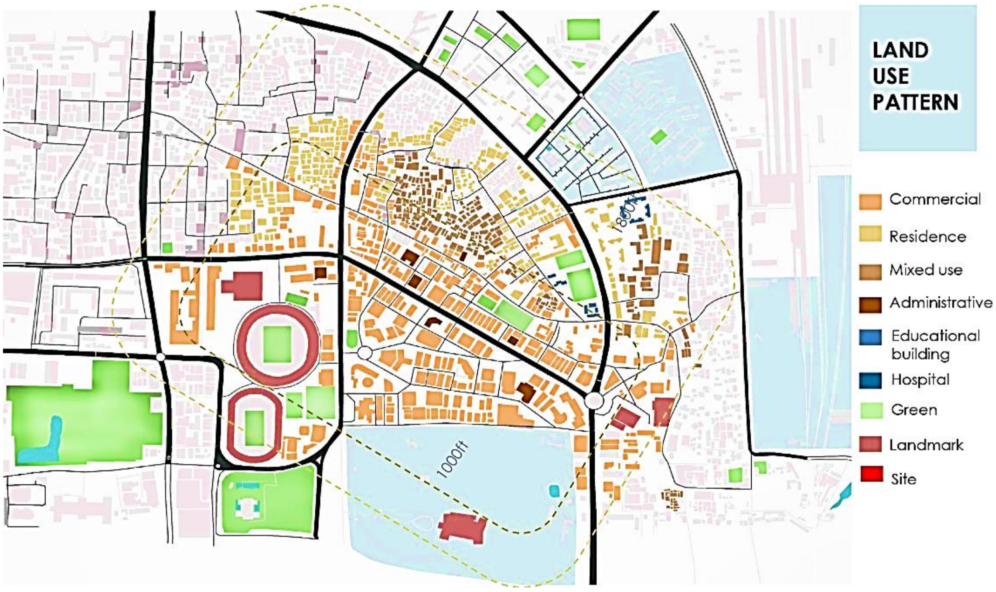


Figure-4.1: Land use map of Motijheel (Source: Department of Architecture, Southeast University)

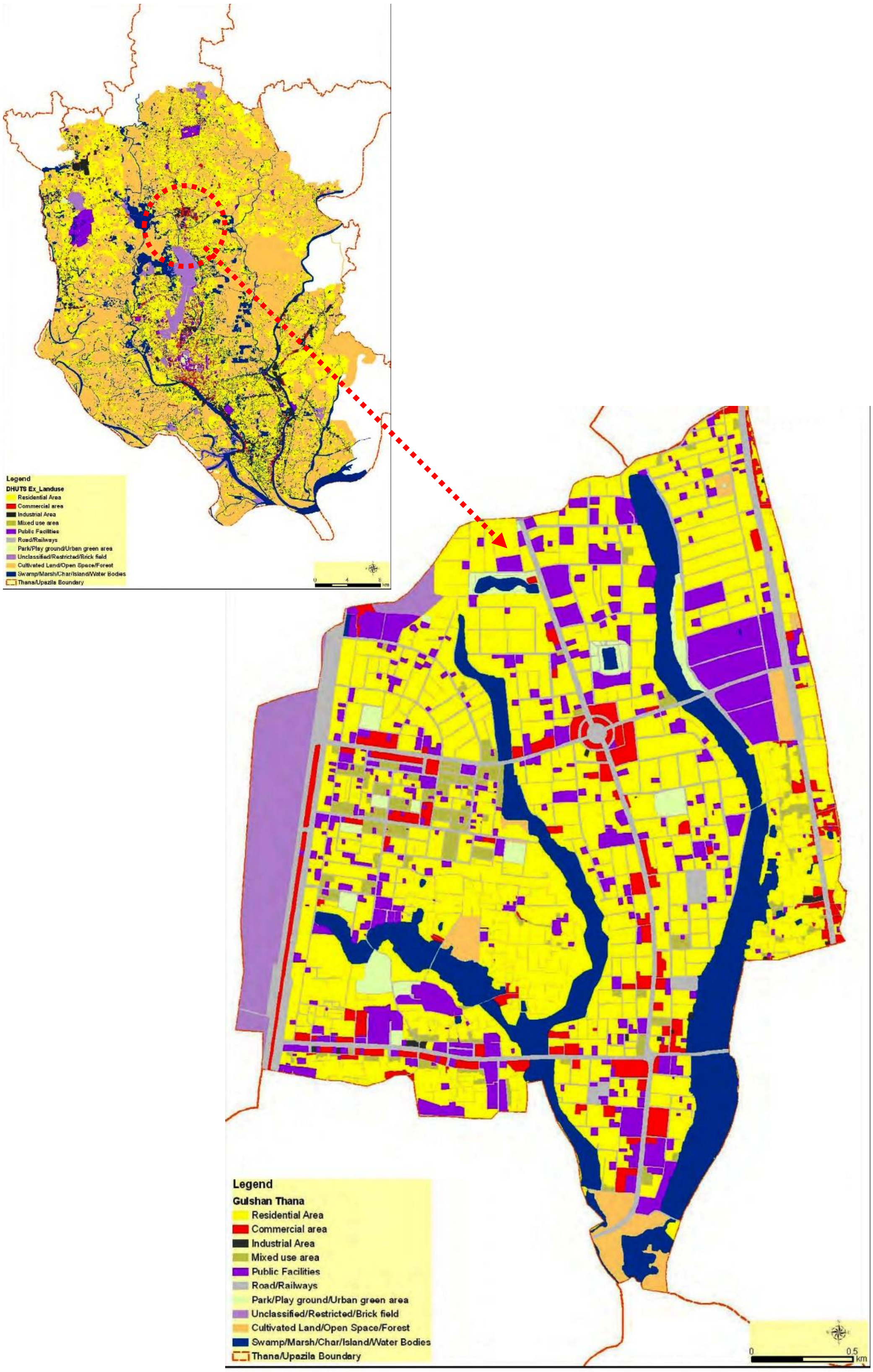


Figure-4.2: Existing Land use in Dhaka (2009) focusing Gulshan thana (Study area) (Source: Dhaka Urban Transport Network Development Study, 2009)

Gulshan is one of the areas, which was designed as a planned residential area, but due to rapid growth in the corporate sector, now mostly has mixed-use construction along the spine roads. This can be understood from the land use map of this area (Figure-4.3)

For this research, commercial high-rise buildings of Gulshan avenue have been chosen as a base case, as this avenue has a growing trend of commercial land use (Figure-4.3). These new commercial buildings have been built following the new FAR (Floor Area Ratio) rules, updated in the 'Imarat Nirman Bidhimala' after 2008 [4]. Gulshan avenue runs north south. Therefore, a significant number of the buildings on the avenue face west directly. Due to the west orientation, buildings along this avenue, have difficulties in keeping the indoor environment cool. Therefore, façade treatment of these buildings are considered as a critical feature, which needs to be carefully addressed by the designers, to control the incoming sun, and to minimize the cooling loads. Moreover, such considerations at the design phase, can contribute to reducing the total energy consumption. As part of this study, several buildings have been surveyed, in order to identify the architectural features, specifically to understand the types of façade treatment, and the characteristics of the shading devices used.

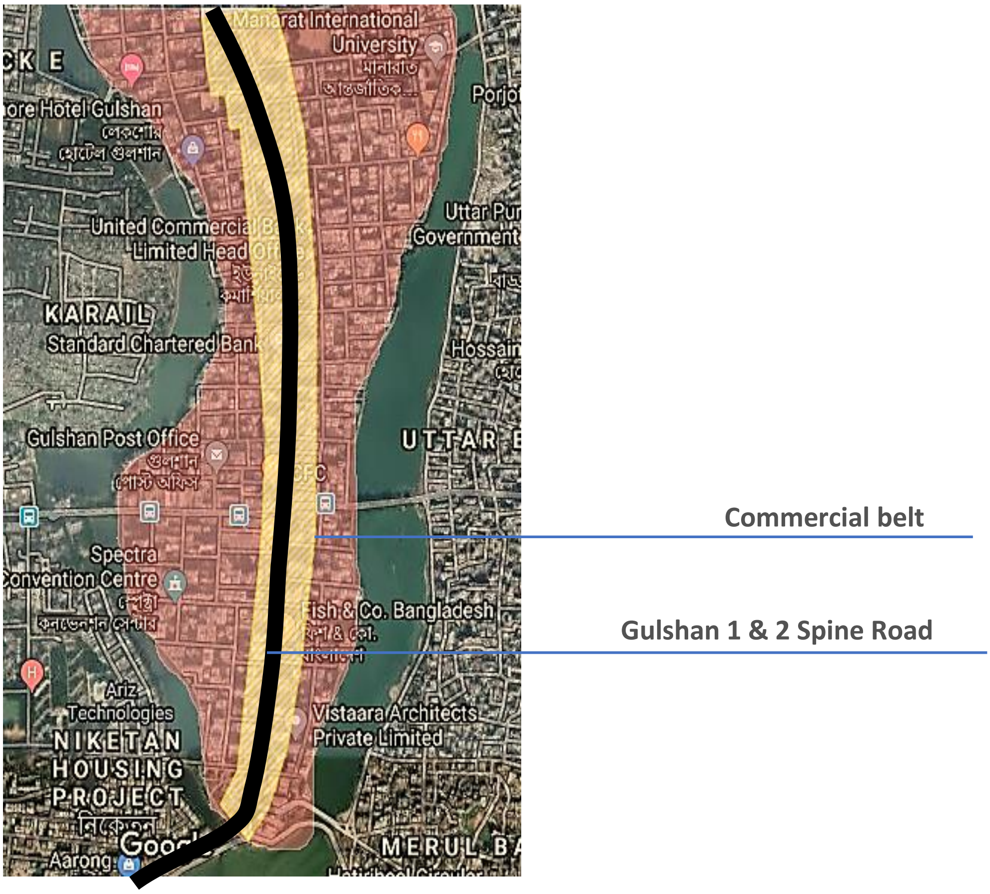


Figure 4.3: Gulshan Avenue (Source: Google maps

4.3 Process of analysing case buildings

One of the objectives of this research was to document the architectural features and energy use related information of contemporary commercial buildings in Dhaka, for which the buildings of Gulshan Avenue were selected.

The case buildings have been analysed in the following ways:

1.Field observations

2.Collecting primary/necessary/secondary data from stakeholders (architects, engineers and building owners).

3.Extracting information based on observation, from the architectural layouts, elevations and details of the building façades.

4.3.1 Choice of case buildings

For this research five case buildings have been chosen for documentation, and this information was then used for further analysis in the following Chapter. These case buildings are considered as landmarks, due to their unique features. The main criteria for selection of the specific buildings are_

1. The buildings face West along the avenue.

2. The buildings are built after 2008, following the Dhaka Imarat Nirman Bidhimala.

3. The buildings have different types of façade treatments, which covers most of the façade types considered to be climate responsive, as mentioned in Sections-3.2 and 3.3.

In order to get an idea regarding maximum energy consumption within the case buildings, the 11th or 12th storey of each building has been studied. These floors are sandwich floors, having upper and lower levels, and are thus exposed only through the exterior walls. The floors are also not receiving shading from the west for most of the day, by buildings across the Avenue, and thus have maximum exposure to sun. The upper and lower floors however, also contribute to the energy use of the selected floor. Gulshan avenue buildings have a height limit of about 46m according to the standard set by the Civil Aviation Authority of Bangladesh. The buildings chosen for case study were_

1.Rangs RD square

2.EBL headquarters

3.Glass House

4.Navana Pristine Pavilion

5.South breeze square

The brief features of these west facing case buildings of Gulshan Avenue, that are built under the 'Imarat Nirman Bidhimala 2008' are given below-

4.4 Description of case buildings

4.4.1 Rangs RD Square

Project Description:

The significance of the Rangs RD square building enhances due to it's location being at the entry to Gulshan avenue from the southern part of Dhaka. It is a west facing building measuring 27.44 m by 48.78m. Both the ends of the western façade are 30^{o} tilted from the site line towards opposite direction. The south-west side is covered with horizontal aluminium slats over double glazing for shading, and the north-west side is given double-skin treatment (Figure 4.6). The unique feature of diagonal lines on the front façade, which unfolded into two forms juxtaposing each other, was a major deciding factor for choosing this building for study. The two forms are contrasting, both in material employed, as well as in formal expression [5]. The details of the glass façade and shading devices used are given in table-4.2.

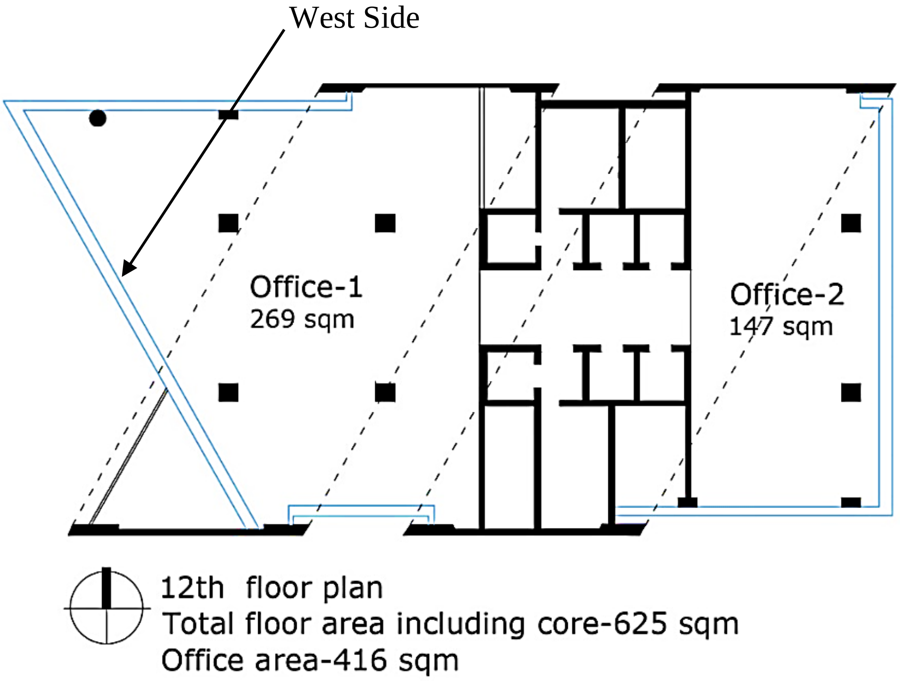


Figure-4.4: Rangs RD square 12th floor plan (Source: dotbangladesh.com)

Table-4.1. General information of Rangs RD square

(Source: dotbangladesh.com)

Project Location	Gulshan Avenue
Client	Rangs Properties Ltd.
Principal Architect	Mustapha Khalid Palash
Site area	1338.30 sqm
Built up area	11700 sqm
Completion	2012-2017
MGC	50% of the land area
No of Stories	14
Building height	45.72m (given height limit by Civil aviation authority of Bangladesh)
Existing typical floor area	646 sqm
Office area	416 sqm (office-1 and 2) (Figure-5.6)

Table-4.2. Façade Detail of Rangs RD square

(Source : CHB Building technologies Ltd. Available at: https://chbbd.com/)

<table>
<tr><td>Widow-wall ratio</td><td colspan="3">50-50 (calculating all four sides)</td></tr>
<tr><td rowspan="5">Façade treatment</td><td rowspan="4">Horizontal aluminium panels over double glazing on south-west side</td><td>Thickness</td><td>40 mm</td></tr>
<tr><td>Length</td><td>Full glass length</td></tr>
<tr><td>Width</td><td>200 mm</td></tr>
<tr><td>Distance from glass</td><td>152 mm</td></tr>
<tr><td colspan="3">Double glazing on north-west side</td></tr>
<tr><td>Glass Type</td><td colspan="3">Energy Saving Insulated Glass Unit</td></tr>
<tr><td rowspan="2">Sample information</td><td>Sample Size</td><td colspan="2">300 X 300mm</td></tr>
<tr><td>Sample Colour</td><td colspan="2">Light Grey</td></tr>
<tr><td>Coating Type</td><td colspan="3">Coating</td></tr>
<tr><td>Outboard</td><td colspan="3">6mm Clear Coating</td></tr>
<tr><td>Fill</td><td colspan="3">Air Spacer 12 mm</td></tr>
<tr><td>Inboard</td><td colspan="3">6mm Clear</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Visible Light Transmittance (%)</td><td colspan="3">55.34</td></tr>
<tr><td>U-Value (W/m2 • K)
NFRC U- Value Sum</td><td colspan="3">2.8</td></tr>
<tr><td>Exterior Reflectance</td><td colspan="3">13.43</td></tr>
<tr><td>Interior Reflectance</td><td colspan="3">21.03</td></tr>
<tr><td>Solar Heat Gain Coefficient</td><td colspan="3">0.56</td></tr>
</table>

Shading Coefficient	0.64

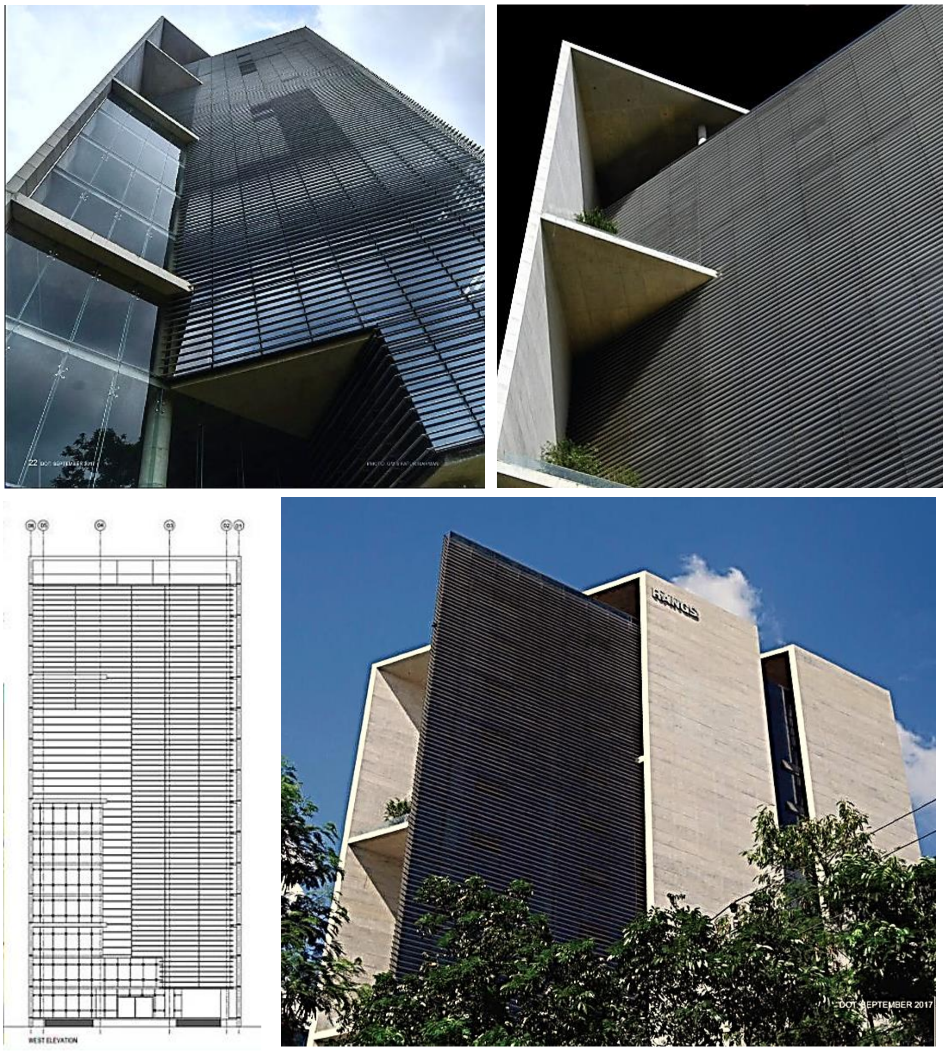


Figure-4.5: Different views of Rangs RD square (Source: dotbangladesh.com)

4.4.2 EBL Headquarters

Project Description:

The plot of the EBL headquarter is situated in the eastern part of the spine road (Figure 4.5), with the approach façade facing west. Therefore, while designing, the primary concern of the architect was, to face the challenges raised due to the western orientation of the plot. In order to save energy, the full height of the west façade has been treated with horizontal sun screens, designed to protect from the afternoon sun. The 52m tall sun screen is placed 8m away from the main structure. This lofty space acts as a buffer for the main structure, and protects it from the direct incoming sun. On the roof, a louvered canopy is provided, which works as a double roof, shading the upper part. Low-E insulated glass has been used on the building façade, in order to reduce the heat penetration indoors.

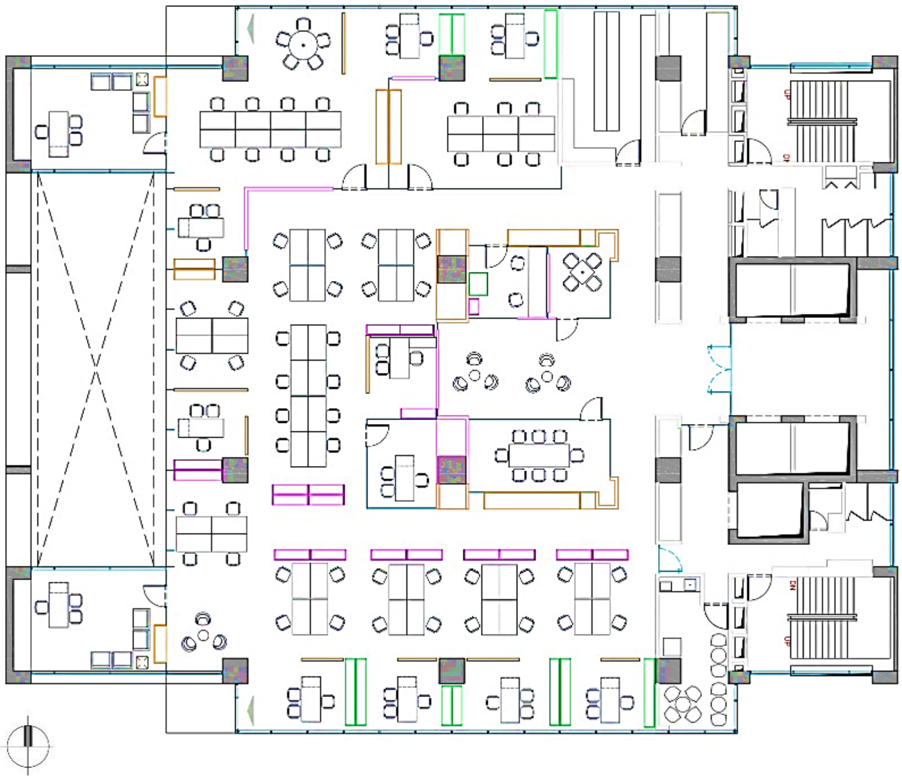


Figure-4.6: EBL headquarters 11th floor plan (Source: Admin, EBL Headquarters)

Table:4.3 General information of EBL Headquarters

(Source: dotbangladesh.com)

Project Location	Gulshan Avenue
Client	EBL
Principal Architect	Mustapha Khalid Palash
Site area	1756.00 sqm
Built up area	19000 sqm
Completion	2017
MGC	50% of the land area
No of Storey	15
Building height	45.72m (given height limit by Civil aviation authority of Bangladesh)
Existing typical floor area	1209 sqm
Office area	800 sqm

Table : 4.4. Façade Detail of EBL Headquarters

(Source : CHB Building technologies Ltd. Available at: https://chbbd.com/)

<table>
<tr><td>Widow-wall ratio</td><td colspan="3">74-26 (Calculating all four sides)</td></tr>
<tr><td rowspan="4">Façade treatment</td><td rowspan="3">Horizontal sun screen on the west</td><td>Thickness</td><td>40 mm</td></tr>
<tr><td>Length</td><td>Full glass length</td></tr>
<tr><td>Width</td><td>152mm</td></tr>
<tr><td colspan="3">Double glazing on west facade</td></tr>
<tr><td>Glass Type</td><td colspan="3">Energy saving insulated Glass unit</td></tr>
<tr><td>Glass Thickness</td><td colspan="3">24 mm</td></tr>
<tr><td rowspan="3">Sample Information</td><td colspan="3">High performance Low-E</td></tr>
<tr><td>Sample Size</td><td colspan="2">1735X857 mm</td></tr>
<tr><td>Sample Colour</td><td colspan="2">Ocean Blue</td></tr>
</table>

Coating Type	Tempered -00Ocean Blue
Outboard	6mm
Fill	12mm
Inboard	6mm
Visible Light Transmittance (%)	49%
U-Value (W/m2 • K) NFRC U- Value Sum	1.6 1.6
Exterior Reflectance	18%
Interior Reflectance	20.65%
Solar Heat Gain Coefficient	0.38
Shading Coefficient	0.32

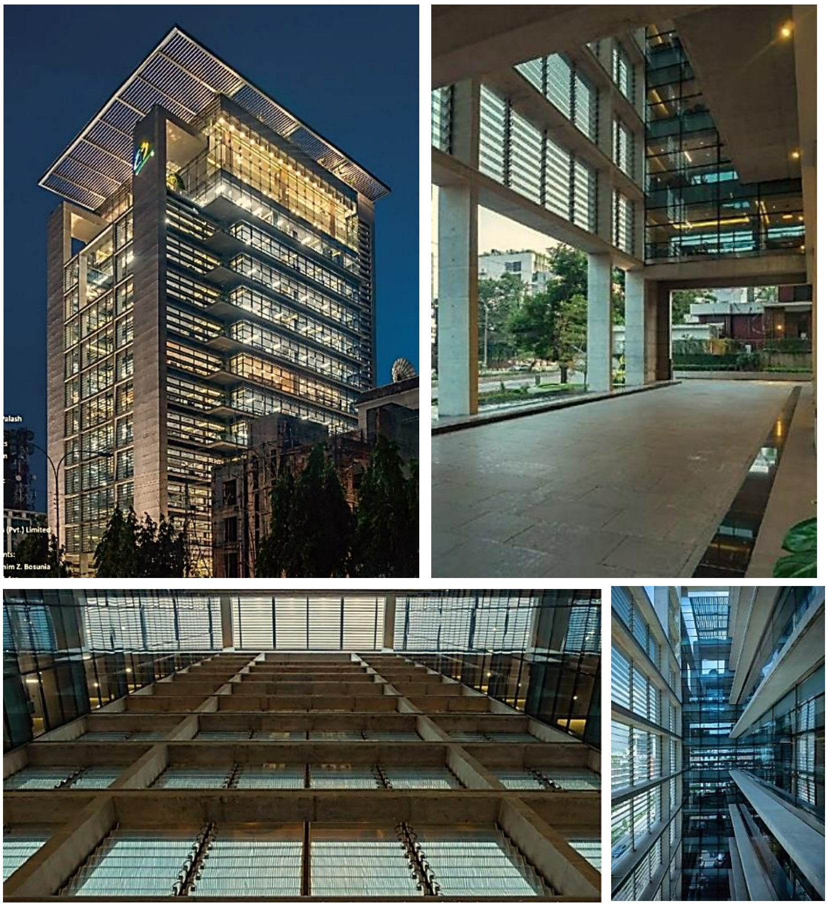


Figure:4.7: Different views of EBL tower (Source: dotbangladesh.com)

Table-4.5: Existing monthly energy consumption and electricity bill of EBL for the year 2021 (Source: Admin, EBL Headquarters)

Month	Energy Consumption Kwh/m^2	Electricity bill BDT
Jan	2662	21,590.34
Feb	2721	23,578.56
March	2790	20,171.05
April	2854	30,327.76
May	2928	32,227.14
June	3238	35,839.35
July	3676	38,522.96
August	***3925***	***40,128.72***
September	2675	35,567.45
October	2843	30,457.55
November	2345	27,468.54
December	2067	22,456.46

In table 4.5 the monthly energy consumption by an office floor of the EBL headquarters is presented during the year 2021. It should be mentioned here that during the year-2021 the offices were not fully functional due to COVID-19 outbreak. Due to availability of the data of the EBL building during 2021, it has been placed here in this research. Therefore, it can be assumed that at the time of full occupancy energy consumption and electricity bill would be slightly higher than the above data.

4.4.3 Navana Pristine Pavilion

Project Description

The presence of low rise structures around the site, encouraged the architects to use an all glass façade, while treating the elevation of Navana Pristine Pavilion. The glass facades are tilted in various directions, to express the form as a cut diamond, reflecting both the sky and surrounding green. Double glazed heat reflecting glass façade was used in this building, to reduce energy consumption through the huge areas of glass. Though using this glass was costly, it was used for aesthetic purposes to make the building a landmark, as it can be viewed from a distance.

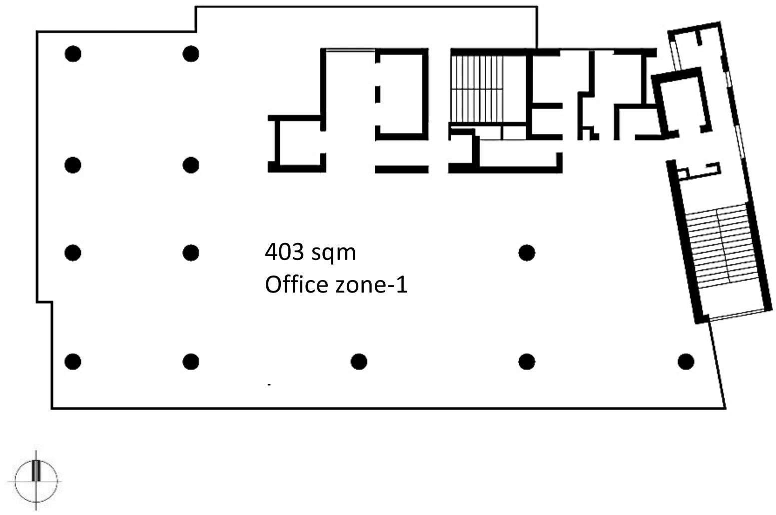


Figure 4.8: Navana Pristine Pavilion 12th floor plan (Source: dotbangladesh.com)

Table:4.6 General information of Navana Pristine Pavilion

(Source: dotbangladesh.com)

Project Location	Gulshan Avenue
Client	Navana Real Estate Ltd.
Principal Architect	Mahmudul Anwar Riyad Mamnoon Murshed Chowdhury
Site area	1366.00 sqm
Built up area	12234 sqm
Completion	2018
MGC	50% of the land area
No of Storey	14
Building height	45.72m (given height limit by Civil aviation authority of Bangladesh)
Existing typical floor area	530 sqm
Office area	403 sqm

Table-4.7 Façade Detail of Navana Pristine Pavilion

(Source : CHB Building technologies Ltd., Available at: https://chbbd.com/)

<table>
<tr><td>Widow-wall ratio</td><td colspan="3">77-23 (counting all four sides)</td></tr>
<tr><td rowspan="2">Façade treatment</td><td>Tilted glass facade</td><td>Thickness</td><td>24mm</td></tr>
<tr><td colspan="3">Double glazing on all facade</td></tr>
<tr><td>Glass Type</td><td colspan="3">Energy saving insulated Glass unit</td></tr>
<tr><td rowspan="3">Sample Information</td><td colspan="3">High performance Solar Reflective</td></tr>
<tr><td>Sample Size</td><td colspan="2">1367X1260 mm</td></tr>
<tr><td>Sample Colour</td><td colspan="2">Deep Blue</td></tr>
<tr><td>Coating Type</td><td colspan="3">Deep Blue</td></tr>
<tr><td>Outboard</td><td colspan="3">6mm</td></tr>
<tr><td>Fill</td><td colspan="3">12mm</td></tr>
<tr><td>Inboard</td><td colspan="3">6mm</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Visible Light Transmittance (%)</td><td colspan="3">55%</td></tr>
<tr><td>U-Value (W/m2 • K)
NFRC U- Value Sum</td><td colspan="3">1.8
1.85</td></tr>
<tr><td>Exterior Reflectance</td><td colspan="3">17%</td></tr>
<tr><td>Interior Reflectance</td><td colspan="3">10%</td></tr>
<tr><td>Solar Heat Gain Coefficient</td><td colspan="3">0.44</td></tr>
<tr><td>Shading Coefficient</td><td colspan="3">0.49</td></tr>
</table>

Figure 4.9: Different views of Navana Pristine Pavillion (Source: dotbangladesh.com)

4.4.4 Glass house

Project Description

The glass house is a landmark building facing west on Gulshan Avenue. It is an iconic steel structure building, that resonates the tenacity and resilience of Dhaka city. High performance solar reflective glass is used on all façades of this building. The glass is of the energy saving double glass unit type, that affects reduced heat inside.

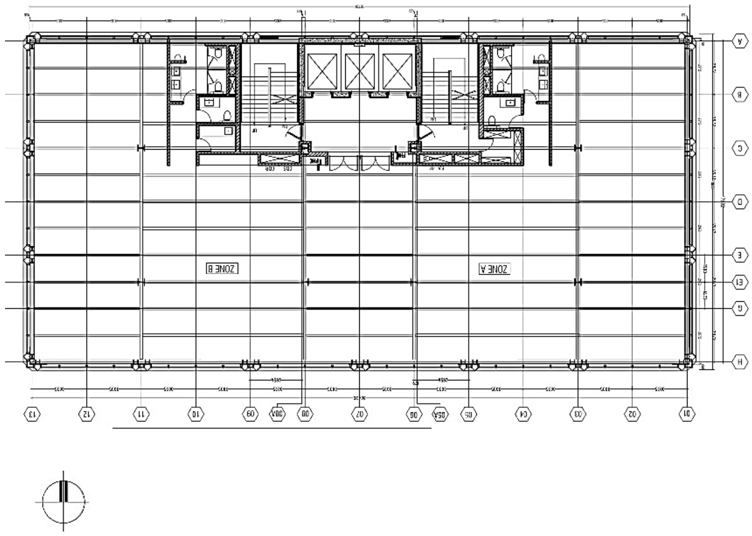


Figure 4.10: 11^{th} floor plan of Glass house (Source: EHSAN KHAN ARCHITECTS LTD)

Table:4.8 General information of Glass House

(Source: EHSAN KHAN ARCHITECTS LTD)

Project Location	Gulshan Avenue
Client	Shanta Holdings Ltd.
Principal Architect	Ehsan Khan
Site area	1377.00 sqm
Built up area	1057 sqm
Completion	2019
MGC	50% of the land area
No of Storey	14

Building height	45.72m (given height limit by Civil aviation authority of Bangladesh)
Existing typical floor area	1057 sqm
Office area	817 sqm

Table 4.9 Façade Detail of Glass

(Source : CHB Building technologies Ltd., Available at: https://chbbd.com/)

Widow-wall ratio	87-13 (considering all façade)		
Façade treatment	Tilted glass facade	Thickness	24mm
	Double glazing on all facade		
Glass Type	Energy saving insulated Glass unit		
Sample Information	High performance Solar Reflective		
	Sample Size	1367X1260 mm	
	Sample Colour	Silver gray	
Coating Type	Silver grey		
Outboard	6mm		
Fill	12mm		
Inboard	6mm		
Visible Light Transmittance (%)	**33%**		
U-Value (W/m2 • K) NFRC U- Value Summer	**1.7** **1.67**		
Exterior Reflectance	**45%**		
Interior Reflectance	**15%**		
Solar Heat Gain Coefficient	**0.25**		
Shading Coefficient	**0.29**		

Figure-4.11: Different views of Glass House (Source: Google Photos)

4.4.5 South Breeze Square

The 14 storey South Breeze Square building occupies it’s spot in between an array of tall west facing buildings (Figure 4.15) on the northern border of Gulshan avenue.

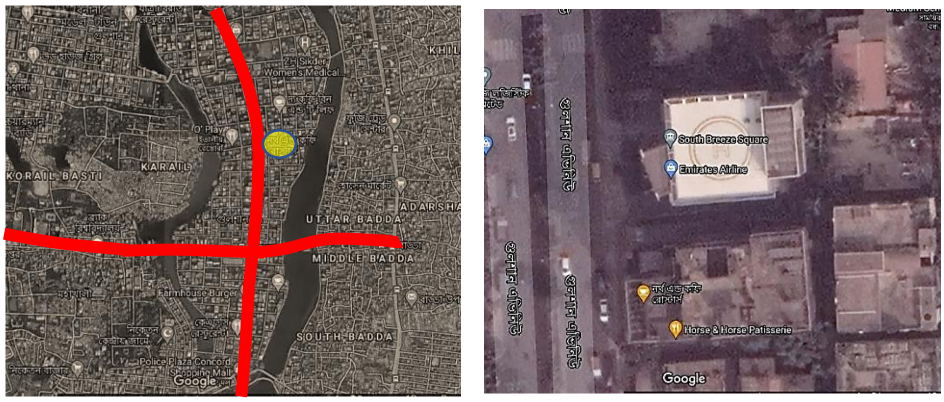


Figure-4.12: Location of south breeze square (Source: Google maps and self)

The building was selected for the third phase of analysis in this research (Chapter-05), the details of which are elaborated in Section 5.4. The building resources were available for study during the Covid pandemic restrictions, which is why it has been taken as the case building for running simulations. In case of most of the study buildings mentioned above, energy data could not be retrieved, due to security reasons of the office. South Square is a LEED certified building. While selecting the appropriate building floor for analysis, it was essential to select the level which is subjected to maximum heat penetration, through the west façade during office hours. In order to evaluate the effect of the west façade on the building interior, the 11th floor (Figure 4.16) was chosen for simulationg. The topmost floor (14th floor) is subjected to roof top solar radiation, and is, therefore, not considered for the simulation exercise. The13th floor was not selected as it has a void, which reduces the floor area, and the effect of it would also be evident on the 12th floor. Therefore, 12th,13th or 14th floor were not considered for the simulations. The 11th floor of the building receives sunshine till the late hours of the day, not being shaded by buildings on the opposite side of the road, which makes it eligible for the survey.

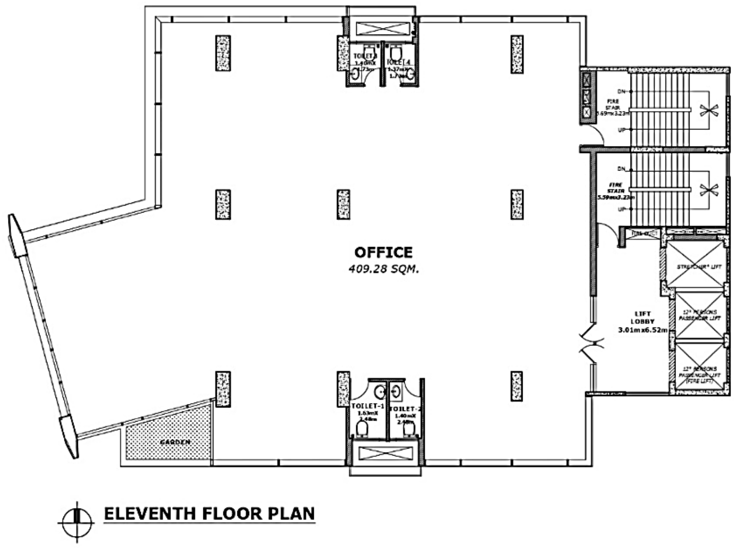


Figure-4.13: 11th floor plan of south breeze square (Source: ARC Architectural Consultants)

Table:4.10 General information of South Breeze Square

(Source: ARC Architectural Consultants)

Project Location	Gulshan Avenue
Client	South Breeze Housing Ltd.
Principal Architect	Nahas Ahmed Khalil
Site area	1012 sqm
Built up area	13000 sqm
Completion	2019
MGC	50% of the land area
No of Storey	14
Building height	45.72m (given height limit by Civil aviation authority of Bangladesh)
Existing typical floor area	502 sqm
Office area	410 sqm

Table-4.11 Façade Detail of South Breeze square

(Source: CHB Building technologies Ltd., Available at: https://chbbd.com/)

Widow-wall ratio	85-15 (considering all façade)	
West Façade treatment	Twisted concrete vertical louver on tilted façade	
	Double glazing on all facade	
Glass Type	Low E	
Sample Information		
	Sample Size	1367X1260 mm
	Sample Colour	Grey
Coating Type	Grey	
Outboard	6mm	
Fill	12mm	
Inboard	6mm	
Visible Light Transmittance (%)	46%	
U-Value (W/m2 • K) NFRC U- Value Sum	1.6 1.66	
Exterior Reflectance	30%	
Interior Reflectance	15%	
Solar Heat Gain Coefficient	0.34	
Shading Coefficient	0.39	

It needs to be mentioned here that the properties of glass such as visible light transmittance , U-Value , reflectance, solar heat gain co-efficient, shading co-efficient are an indicator of glass performance. For example : The lower the U-value, the better the material will be heat insulator. Therefore, selecting glass having lower U-value would protect direct heat from entering the building and thus will enhance the energy performance of the building. The glass properties are briefly discussed in Appendix A.

Figure-4.14: Views of South square building (Source: Google Photos and self)

Table-4.12: Existing data of energy consumption and electricity bill for the year-2019 (before Covid-19) (Source: Admin, South Breeze Square)

Month	**Energy Consumption Kwh/m^2**	**Electricity bill BDT**
Jan	1391.11	131590.34
Feb	1780.25	181778.56
March	1991.03	2,0171.05
April	3429.88	35,327.76
May	3184.50	32,227.14
June	3768.86	37,839.35
July	3829.11	38,022.96
August	***4229.41***	***42,124.92***
September	2212	30,218.51
October	2943.60	28,758.97
November	2565	24,983.10
December	2187	21,651.30

Table 4.11 shows the energy consumption of the office space throughout the year, where the month of August (consumption of 4229.41 Kwh/m^2) is italicised, as it is the highest during a year. This matches with the annual weather data (Figures 2.2 and 2.3) of Bangladesh, where it is seen that August is

considered as the most humid month. The results from this existing survey, can be compared through software simulations. It should be mentioned here that the data of 2020 and 2021 was not considered, because during the time of the pandemic the actual scenario could not be determined, due to office lockdowns.

Table-4.13: Summary of case buildings

	Rangs RD	**EBL**	**Navana Pristine**	**Glass House**	**South Breeze Square**
Plot size (sqm)	1338.3	1756.0	1366.0	1377.0	1012
Total build up area (sqm)	11700	19000	12234	14000	13000
No of floors	14	15	14	14	14
MGC	50%	50%	50%	50%	50%
Typical office floor area (sqm)	625	800	403	817	410
Ventilation System	VRV (Variable Refrigerant Volume)				
Window-Wall ratio (West Facade)	50-50	74-26	77-23	87-13	85-15
Plan Layout/ orientation	Both end of west side 30^{o} tilted from site	True north	True north	True north	Portion of west side 15^{o} tilted from south to north
Type of glass (West façade)	Double glazing 6mm outside +12mm air gap+6 mm inside	Low E insulated glass panes	Energy saving insulated Glass unit	Energy saving insulated Glass unit	Low E insulated glass panes
Type of shading	Horizontal aluminium slats	Horizontal louver	N/A	N/A	Vertical Louver
Material of shading	Aluminium Slats	Photovoltaic panels/ Glass solar panels	N/A	N/A	Concrete louver
U-Value	2.8	1.6	1.8	1.7	1.6
Solar heat gain co-efficient	0.56	0.38	0.44	0.25	0.34
Transmittance	55.34 %	49%	55%	33%	46%

Table 4.13 shows that the case buildings in Gulshan avenue have some common features, and most of these common features are characterized by the building regulations. The difference façade treatments have been generated depending on the architects' individual perspectives, towards sustainability, functionality and aesthetics. The MGC of the case buildings determined the floor area of the typical model discussed in Section-5.5, created for the simulations. Moreover, the glass specifications found from the table also helped to formulate the different type of model façade for computer simulations.

It has been observed from table-4.13 that the U-value of the glass façade of the case buildings differ from one another. As mentioned in Appendix A, the lower the U-value the better the glass works as an insulator. From table-4.13 it can be seen that U-value of the glass used in EBL and south breeze square is the lowest among others. In terms of solar heat gain co-efficient the value of Glass house i.e 0.25 indicates lowest which also suggests efficiency (Appendix A). If closely analysed it can be seen that the glass properties of Glass house building suggests less heat gain through the glass façade. Therefore, while designing the west facing buildings in the case study area designers can apply glass having lower U-value and other combinations mentioned in Appendix A that enhances less heat gain.

4.5 The Questionnaire

4.5.1 Introduction

In Section-4.5 the questionnaire required to conduct the research is explained. A questionnaire is prepared in order to collect data related to thermal preference from the occupants of existing office spaces in the study area. The collected data was eventually inserted in the thermal comfort tool mentioned in Chapter-5, to determine the users' feedback regarding thermal comfort. Guidelines followed for preparing the questionnaire, have been elaborated Section-4.5.2.

4.5.2 Preparing the questionnaire

A questionnaire can be a great source of interviewing, a tool that helps to extract users' feedback, regarding a particular phenomenon. Here, in this research, a questionnaire (Appendix D) was delivered to occupants of west facing commercial buildings in Gulshan Avenue, in order to know about their perceptions inside the office, regarding the thermal environment. For preparing the questionnaire an abbreviated version of *ASHRAE 55* was followed [6]. The data extracted was then inserted in thermal comfort tool to determine PMV-PPD values (Section-5.2.2). As previously mentioned in Section-1.6, PMV-PPD values attained from the collected data gathered from the questionnaire, would help to determine users' feedback regarding thermal comfort, in these west oriented offices of Gulshan (Section-5.2.2).

4.5.3 Content of the questionnaire

The questionnaire includes relevant information, such as seasonal conditions, worker activity level, and location of work space within the building (orientation, floor number, envelope proximity) [7]. Lastly an open-ended question was included, in order to know their suggestions for improvement.

For record keeping, the questionnaire began with input of the basic data of respondents, i.e. Name, Gender, Age, Years of working in the space, along with date and time of response.

Questions following that were related to the cooling system and occupants' behavioural attitudes with regard to it. Such as-

-Mode of controlling office environment
-ventilation system
-preferable temperature
-Blinds are pulled down or not
-Season wise satisfaction (indoor temperature)
-Clothing worn
-Activity level generally employed

All the above questions were multiple choice questions. Of them some had multiple options and some were likert scale questions. The reason behind providing multiple choice, was it allowed the users to respond accurately, and the responses could be quantified. Finally, an open-ended question was added, asking the respondents regarding their suggestion of improving the indoor environment. A copy of the questionnaire response is given in Appendix-1. The acquired data was used for the analysis in Chapter-05, to determine PMV-PPD values for the office spaces in the study area.

4.6 Summary

Chapter-04 provides a clear picture of existing case buildings. Detail information of the building façade is also provided with each case building. Another significant feature of this chapter is the introduction of questionnaire that is used to analyse occupants' response regarding thermal comfort preference. Based on the data presented on Chapter-04 the detail analysis for the research is conducted in Chapter-05. Therefore, Chapter-05 highlights both on the simulation process and also on analysing the questionnaire data.

References

[1] Ahsan R.M.; 1991; Changing Pattern of the Commercial Area of Dhaka City; Dhaka Past, Present & Future; in Ahmed.S.U. (Ed.);The Asiatic Society of Bangladesh.

[2] Hossain, N.; 2001; The Socio-Spatial Structure of Spontaneous‟ Retail Development in Dhaka City; Unpublished PHD Dissertation; Faculty of the Built Environment; Bartlett School of Graduate Studies, UCL; London, UK.

[3] Islam, N.; (1996); Dhaka from city to megacity ; Urban Studies Programme, Department of Geography; University of Dhaka.

[4] *Dhaka Building Construction Act, 2008*, Government of Bangladesh, Ministry of Housing and public works, Dhaka

[5]Dot Art and Architecture Bangladesh, 2017; Volume-3;Issue-01, Available at:https://www.dotbangladesh.com/dot-archive,*pp-20-28*

[6] December 2015; *"Thermal Comfort Survey"*, Buildings, Available at: https://www.buildings.com/articles/29250/thermal-comfort-survey.

[7] Ibid.

Chapter 05: Analysis and Findings

5.1 Background of the analysis

In the previous chapter detailed information of the case buildings have been provided, from field survey, drawings and interviews. From these details a rough typology of western facades in practice in Gulshan avenue could be understood. This understanding helps to set the criteria for analysis or more specifically computer generated simulations in this Chapter. The discussion begins with mentioning the steps of analysis. In Section-5.2 the questionnaire responses mentioned in Section-4.5 are analysed and numerical data is extracted using different charts and graphs. These are put in the thermal comfort model, to determine users' responses, regarding thermal comfort in the case buildings. This covers two steps of analysis out of three mentioned in Section-1.6.

The third phase of analysis is computer generated simulation which is presented in Sections-5.4 and 5.5. Here simulations have been run to judge the pattern of energy consumption in a west-facing case building in Gulshan Avenue. A typical model is derived after studying the case buildings (described in Section-4.4). This will help to determine the best output, in terms of energy use, driven by treatment of façade in the west, which would serve objective one of this investigation (see Section-1.3). The typical model is generated based on the maximum ground coverage (MGC) (Table-4.12) that can be obtained on the plots of commercial belt of Gulshan avenue (Figure-4.5).
It is evident from studying the Gulshan Avenue commercial buildings, built after 2008, that most of them are either 14 or 15 storied (Table-4.12), due to height being limited to 45 m (approx.) by Civil Aviation Authority of Bangladesh. These buildings are constructed maintaining the FAR (floor area ratio) rules mentioned in "Dhaka Imarat Nirman Bidhimala 2008", and the plot sizes are also more or less similar (Table-4.12).

A brief description of the simulation tools that have been used for this third stepe of analysis, is presented in Section-5.3.1.

5.2 Extraction from the questionnaire

Before presenting the extraction from the questionnaire one thing should be mentioned here. Due to the COVID-19 outbreak, collecting questionnaire responses was limited to a single case building, having western orientation. In Section-4.5, the questionnaire prepared for collecting data, for thermal comfort preference of office occupants in Gulshan Avenue, has been discussed. The questions have been pointed out in Section-4.5.3 and the process of preparing questionnaire has been discussed in Section-4.5.2. In this section, the responses received from the questionnaire are analysed, and then the data extracted is inserted in the thermal comfort model, to determine users' response to thermal comfort.

5.2.1 Broad Analysis of the data from the questionnaire

In this section the data collected from questionnaire interview have been broadly discussed, in order to have clear idea of user' thermal comfort preferences, by PMV-PPD analysis. The users' feedback has been presented through charts and description. The analysis of this questionnaire data is presented here.

According to the responses from the occupants, most of them have been working in the case building for more than six months. This points to them having an understanding of their thermal situation. About 88% said that they control the indoor environment, by adjusting the air-conditioning unit, which is always operational.

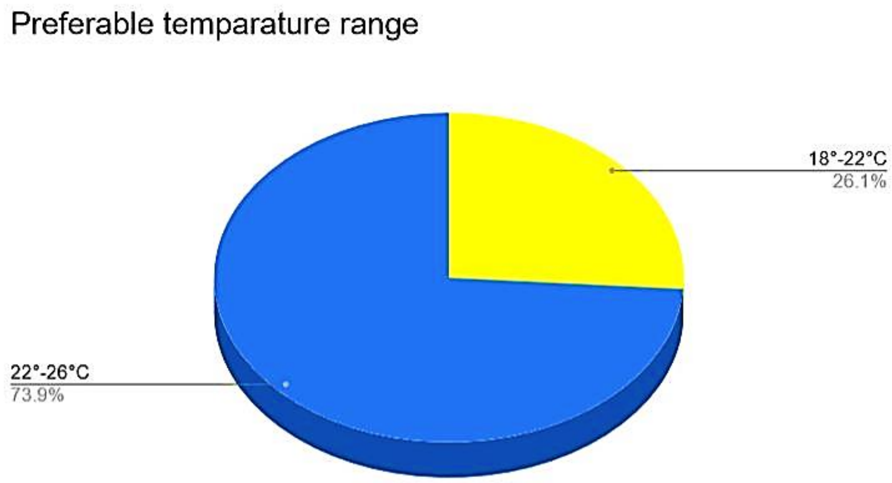


Figure-5.1: Chart showing preferable temperature range

In case of determining preferable temperature range indoors about 74% voted for a temperature range between 22^o-26^oC. None of the occupants voted for temperature range above 26^o C (Figure-5.1). Therefore, while considering temperature for input in the thermal comfort tool, the average temperature from the range that the majority of the people voted as preferable temperature, i.e. 24^o C was selected.

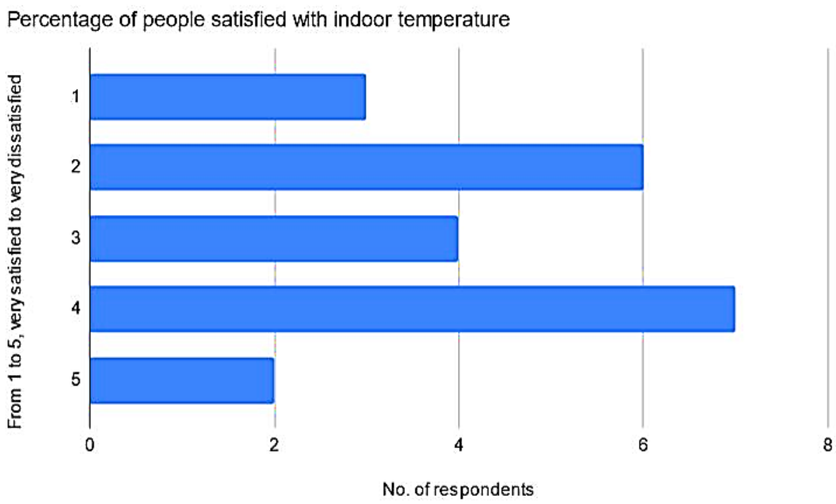


Figure 5.2: Satisfaction rate of users in terms of indoor temperature

From Figure-5.2 it is seen that more or less similar numbers of occupants are satisfied or dissatisfied with the indoor temperature. This indicates the factor that different people have different sensation regarding thermal comfort in the same condition.

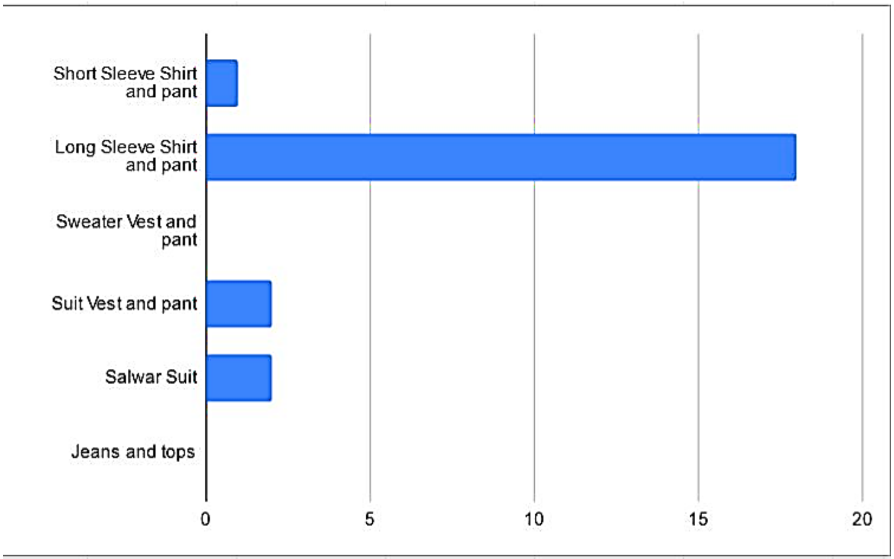


Figure 5.3: Clothing Chart

Another important aspect of assessing thermal preference was to find out the clothing level of the occupants. From the above chart of clothing (Figure 5.3) it can be understood that most of the office occupants (80%) wear Long Sleeve Shirt and pant. There might be two reasons behind this type of clothing. One is the case buildings mostly house corporate offices like banks, telecoms, insurance companies and international chains, where there is certain dress code. Another reason is likely to be the offices being mechanically controlled i.e. air-conditioned, are cooler than outdoors, requiring more clothing cover. Due to being mechanically controlled, certain AC temperature is maintained in the office, which led occupants to wear long sleeve shirt and pant, as they are exposed to chilled indoor environment most of the year. Based on the type of clothing, the clo value considered for input in the thermal comfort tool was selected as 0.61 (Table 2.4) [1]. A majority of people (about 92%) said that they feel moderate in their clothing.

A majority of the people (about 87%) said, that they remain in same clothing condition indoors, as outdoors, i.e. they do not take off coats or parts of their clothing ensemble. This finding is also an indicator, why most people can adjust easily in any condition, as mentioned below.

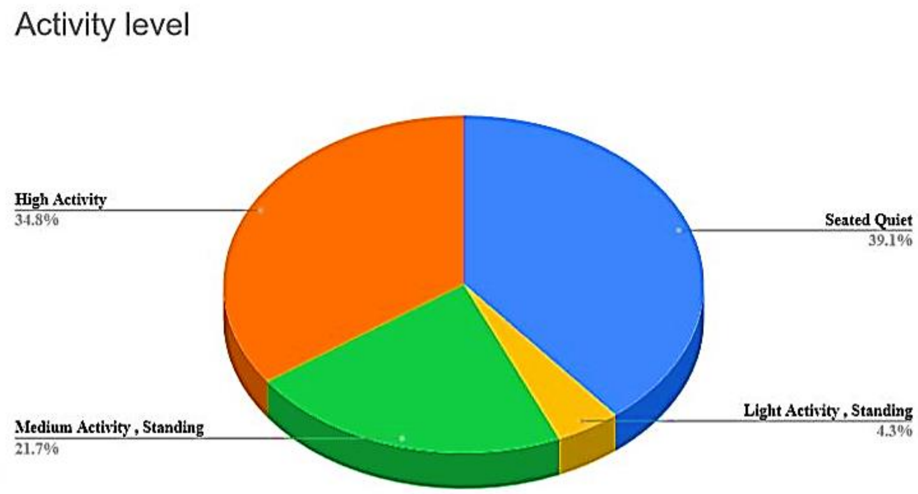


Figure 5.4: Activity level

Activity level of the occupants should be given utmost importance while determining thermal preference. Figure-5.4 shows that majority of users are engaged with sedentary activities. Table-2.5 suggests that MET value for being seated quietly is 1, seated writing is 1.0, seated typing is 1.1, seated filing is 1.2 and standing filing is 1.4. Mostly corporate office occupants are engaged with their laptops or computers typing. Therefore, MET value considered for putting in PMV-PPD calculator would be 1.1. As majority of people are engaged in sedentary activities they can adjust with the indoor environment easily.

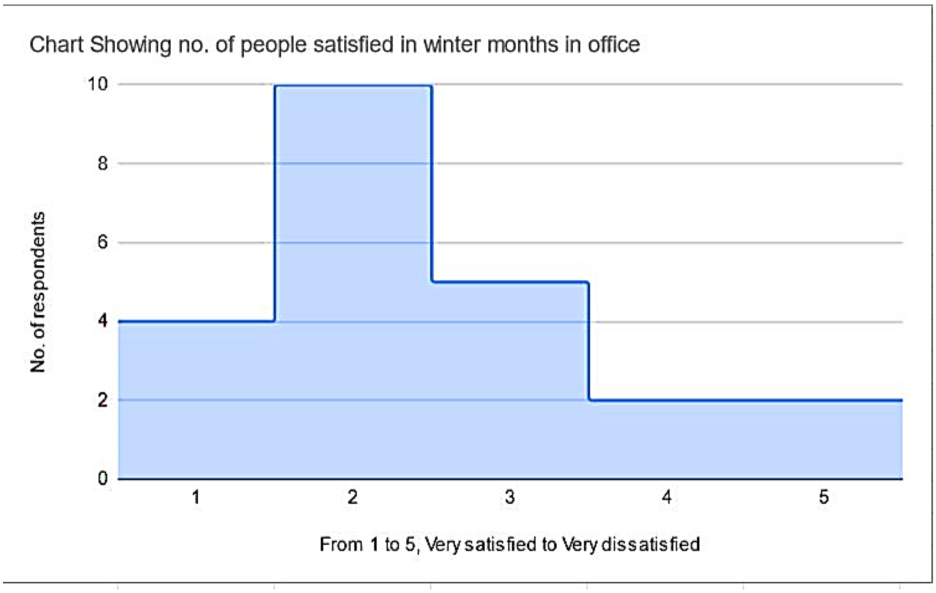


Figure 5.5: Chart showing peoples' response in winter months

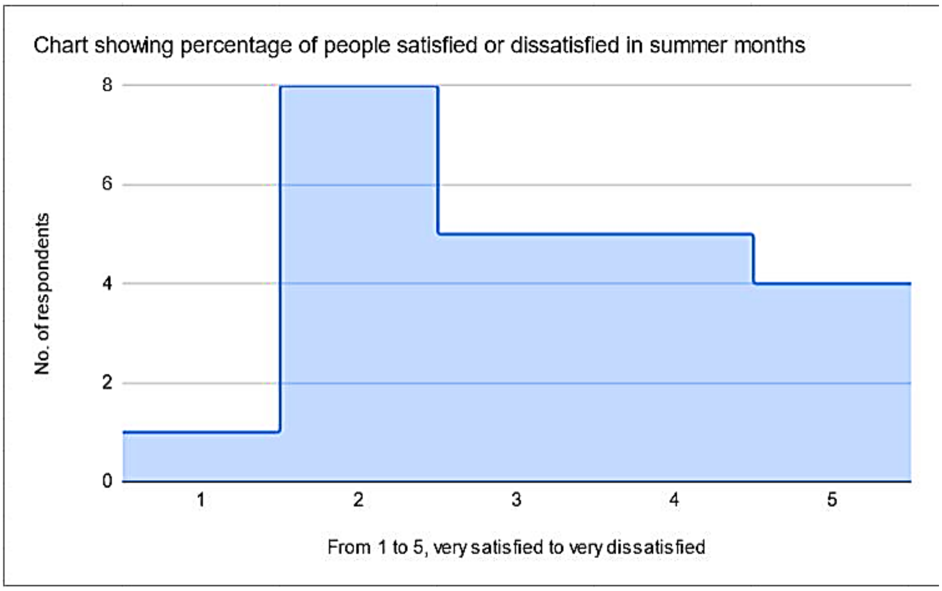


Figure 5.6: Chart showing peoples' response in summer months

Both of the graphs (Figures 5.5 and 5.6) indicate that majority of the users are satisfied with the office environment. This finding can be further linked with the observation from users' thermal exposure at home, outdoors and their mode of transport.

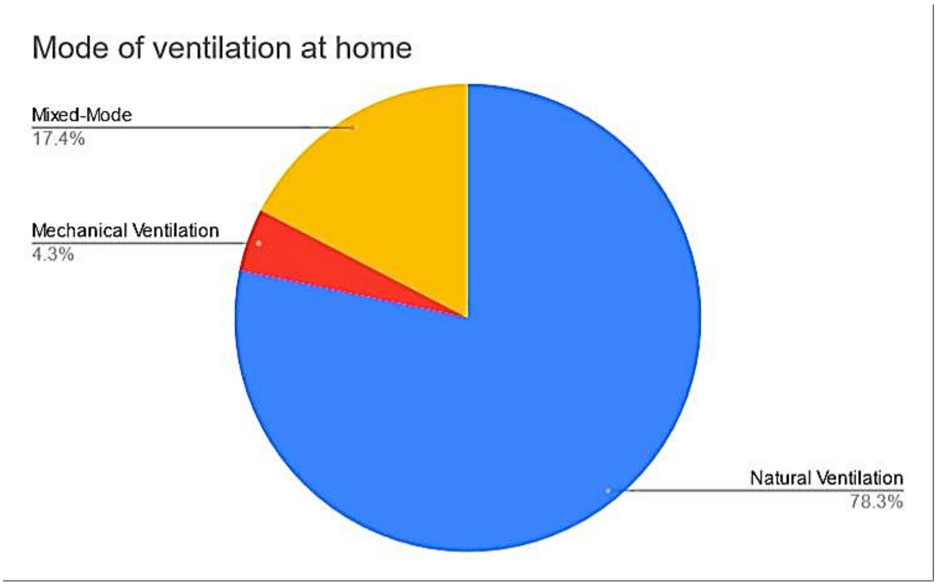


Figure-5.7: Percentage of respondents' ventilation types at home

Figure-5.7 shows that most of the occupants (about 78%), have natural ventilation at home. Initially it seems like that most people might face difficulty adjusting in controlled environment, as they do not have mechanical ventilation, either at home or their transport. But this is not what happens in reality. As mentioned above, about 47% can easily adjust with the office environment.

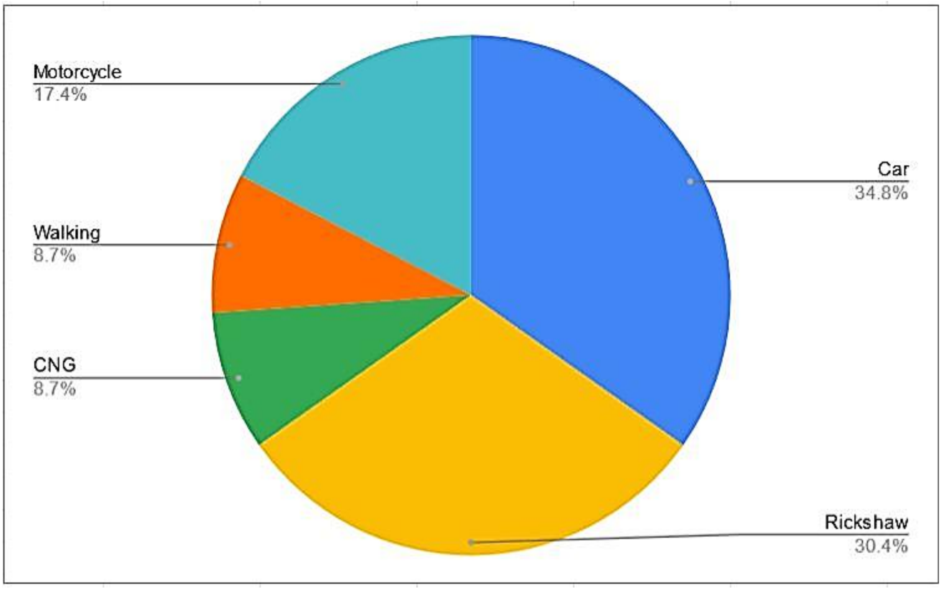


Figure 5.8: Chart showing percentage of mode of transport

The above chart (Figure-5.8) shows that 35% of the user's come to the office by car, 30% by rickshaws, and 18% by motorcycle. The rest come either by walking or by CNG. Another query suggests, that of these only 35% users come via air-conditioned transport. This finding suggests that most people are not exposed to air-conditioning outside the office.

From the respondents about 65% answered that they do not have AC on their mode of transport. Most of the users are therefore, exposed to different conditions than their office environment. It is also seen that about 80% have only natural ventilation at home, while the office is fully mechanically controlled.

From the responses it has also been identified that about 47% users can adjust with the office indoor environment easily, whereas 37% said they find it difficult. About 16% did not respond to this question. Therefore, it is clear that instead of being exposed to different thermal conditions at home and outside office most people do not have problems adjusting with the indoor controlled environment in office.

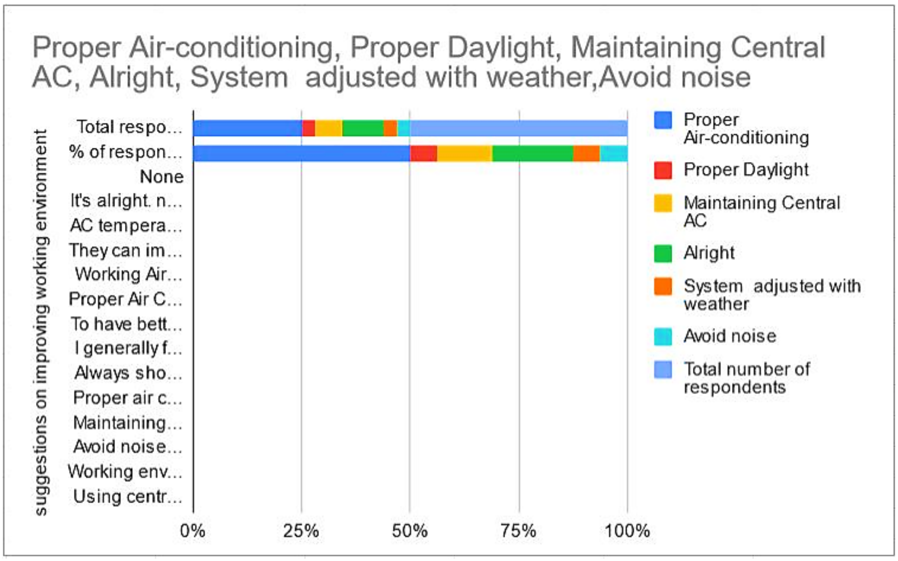


Figure 5.9: Graph analysing respondents' feedback on improving working environment

The graph at Figure-5.9 suggests that most of the respondents think, by providing proper ai-conditioning and adequate day light the internal environment of an office building can be improved.

5.2.2 Thermal Comfort model

As previously mentioned, the CBE thermal comfort tool has been used in this research, to determine PMV-PPD values. Data extracted from the questionnaire was input into the comfort calculator. The comfort calculator needs data related to the environmental conditions, such as operative temperature, air velocity, relative humidity, as well as personal variables of metabolic rate and clothing level. The extracted values are given in able-5.1

Table 5.1: Values of thermal comfort indices extracted from questionnaire and field survey

Thermal Comfort Indices	**Values extracted from questionnaire and field survey**
Operative temperature	**24^{o} C**
air velocity	**0 m/s^2**
relative humidity	**50%**
metabolic rate (MET)	**1.1**
clothing level (Clo)	**0.61**

The values such as operative temperature, MET rate and Clo are obtained from data analysis from the questionnaire, mentioned in Section-5.2.1. The average relative humidity data was collected from measuring indoor condition by hygrometer during the survey which was 35%. Since the standard humidity range for office indoors is set to 50%-60% according to section 2.7.2, Table-8.2.1 of Bangladesh Gazette, 2021, therefore, 50% relative humidity has been applied here in case of determining results from the comfort tool. Here the offices are mechanically controlled which is why the air velocity is considered to be still, i.e. 0 m/s^2. Putting the values from Table 5.1 into the CBE thermal comfort tool (Figure 5.10), the PMV-PPD values for the occupants of the case building were determined.

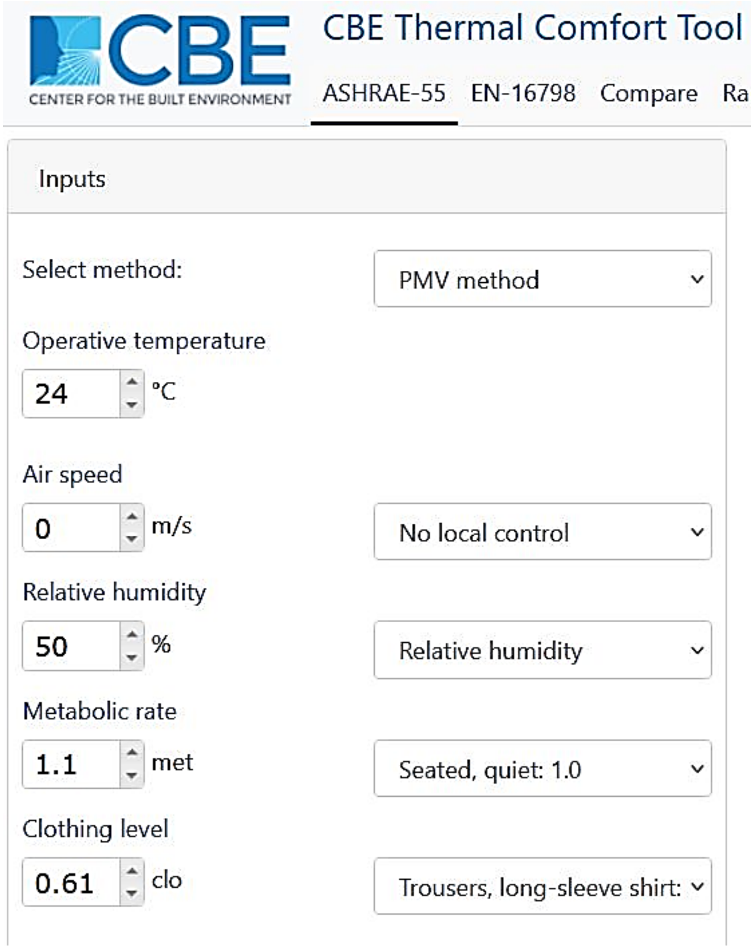


Figure-5.10: Putting values in CBE thermal comfort tool

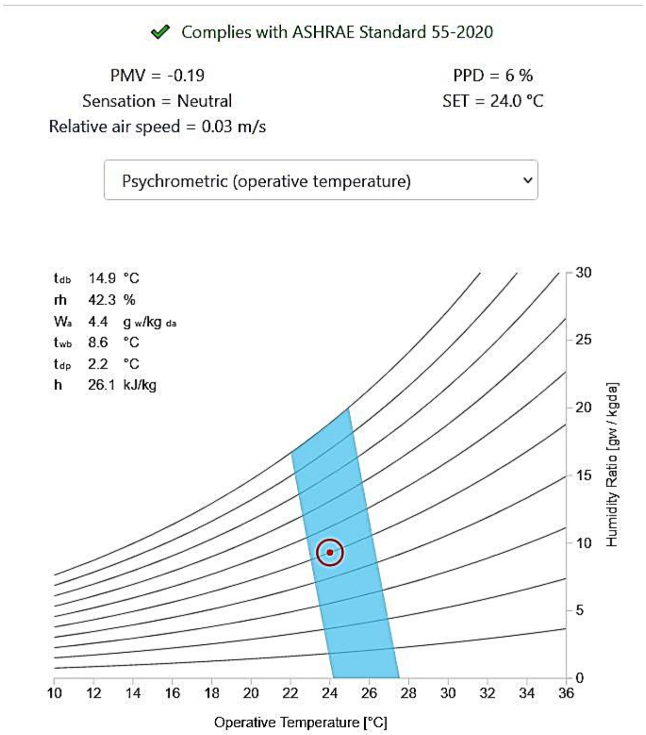


Figure 5.11: PMV-PPD values and Psychrometric Chart

Figure 5.11 shows that the PMV value, thus determined, is -0.19 and the PPD is 6%, which indicates most people have a neutral sensation in terms of thermal comfort. This can be cross matched with ideal PMV values, mentioned in Table-2.1. The result of PPD is also more or less acceptable, as per Section-2.5. The results from the thermal comfort tool, is also found to be compatible, with the questionnaire responses, in terms of adjustment.

5.3 Simulation tools

5.3.1 Brief Description of the simulation tools

The Software used for simulations, and calculating energy consumption in this research, is discussed in this section. At first, the existing case building was generated in the Rhinoceros-Grasshopper platform (Figure 5.13). Rhino has been used for model-making. Grasshopper is used for setting the parameters, and finally Climate Studio is used for occupancy setup. All of these tools are briefly discussed in this section.

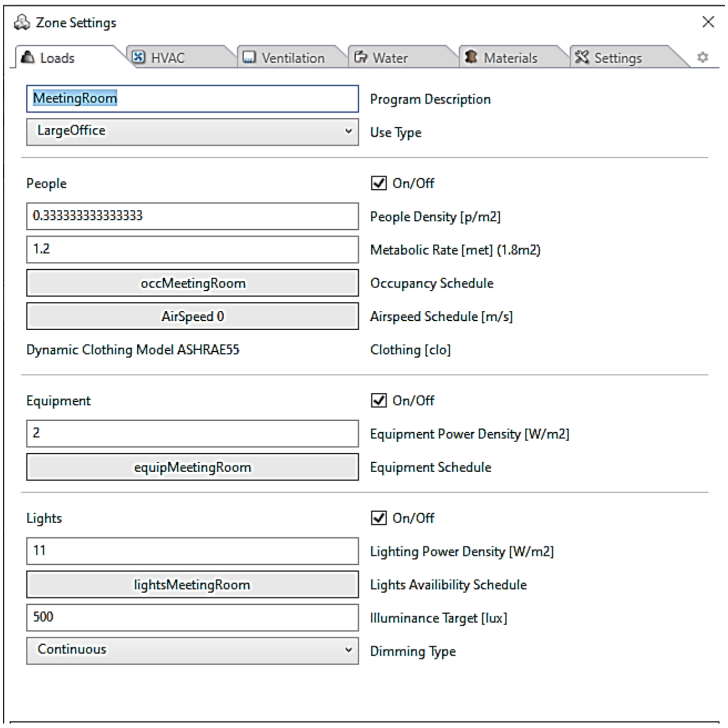
Rhinoceros 3D is a stand-alone, commercial modelling tool, originally developed by McNeel & Associates (2001), as a plug-in for Autodesk's AutoCAD. Rhinoceros 3D is commonly used for Industrial design, architecture, Marine design, Jewelry design, Automotive design, CAD / CAM, rapid prototyping, reverse engineering as well as the multimedia and graphic design industries. Rhinoceros 3D application has the capacity to create, edit, analyze, document, render, animate, and translate NURBS. According to McNeel & Associates (2001), NURBS (Non-Uniform Rational B-Splines) are mathematical representations of 3D geometry that can accurately describe any shape from simple 2D elements (line, circle, arc, or curve) to the most complex 3D organic free-form surface or solid [2].

On the other hand Grasshopper is an algorithmic modeling plugin for Rhino that uses a visual programming language. It is a parametric design tool. Grasshopper allows one to reference Rhino geometry objects from it (points, curves, surfaces, etc.), create geometry or *bake* Grasshopper geometry back into Rhino [3].

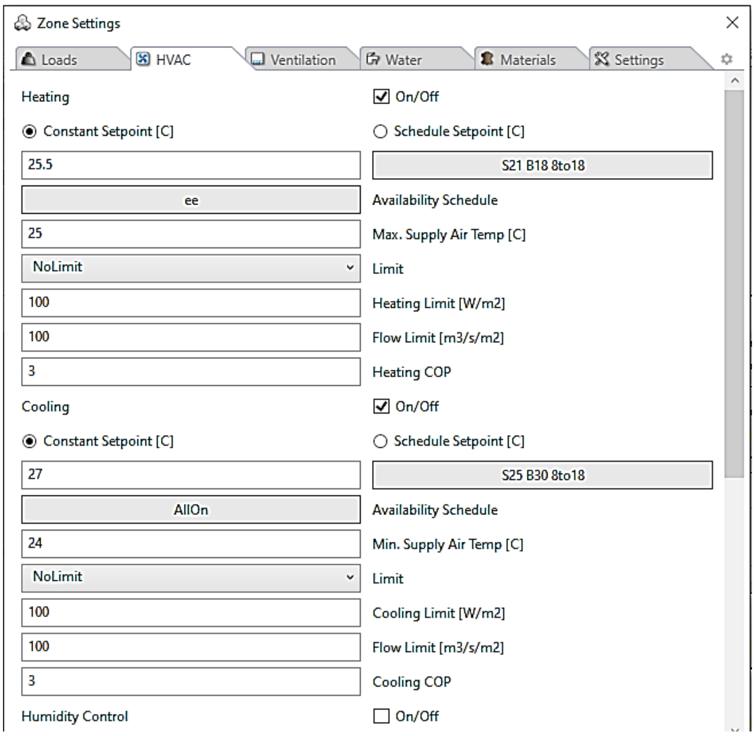
Here Climate studio, Open Studio were deployed to run simulations. Open Studio is a cross-platform, collection of software tools to support whole building energy modelling using Energy Plus. Climate Studio delivers energy results using Energy Plus, and a unique RADIANCE-based path tracing method. Climate Studio provides a list of materials, constructions, and templates based on real-world measurements and sources, that have been validated.

5.3.2 Step by step simulation process

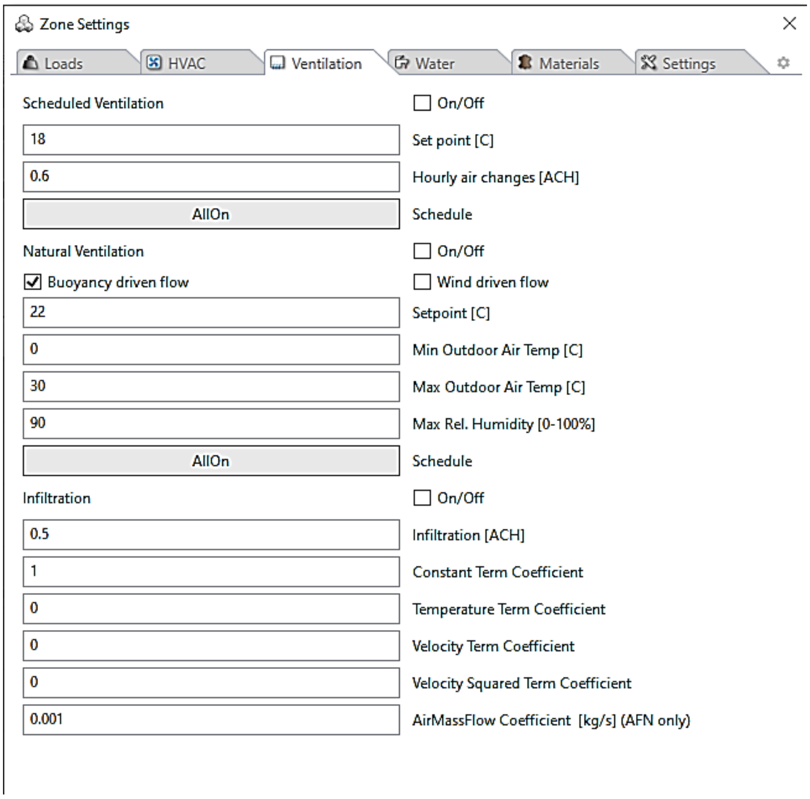
As mentioned, the first step was to generate the existing case building model into the Rhinoceros-Grasshopper platform. Then the model was fed and the parameters were set up. The sample schedule setup, before running the energy simulation is given below (Figure-5.12). Many of the information were directly retrieved from the weather file which was inserted while schedule setup. One such example is humidity data. Some features are used directly from the standard that are set in the software.



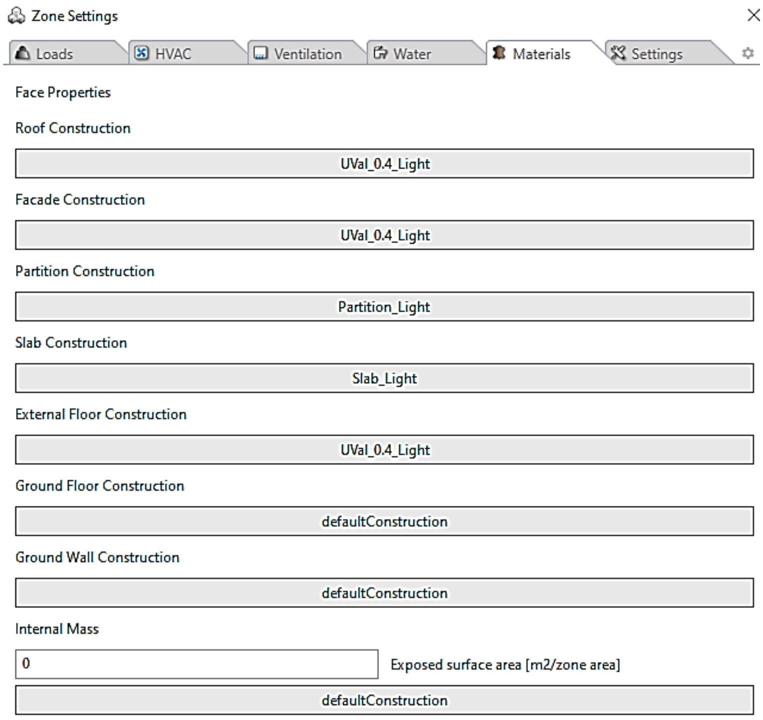
(a)


Zone Settings
Loads
HVAC
Ventilation
Water
Materials
Settings
Heating
On/Off
Constant Setpoint [C]
Schedule Setpoint [C]
25.5
S21 B18 8to18
ee
Availability Schedule
25
Max. Supply Air Temp [C]
NoLimit
Limit
100
Heating Limit [W/m2]
100
Flow Limit [m3/s/m2]
3
Heating COP
Cooling
On/Off
Constant Setpoint [C]
Schedule Setpoint [C]
27
S25 B30 8to18
AllOn
Availability Schedule
24
Min. Supply Air Temp [C]
NoLimit
Limit
100
Cooling Limit [W/m2]
100
Flow Limit [m3/s/m2]
3
Cooling COP
Humidity Control
On/Off

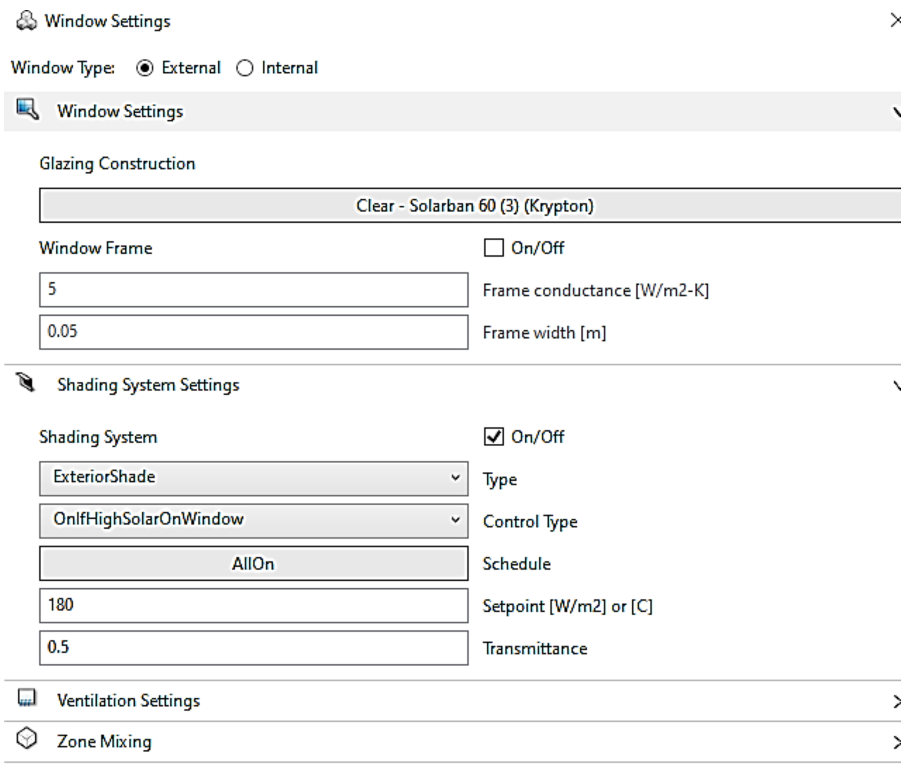
(b)


Zone Settings
Loads
HVAC
Ventilation
Water
Materials
Settings
Scheduled Ventilation
On/Off
18
Set point [C]
0.6
Hourly air changes [ACH]
AllOn
Schedule
Natural Ventilation
On/Off
Buoyancy driven flow
Wind driven flow
22
Setpoint [C]
0
Min Outdoor Air Temp [C]
30
Max Outdoor Air Temp [C]
90
Max Rel. Humidity [0-100%]
AllOn
Schedule
Infiltration
On/Off
0.5
Infiltration [ACH]
1
Constant Term Coefficient
0
Temperature Term Coefficient
0
Velocity Term Coefficient
0
Velocity Squared Term Coefficient
0.001
AirMassFlow Coefficient [kg/s] (AFN only)

(c)



(d)



(e)

Figure 5.12: Different schedule setups for giving input in simulations (a), (b), (c), (d) and (e).

User behaviour, on energy consumption and other criteria, were considered while giving input. The average energy consumption of the study building, was input on the proposed commercial building geometry. Regular use of AC, fan and other electric appliances was emulated on the proposed building.

To test façade treatments, different types of façades were analysed individually on the existing building and proposed building, to generate results to compare the consequent indoor environment created, for each façade.

5.4 Analysis

5.4.1 Analysis of the case building (South Breeze Square)

The brief description of the south breeze square building is presented on Section-4.4.5. Some portion of the west façade of this building is placed in an angular direction which provides shading to the portion directly exposed to west. ThFor analysis of this case building, the floor area was divided into the following thermal zones, during the simulation exercise.

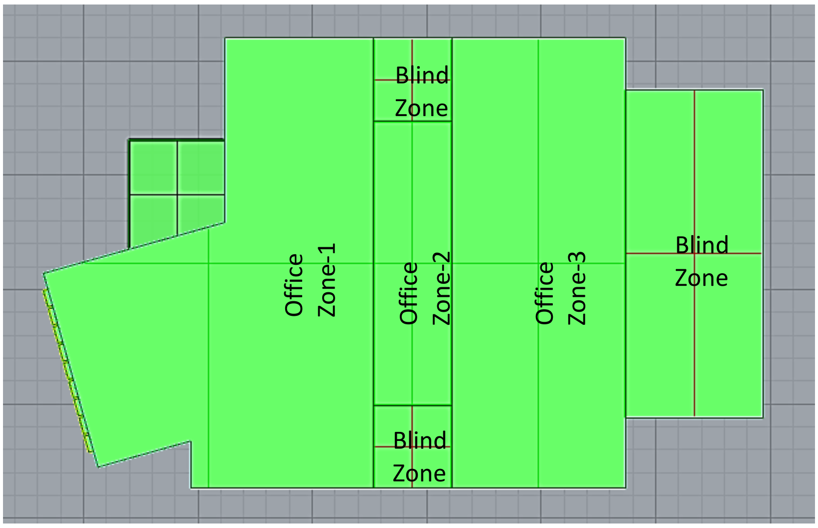


Figure-5.13: Thermal zones of the study area identified on the 11th floor plan.

In order to test the effect of the westerly façade, only results from office zone-1 (Figure 5.14) are considered in the simulation. The other three sides are kept solid in the model. The study focuses on manipulating the western façade and related features, to determine changes in energy consumption, due to various types of treatment.

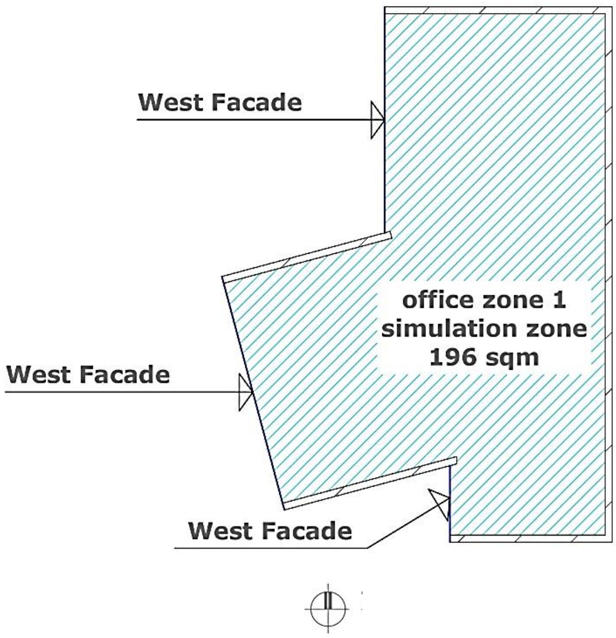


Figure 5.14: Office zone-1 (Exposed to west) – used in the simulation model

5.4.2 Simulation of office zone -1(existing case building) using different treatment at west facade

To analyse the efficiency, of the office floor of the case study area buildings, in terms of energy use, the sequence of investigation followed is given below-

1.Type of glass.

2.Window-Wall Ratio (WWR)

3.External Shading Device on West Façade (perpendicular and angular to the façade) (Chapter-3.3)

From field observation it can be extracted that two types of glass has been used on the west façades of Gulshan Avenue buildings (Chapter-4):

1.Single glazing (laminated)

2.Double glazing (outer layer laminated)

5.4.3 Simulation on basis of type of Glass

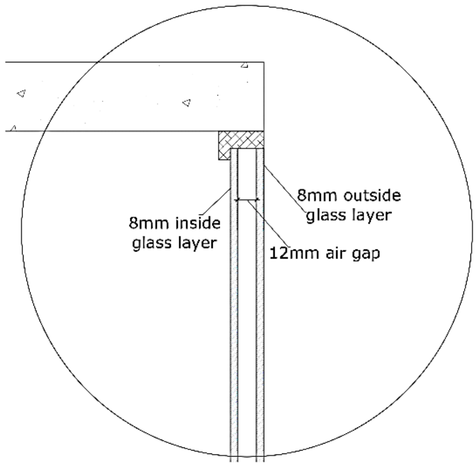


Figure 5.15: Section through double glazing on west façade (used in case building model)

The preliminary simulation results of monthly energy consumption by office zone-1 with single glazing and double glazing on west are given in Table 5.2.

Table 5.2: Monthly energy consumption using single laminated glazing (8mm thick) and double glazing (8 mm thick outside layer, 12mm air gap and 8 mm thick inside layer) on west façade of office zone-1

Month	**Energy Use Intensity (KWH/m^2)**		**Difference**	**Increased from single glazing (%)**
	Single glazing	**Double glazing**		
January	2037.81	2089.51	51.7	2.4%
February	1610.06	1812.43	202.37	11%
March	2105.44	2541.01	435.57	17%
April	2626.25	3140.09	513.84	17%
May	3493.06	4116.37	623.31	15%
June	*4498.89*	*5270.05*	*771.16*	15%
July	*4445.05*	*5274.77*	*839.73*	16%
August	***5163.83***	***6016.75***	***852.92***	***14%***
September	3292.47	3981.84	689.37	17%

October	2600.14	3128.83	528.69	17%
November	1593.15	1862.83	269.68	15%
December	1739.53	1816.81	77.28	4.2%

The results from Table-5.2 suggests, that using double glazing on the west façade, involves more energy than that of single glazing. One of the reason can be the less exposure to natural light due to using double skin. Moreover the use of double glazing on the façade, may have triggered the use of more artificial light in the interior, which contributes to more energy needs. In a way the perception of lower light, creates preferable thermal comfort conditions indoors for the occupants. Despite it is seen from Table-5.2 that double glazing involves more energy, the use of double skin is higher in the surveyed case buildings (Chapter-04), as it reduces direct sunlight. Many studies differ from the results of Table-5.2. A study in a moderate climate like Istanbul, Turkey suggested that double skin glass façade is about 22.84% more efficient than the most energy efficient single skin glass façade. It also suggested that most cost efficient single skin glass façade is about 24.68% more efficient than the most cost efficient double skin glass façade is [4]. A general agreement is found that the application of Double Skin Façade(DSF) positively affects building performance or the environment, but compared to the single-skin façade (SSF), maintenance and construction costs of DSF is higher [5]. Therefore, both single and double glazing have some advantages and disadvantages. In a developing country like ours, reducing the building operation would be very beneficial for the building. Here in this study single glazing has been used for rest of the simulations.

It has been observed from the case buildings, that one of the ways of treating the commercial building façades, is combining solid wall with glazed surface. Therefore, the next criteria considered for the simulation exercise, involved changing the window-wall ratio on this façade, with the window area rising from 30% to 70% of the façade surface. The results are displayed in Table-5.3.

5.4.4 Simulation on basis of Window-wall ratio

Table 5.3: Changing Monthly energy consumption using 15-85, 30-70, 50-50, 60-40 and 70-30 Window-Wall Ratio on west façade of office zone-1

Month	**Energy Use Intensity (KWH)**				
	Window Wall Ratio (15-85)	**Window Wall Ratio (30-70)**	**Window Wall Ratio (50-50)**	**Window Wall Ratio (60-40)**	**Window Wall Ratio (70-30)**
January	1789.45	1832.16	1846.40	1878.12	1923.65
February	1290.33	1320.40	1322.86	1388.35	1459.35
March	1602.12	1634.32	1687.86	1778.52	1886.39
April	1887.23	1964.32	2105.09	2229.28	2364.67
May	2543.45	2719.94	2875.29	3023.10	3182.87
June	**3040.34**	**3456.91**	**3737.88**	**3928.96**	**4125.37**
July	**3212.45**	**3414.22**	**3702.11**	**3885.30**	**4076.82**
August	***4008.34***	**4109.95**	**4381.97**	**4569.29**	**4770.40**
September	2389.45	2455.80	2652.12	2808.98	2974.78
October	1945.44	1982.83	2098.06	2218.44	2348.75
November	1309.34	1334.12	1309.89	1371.42	1442.29
December	1512.23	1634.55	1551.72	1583.83	1629.76

From the results examining WWR (Table-5.3), it is seen that as the ratio of glass in the façade increases, the energy consumption tends to increase. This is expected, as more heat is penetrating through the west façade. It can be observed from Table-5.3 that window-wall ratio (WWR) 15%-85% is the most energy efficient. The lowest figure in August, is highlighted on Table-5.3 i.e. 4008.34 KWH. It should be added here that 85% solid surface on the front façade will cut off a large portion of the view, also impacting the architectural character of the building, which diminishes the significance of the landmark building. It is mentioned in clause 59.2 of the Bangladesh Gazette,2021 that at least 15% of the building façade should have openings, that's why it has been followed while running simulations.

From observing the results of Table-5.3 it can be said that designers would be benefitted more if shading devices were applied on full glass façades, rather than a combination of window-wall. Moreover, the architectural trend of the times, point to the use of full glass. Therefore, for the study, it was decided to investigate the western façade with a WWR of 100%.

Note: Only the months June, July and August are presented for the rest of the simulations, as these months are found to consistently consume most energy (Tables-4.11, 5.2, 5.3). Therefore, the lowest energy consumption for different façade criteria in high humid months, are observed in this study, to understand best outcomes in terms of energy efficiency. The lowest energy use in the month of August is highlighted in all the following tables, to show which criteria brings the best result, in the most humid month (Section-2.2.3, Figure 2.2).

5.4.5 Simulation on basis of shading device

After checking the window-wall criteria, the next criteria analysed was the application of different types of shading devices, on the west facade. The shading devices that are used for simulation are derived from the literature review (Figure-3.9).

Simulation using horizontal louvers on west façade

Horizontal louvers are widely used on commercial buildings of Dhaka city (Sections-4.4.1, 4.4.2). First of all, horizontal aluminium slats of varying gaps (8 cm to 23 cm) are placed on the west façade glass, in order to observe which gap saves most energy. Aluminium is chosen as the material for all types of shading in the analysis, as it is the most common type used in the case buildings

(Chapter-4, Table 4.12). In addition it is locally available, easy to install and maintain, cost effective and light weight.

For simulation the following details have been used-

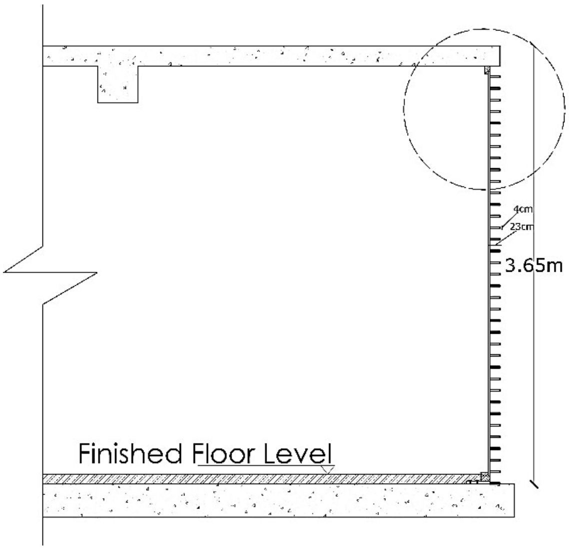


Figure 5.16: Full height section of the western façade of the existing office floor with horizontal aluminium slats attached.

The circular marked area in Figure 5.16 is drawn as blow up sections in Figure 5.17 which shows details of the horizontal louvers at various spacings. Here the horizontal louver length is taken to be as long as the façade length, louver width is 20 cm and thickness is 4 cm. Louver width is considered 20 cm, keeping track with horizontal louvers used in case buildings.

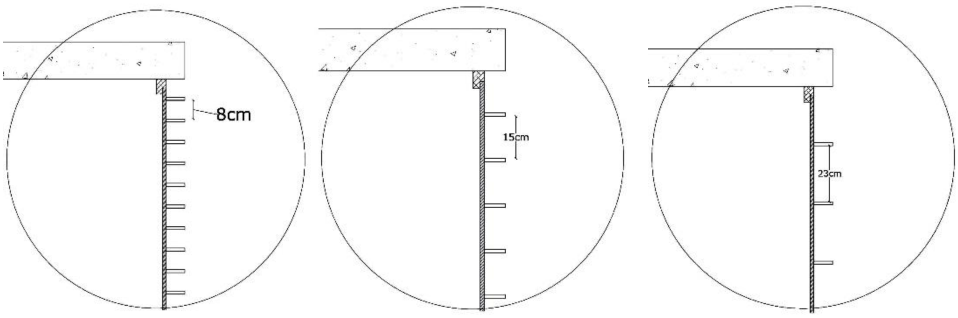


Figure 5.17: Blow up sections of horizontal louvers on west façade of existing case building having 8cm, 15cm and 23cm gap between each other respectively and perpendicular to the facade (from left to right).

Table-5.4: Monthly energy consumption, using horizontal louvers at 8cm, 15cm, 23cm and 30cm spacing, throughout the height of the glass façade.

Month	**Energy Use Intensity (KWH)**			
	Horizontal Louvers at 8cm spacing	**Horizontal Louvers at 15 cm spacing**	**Horizontal Louvers at 23cm spacing**	**Horizontal Louvers at 30cm spacing**
June	3765.33	3848.83	4065.44	4124.21
July	3700.78	3724.99	4032.48	4043.09
August	***4365.44***	4444.70	4654.33	4762.59

It is observed from the Table-5.4 that horizontal aluminium slats at 8 cm gap on west façade are most efficient in terms of energy use, i.e. 4365.44 KWH. If the spacing between the aluminium slats are less, it will allow less percentage of heat through the façade but it would cut off maximum view from the western side i.e front side for the case buildings. The geometry of horizontal louvers are briefly discussed in Section-3.3. The outcome of Table-5.4 can be noted as a recommendation for the designers to save energy.

Simulation using sun breakers

Sun breakers are a common type of shading device, used to reduce the effect of direct sunlight (Figure-3.9). The details of the sun breaker, tested for use on west façades in the simulation exercise for this study, is given below (Figure-5.18)

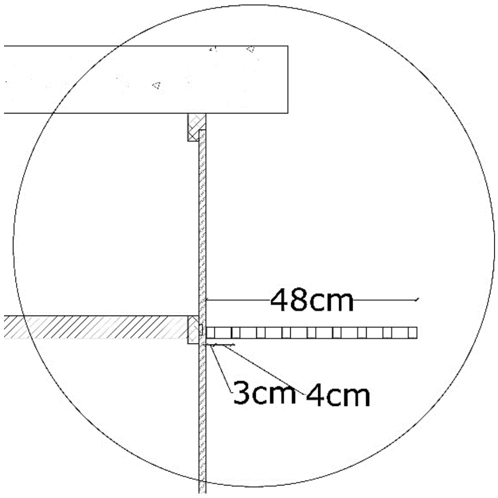


Figure-5.18: Sun breaker at 4cm distance and 48cm overhang from the west facade

Table-5.5: Monthly energy consumption using sun breakers on west façade of office zone-1.

Month	**Energy Use Intensity (KWH)**
	Sun Breakers
June	4332.43
July	4268.91
August	***4976.91***

From table 5.5 it is seen that on August the energy consumption of the floor is 4976.91 kwh which is greater than the consumption results on August got from Table-5.4 using horizontal louvers. Therefore, sun breakers as a shading device can be excluded for further simulations.

Simulations using vertical louvers

Vertical louvers at different angles and distances on west façades also reduce the impact of direct sunlight (Figure-3.9). Therefore, to see the impact of façade treatment on energy efficiency, vertical louvers 15 cm apart, at various angles, have been used for simulation of office zone-1 (existing case building). The full height of the floor has been set as the vertical louver height, with a louver thickness of 4cm (see Figure 5.20).

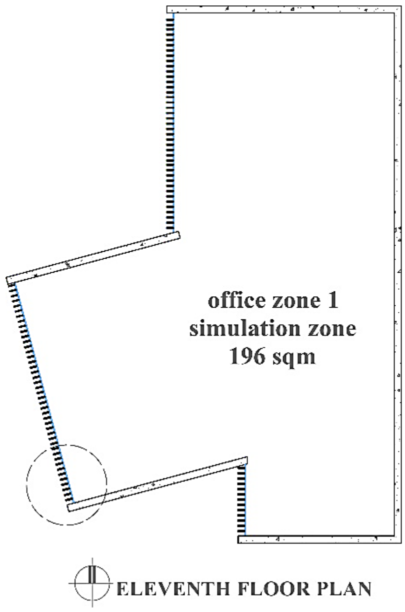
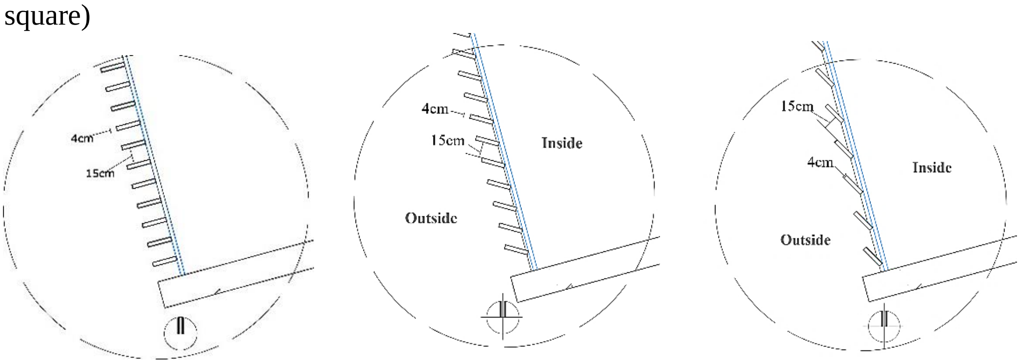


Figure 5.19 Key plan showing vertical louver on existing case building (south breeze square)



(a) (b) (c)

Figure 5.20: Blow up plans of vertical louver at different angles on west façade attached to the glass.

(a) Blow up Plan showing vertical louver perpendicular to the façade attached to the glass

(b) Blow up Plan showing vertical louver 30 ^{o} tilted towards north attached to the glass(c) Blow up Plan showing vertical louver 60 ^{o} tilted towards north attached to the glass.

Table-5.6: Monthly energy consumption using vertical aluminium louvers (each slats have 15cm gap between each other) perpendicular to the façade, 30^0 and 60^0 tilted towards north respectively on west façade of office zone-1.

Month	Energy Use Intensity (KWH)		
	Vertical Louver perpendicular to facade	**Vertical Louver 30^0 tilted towards north**	**Vertical Louver 60^0 tilted towards north**
June	4083.64	4293.10	4310.48
July	4007.42	4221.17	4238.11
August	***4715.88***	4938.52	4954.63

It is seen from Table-5.6 that vertical louver (slats having 15 cm gap between each other) perpendicular to the façade saves more energy (4715.88 KWH) than that of angular louvers. But this is higher than the best result for horizontal louvers, obtained from Table-5.4 i.e energy consumption of 4365.44 KWH for the same month.

Comparing the results from the simulation using different types of shading devices (Table-5.4, 5.5, 5.6) on west façade of the existing office zone (office zone-1) of South Square building, it can be said that if horizontal aluminium slats are placed at close spacing (8cm apart) on west façade, then the energy use would be 4365.44 KWH on the month of August. This is lowest in terms of energy use in August, compared to other types of shading devices. The reason for comparing among the results from August is that it is the most humid month (Figure-2.2). Therefore, the lowest energy consumption for different façade criteria in the most humid month, are observed in this study, to understand best outcomes in terms of energy efficiency (Section-5.4.4). For the rest of the simulation analysis, using a typical model (Section 5.5), the other types of shading can be excluded rather than the best ones. Here it can be added that from the analysis of window-wall ratio (30-70 and 50-50 ratio), similar results as horizontal aluminium louvers at 8cm spacing were obtained. But while designing, use of shading devices on glass façades would be more effective than that of combination of window and wall (Section 5.4.4). That is why use of shading device is the preferred thermal control option.

5.5 Analysis of the typical case model

The discussions so far, have focused on an existing building in the study area. For analysing further possibilities, on the existing sites of Gulshan Avenue, a model was created maintaining maximum floor area, to test the limits of possibilities on these sites.

5.5.1 Examining Energy implications of glass façade at various inclinations

For further analysis, therefore, a typical layout was obtained (Figure 5.21), implying the rules of setback and MGC (Maximum ground coverage), following Dhaka Imarat Nirman Bidhimala 2008, in existing commercial plots of Gulshan Avenue. The layout ensures maximum utilization of ground area, given these existing regulations, a feature that is sought by developers who want to maximize profits.

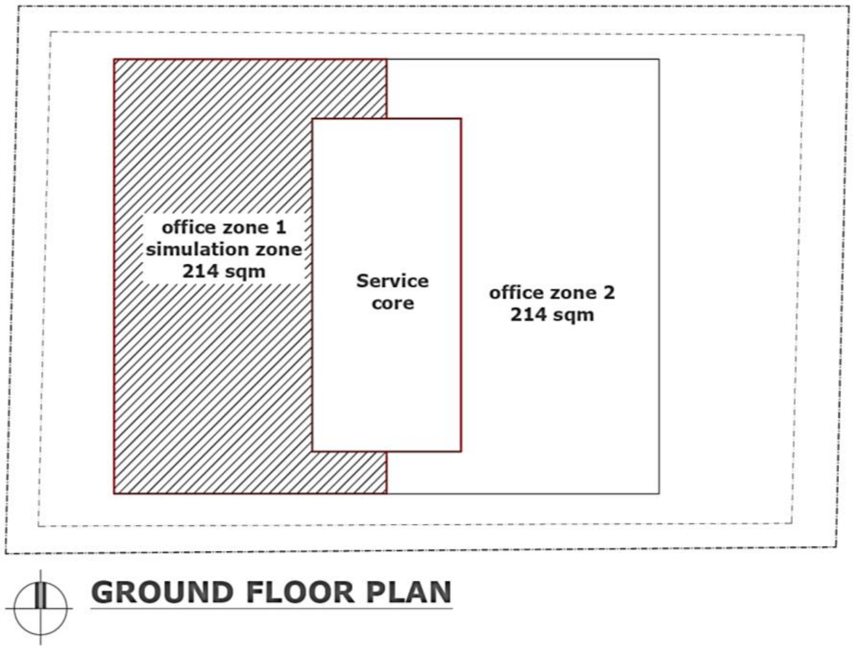


Figure-5.21: Typical layout for simulation

The site area for the above layout (Figure-5.21) is 1030 sqm, obtained from analysing the case buildings in Chapter-04. According to regulations, F1 commercial type buildings can have MGC up to 52% of the site area i.e. 536 sqm for the above layout. The building is divided into two offices per floor, with a central distribution space, as can be considered typical for this area. The shaded zone in the plan (office zone-1) has been chosen as the thermal zone for running simulation. This zone is west facing, which is the research interest. Only the zone exposed to the west, has been taken for simulation, to understand the impact of the west façade exclusively, and also to get maximum impact of the west façade in terms of energy consumption. The other three facades of office zone-1 have been assumed to be solid.

For the simulation analysis, various treatments have been implied to the west façade of the typical layout, and then simulation has been run. From the results and their comparisons, the type of façade combination which is more energy efficient can be determined.

The criteria for façade types, followed in Section-5.4, were also used for running simulations of the typical model. From Table-5.2 it was found that using single glazing on the west façade turned out to be more efficient in terms of energy use, compared to double glazing for the case building. Using double glass façade has proven to be more effective in many cases but in this research simulation results from Table -5.2 showed that single glazing performed better. This might not be true for all case buildings. Based on results of Table-5.2 single glass have also been applied in case of the typical model (Figure-5.21).

To further explore which type of façade reduces the energy needs of the typical model, the west façade was manipulated following the criteria mentioned in Section-5.4.2. Each time, only the best option, of the manipulated design features, were kept for the next series of manipulations.

First of all, simulation was run using 100% glass with no inclination on the west facade. The glass, specifications are provided in table 5.7

Table-5.7: Specifications of the Single glass used in the typical model (Figure 5.21) façade:

Glass thickness	8 mm
Glass type	High performance Low-E
Glass Colour	Ocean Blue
Transmittance	49%
Exterior Reflectance	18%
Interior Reflectance	20.65%
U-Value (W/m2 • K)	1.6
Solar Heat Gain Coefficient	0.38
Shading Co-efficient	0.32

(data taken from specifications provided by CHB for EBL building as from Figure-4.8 it can be said the layout of EBL is similar to the layout of the typical model shown in Figure-5.21)

Here high performance Low-E glass is used for simulation as low-E glass can help reduce heat loss in the winter and prevent heat entry in the summer. According to studies Low-E glass can help keep indoor environment comfortable while reducing energy costs throughout the year and can reduce heat gain up to 30% [6]. In addition the values of glass properties are taken from one of the case buildings, EBL Headquarters mentioned in Section-4.4.2 and applied for simulation model as the typical case model shape and configuration are similar to EBL building.

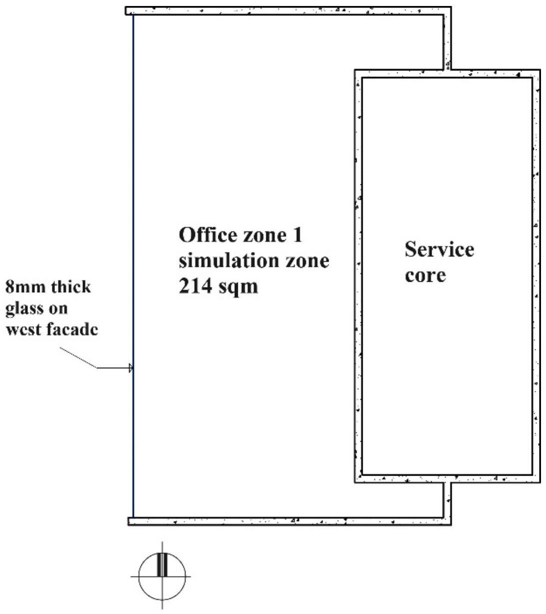


Figure-5.22: The typical case model with single glazing on west

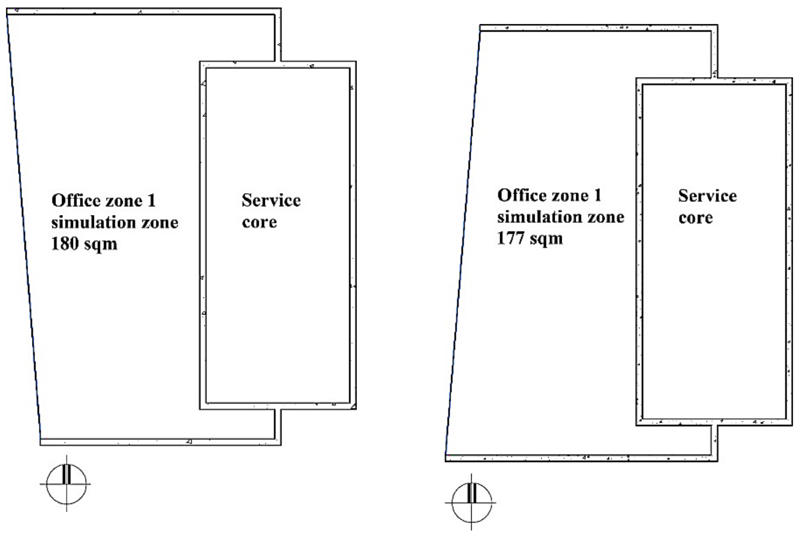
Table 5.8: Simulation Results for single glazing on west façade of office zone-1 of typical model, other sides kept solid.

Month	Energy Use Intensity (KWH)
June	4268.50
July	4213.24
August	***4927.74***

The result of energy consumption from Table-5.8(for typical model), in the month of August is 4927.74 KWH and the result of simulation using single glazing in existing building is 5163.83 KWH (Table-5.1). Therefore, it can be said that energy consumption is less in the former case. To double check, the energy consumed per unit area for these two office zones were calculated. It was found out that the energy consumption by typical office zone (214 sqm) per unit area is 23 KWH and energy consumption by existing office zone (196 sqm) per unit area is 27 KWH. Therefore, the energy consumption by existing office remained higher in both the cases. Since the west façade was slightly tilted from the true north in case of the existing office zone therefore the energy consumption results can vary which is also seen in the analysis of Table-5.9.

With reference to the study of the case buildings (Sections-4.4.1, 4.4.3) it is seen that angular façades have been utilized in both plan and in section. Therefore, the next set of simulations were run, changing the inclinations of the western glass façade, and also tapering it (Figures-5.23, 5.24, 5.28). These changes in inclination and angle of façade were tested, to identify whether or not they are more energy efficient, than the perpendicular façade.

The layout and sections of the different west facing typical case model spaces and the energy use intensity (EUI) per month are given in Figures-5.23, 5.24 and 5.25 (Table-5.9)

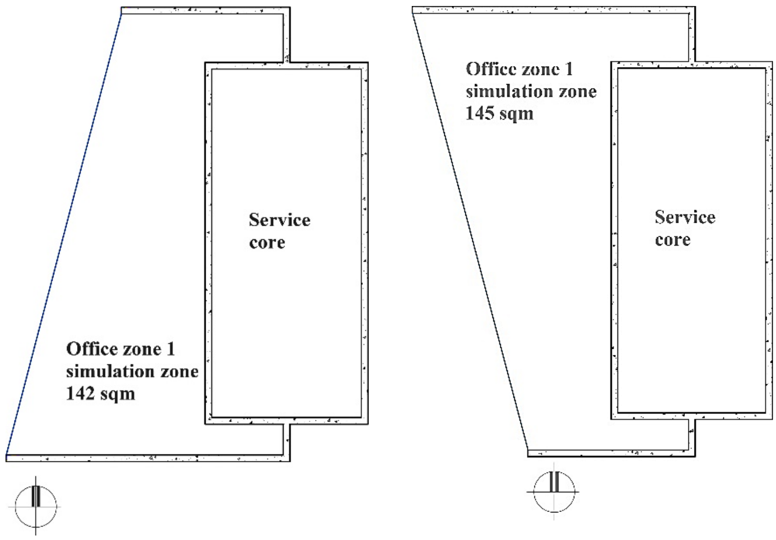


(a) (b)

Figure 5.23: West façade of the office zone-1of the typical model tilted at different angles towards different direction

(a) Plan 5^{o} tilted from north to south,

(b) Plan 5^{o} tilted from south to north

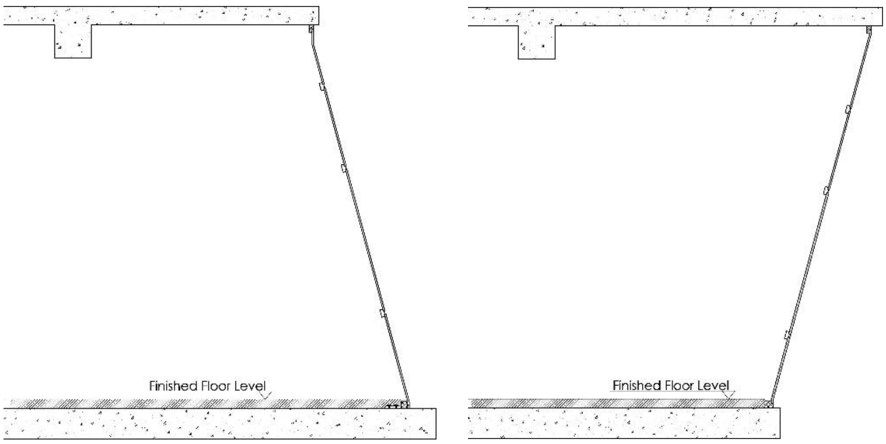


(c) (d)

Figure-5.24: West façade of the office zone-1of the typical model tilted at different angles towards different direction

(c) Plan 15^{o} tilted from south to north,

(d)Plan 15^{o} tilted from north to south



(e) (f)

Figure-5.25: Section through west façade of the typical model

(e) west façade 15^{o} tapered from finished floor level

(f) west façade 15^{o} tapered from roof slab bottom

Table 5.9: Monthly energy consumption implying the conditions shown in Figures-5.23, 5.24, 5.25.

Month	**Energy Use Intensity (KWH)**					
	a	**b**	**c**	**d**	**e**	**f**
June	4445.92	4430.06	4961.62	4905.48	4522.04	4270.53
July	4391.58	4383.53	4899.89	4869.64	4475.88	4220.69
August	5107.02	5114.16	5626.70	5658.24	5182.66	4946.63

After analysing the results from Table-5.9, and comparing them with the results from Table-5.8, it can be confirmed, that none of the conditions mentioned in Table-5.9, would perform better than those mentioned in Table 5.8. Therefore, inclining or tapering the western facades are not more energy efficient than keeping them true West. For this reason, the west façade was kept parallel to the site line for the future set of simulations (i.e. inclination was kept zero, both in plan and section).

The, next criteria for running simulations, was adding shading devices to the west façade of the typical model which is single glazing and west façade inclination is zero.

According to the simulation results obtained from the existing South Square model, it was found that horizontal aluminium panels of 8 cm gaps on the west façade (Table-5.4) engaged lowest energy use, among all the external shading types examined.

To be more accurate, regarding which type of treatment on the west façade ensures higher energy efficiency, horizontal and vertical aluminium louvres are implied in various combinations for the rest of the analysis. These two types of shading devices, as mentioned earlier, are those mostly used in commercial buildings (Section-3.3)

5.5.2 Examining Energy implications of External Shading Devices'

For the next set of simulations, the offset distance of horizontal and vertical louvers that are attached to the glass façade, were changed, to find the most efficient distance, in terms of energy needs.

This section reports on these simulations in three phases. Firstly, the best type of louver was attached to the glass façade (Figure-5.25), then they were placed at various offsets from the glass façade (Figures-5.25) to judge the most efficient option. In the third phase, the further criteria for checking efficiency was that of changing the angle of the louvers (Figure-5.32)

Simulation using horizontal louver on west façade of typical model

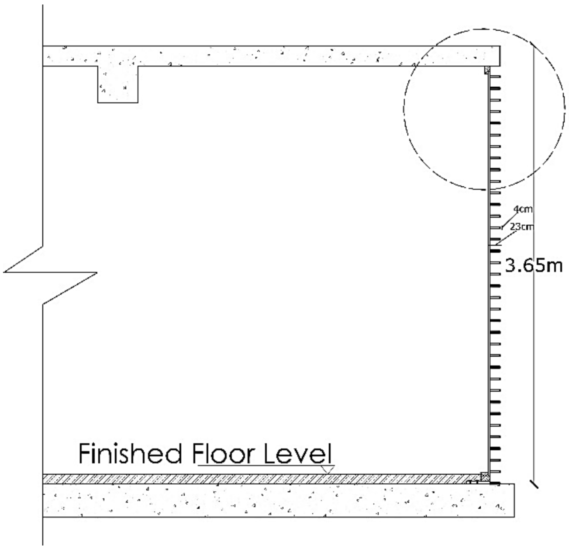


Figure 5.26: Section showing horizontal louvers attached to the west façade of typical model

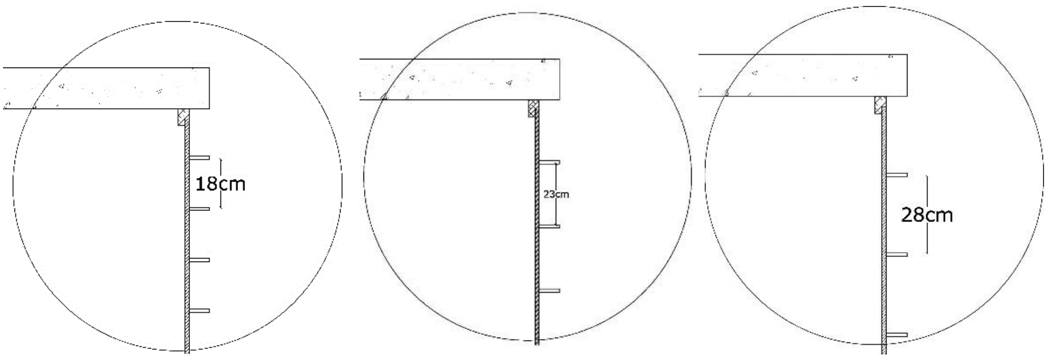


Figure 5.27: Blow up section through horizontal louvers attached to the west façade with 18cm, 23cm and 28cm spacing respectively perpendicular to the facade (Left to right).

Table-5.10: Putting horizontal louvers at 18cm, 23cm, 25cm, 28cm and 35cm gap all through the height of the glass façade (slats attached to the glass)

Month	**Energy Use Intensity (KWH)**				
	18cm	23cm	25cm	28cm	35cm
June	3802.39	3500.16	3896.87	3811.38	4085.03
July	3731.64	3371.73	3813.23	3752.54	4006.74
August	4450.11	***4128.31***	4568.29	4469.82	4761.56

From Table-5.10 it can be identified that horizontal louvers attached to the façade with 23cm gap is most energy efficient of those tested.

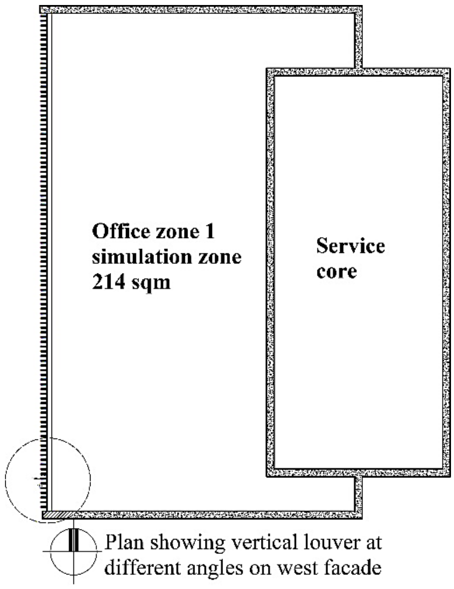


Figure 5.28: Key plan showing vertical louvers on west façade

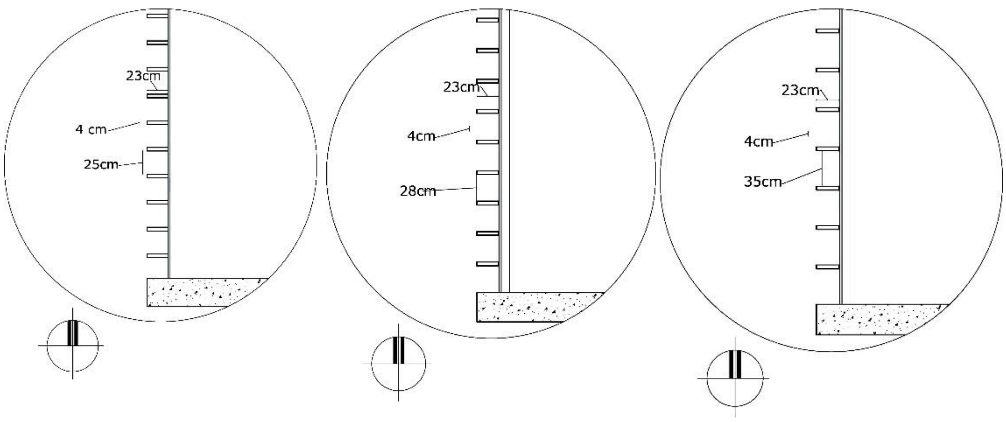


Figure-5.29: Blow up plan showing vertical louvers (perpendicular to the façade) at 25cm, 28cm and 35cm distance

Table-5.11: Putting vertical louvers at 18cm, 23cm, 25cm, 28cm and 35cm gap along the entire height of the glass façade (slats attached to the glass, i.e. with no offset)

Month	**Energy Use Intensity (KWH)**				
	18cm	23cm	25cm	28cm	35cm
June	3802.39	3826.88	3849.67	3808.19	3952.57
July	3731.64	3575.59	3785.39	3724.18	3880.30
August	4471.68	4488.86	4515.27	***4451.66***	4596.73

From Table-5.11, it can be identified that vertical louvers attached to the west facade with an offset distance of 28cm, is the most energy efficient, as the energy use is 4451.66 KWH. But it is higher than the lowest result from table 5.10 for horizontal louvers, which was 4128.31 KWH. Therefore, use of vertical louvers was disregarded, for the next set of simulations. In both of the cases the result of the month of August are compared as it is the most humid month (see Section-5.4.4 for explanation).

At this point of analysis, the final criteria for simulating the typical model was chalked out, as follows, concentrating on horizontal louvers, as displaying the most energy efficient results.

1.Varying gaps between horizontal louvers attached to the glass façade

2.Horizontal louvers put at various offsets from the glass façade, from the best results of the above.

3.Changing the angle of the horizontal louvers, using the best option from the above

For each criteria the best result would be considered as the basis for running simulations, considering the next criteria.

The best combination (horizontal louver with 23 cm gaps) derived from Tables-5.10 and 5.11, were taken for the next set of simulation, for different offsets from the west façade.

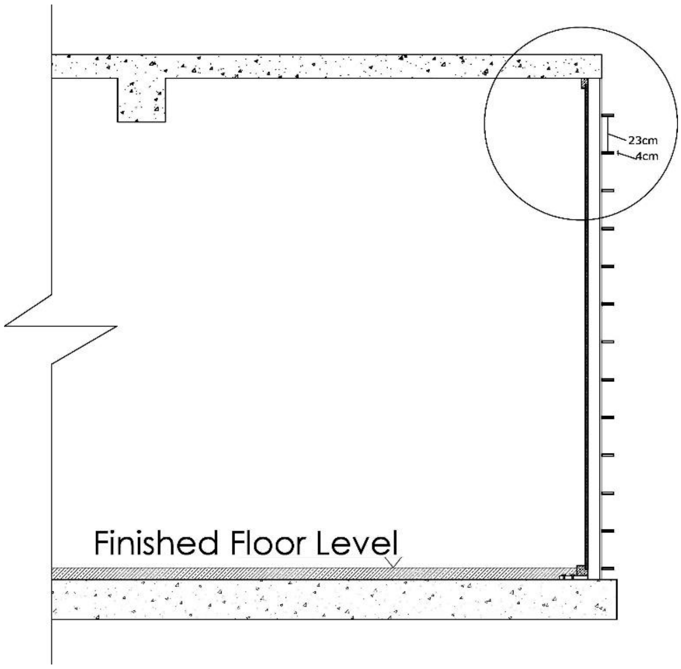


Figure-5.30: Full height section of the floor with horizontal louvers at different offset from west façade

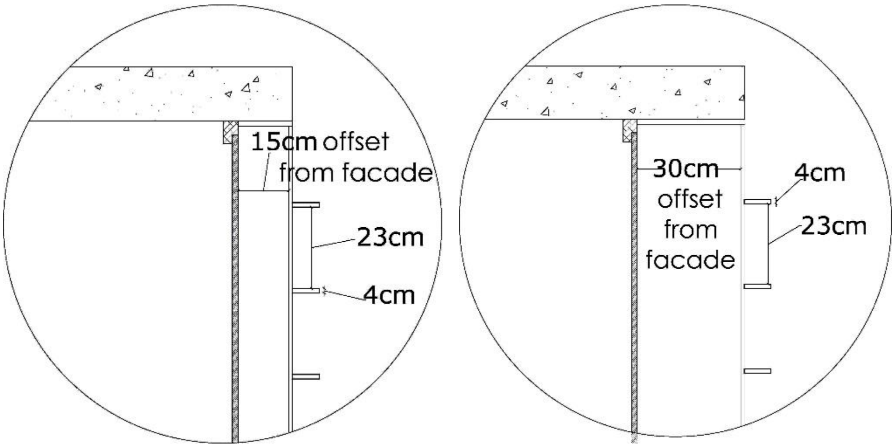


Figure-5.31: blow up section of horizontal louver at 15cm and 30cm offset from west façade respectively

Table-5.12: Putting horizontal louvers with gaps of 23cm (which performed best in terms of energy efficiency according to Table-5.10) at various offset distances from the glass

Month	Energy Use Intensity (KWH)		
	15cm offset	30cm offset	35cm offset
June	3183.69	3185.28	3187.07
July	3039.15	3041.56	3043.81
August	***3788.58***	3791.24	3793.65

From Table-5.12 it is seen, that when horizontal louvers are placed 23cm apart from each other, throughout the height of the external façade, having an offset of 15cm from the glass façade, it brings out most effective results in terms of energy savings, though the differences with other tested offsets, are only minor. Comparing the Tables-5.10, 5.11 and 5.12 it can be said that among all the combinations tested, horizontal louvers with 23cm gap, throughout the height of the external façade, placed at an offset of 15cm from the glass, are most efficient in terms of energy saving.

In the next stage, simulations were run on louvres with different angles to the glass pane, based on these most efficient combinations, i.e. horizontal louvers with 23cm gap and 15cm offset from glass facade placed at angles.

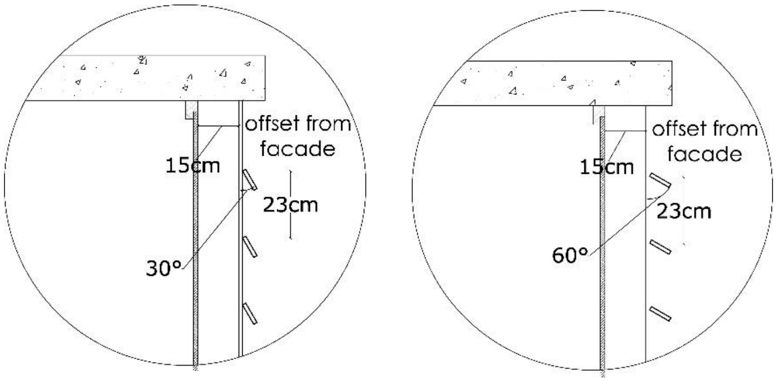


Figure-5.32: Blow up section of horizontal louvers with 23cm gap and 15cm offset from glass façade, with angles of 30^{o} and 60^{o} with the glass pane.

Table 5.13: Monthly energy consumption using horizontal louvers at different angles but same gap and offset (Figure 5.32)

Month	**Energy Use Intensity (KWH)**	
	30^{o} angle	**60^{0} angle**
June	3889.37	3873.50
July	3710.37	3703.66
August	4536.69	***4532.23***

Results from Table-5.13 suggests that in comparison to the best result got from Table-5.12 i.e. 3788.58 KWH, the best result from Table-5.13 i.e. 4532.23 KWH, is much higher. Therefore, it is more energy efficient to place the horizontal louvers at right angles, perpendicular to the glass surface, as it shows better results.

In Section-5.5 a thorough analysis of the typical model (Figure-5.21) have been done. At first the west façade glass was tested putting it at different inclinations. The results showed that west façade paralle1to the site shows better result in terms of energy efficiency rather than any inclinations (Section-5.5.1). After that the west façade was tested implying different shading devices. From the analysis of Section-5.4 it was evident that horizontal louver on west façade at a certain gap turns out to be beneficial in terms of energy saving. Still for the simulation of typical model both horizontal and vertical louvers at different gaps, different angles and different offsets from glass façade are tested in Section-5.5 to gain a clear understanding of which façade combination turns out to be most efficient. Based on the analysis presented on Sections-5.4 and 5.5 a summary of simulation results are displayed on Table-5.14 which step by step simulations. It also views how a certain criteria was excluded from next simulation because it suggests less energy efficiency.

Table-5.14: Summary of the results of the most humid month i.e. August applying all above mentioned criteria

Horizontal louver attached to glass at various gaps	**Energy Consumption (KWH)**	**Remarks**
18cm	4450.11	
23cm	***4128.31***	Most efficient
30cm	4568.29	
28cm	4469.82	
35cm	4761.56	

Offset considered for louvers at 23cm distance		Only 23 cm is considered as it is most efficient
15cm offset	***3788.58***	Most efficient
30cm	3791.24	
35cm	3793.65	
Different Louver Angles tested for and 23cm gap and 15cm offset		
30	4536.69	The results are higher than previous criteria i.e offset from glass therefore these results can be excluded.
60	4532.23	

Due to high consumption during the month of August as previously mentioned (Chapter-2), all the results of energy consumption obtained from that month are compared. It is determined from the summary of all the simulations (Table 5.14) that horizontal louvers with 23cm gap, 15cm offset from glass façade, saves most energy. From all the analysis, some recommendations can be extracted, for cutting off energy use in west facing commercial buildings. It has been identified, that shading devices are more effective, than Window-wall combination. The use of aluminium panels are more effective, in the form of horizontal louvers perpendicular to the glass, in reducing the use of energy.

5.6 Summary

This chapter holds the most significant part of the research i.e the analysis. Here in Section-5.2 the extracted data from questionnaire is analysed and users' thermal preference have been determined using thermal comfort tool. Then in sections-5.4 and 5.5 step by step simulations of an existing case model and a typical model have been conducted. After going through all the simulation results it can be said that the answer to the research question mentioned in Section-1.2, whether façade treatment had any impact on the energy efficiency of an office floor is in the affirmative. Façade treatment has been found to impact energy efficiency to a certain level. Through this research, several façade details have been identified, which can bring about lower energy use within west facing offices, under Dhaka's tropical conditions.

References

[1] Parkinson, T. and de Dear, R., 2017. Thermal pleasure in built environments: spatial alliesthesia from air movement. *Building Research & Information*, *45*(3), pp.320-335.

[2] Available at: http://www.autofieldguide.com/articles/090409.html. assessed on Dec., 12th 2008, 1:12pm).

[3] Available at: https://nono.ma/4-reasons-to-use-grasshopper-in-architecture

[4] Cetiner, I. and Özkan, E., 2005. An approach for the evaluation of energy and cost efficiency of glass facades. *Energy and buildings*, *37*(6), pp.673-684.

[5] Al-awag, E.A.N. and Wahab, I.A., 2022, May. Perspectives in double-skin façade (DSF) advantages and disadvantages. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1022, No. 1, p. 012003). IOP Publishing

[6] Ma, L., Shao, N., Zhang, J. and Zhao, T., 2015. "*The influence of doors and windows on the indoor temperature in rural house*." Procedia Engineering, 121, *pp.621-627.*

Chapter-6: Conclusion and Recommendations

6.1 Introduction

The major goal of this research, was to identify whether changes in treatment of western façades of commercial buildings, have any impact on total energy use of the office floor. The analysis part of the research is presented on the previous chapter i.e Chapter-05. Step by step simulation results, presented in the different sections of Chapter-05 suggests, that changing the treatment of façades do have impact on energy efficiency.

6.2 Summary of the research

At first, simulation was run putting fully glass façades on the west side of an existing case building, without any shading devices (Chapter-5.4.3). Then with the best result, according to type of glass, was further investigated with different types of shading devices, and it was determined that horizontal aluminium slats attached to the glass, at a close gap on west façade, produced the highest energy savings. Here simulation was done putting horizontal louvers of varying gaps, to understand the optimum gap, beyond which energy consumption starts rising (Section-5.4.3). In case of the results from simulations from the typical model, it was seen that horizontal louvers with 23cm gap and 15 cm offset from the glass facade, placed throughout the height of the external façade, saves most energy (Table-5.12). Therefore, it is understood that in the study area, horizontal louvers placed in front of the west glass façade at an offset, would contribute towards greater energy efficiency.

It should be mentioned here, that while observing and documenting the features of the west facing buildings of Gulshan Avenue, various types of façade treatment have been identified (Chapter-04), and many types have also emerged from literature review (Chapter-03). This served the first of the goals of the research, which was to find out the different existing practices regarding types of façade treatment for commercial buildings, used by Architects in Dhaka. In order to achieve the goal of finding which façade treatment achieves higher energy efficiency, many of these treatments have been tested in the simulation exercise in this study. The simulations were used to check the energy efficiency under Dhaka's context. It might be the case that a certain combination of façade treatment shows the best result in terms of energy efficiency, but this does not negate the other combinations.

Apart from the issue of cooling efficiency, thermal comfort preferences of the users of the case buildings were also under investigation, and have been analysed in Chapter-05, based on questionnaire responses. It has been identified that the majority of people can adjust with the indoor environment of the offices tested under the context studied.

At the beginning of this study it was thought that a direct relationship between a building's cooling efficiency could be established from users' thermal comfort preferences. However, during the working process this concept was modified, as a direct connection could not be found. The issue of energy efficiency and thermal comfort has thereby been analysed separately here.

6.3 Indicators of efficient façade design

After studying the case buildings of Gulshan Avenue (Chapter-04) and analysing similar case models (Chapter-05) through computer generated simulations, some key features of energy efficient façade combinations could be obtained. These features may work as guidelines for Architects of Dhaka. In this study, the simulation results for the existing case building suggested that using single glazing would save 14% (Table-5.2) of total energy consumption of the floor in the most critical month. Therefore, single glazing were applied for all other combinations of the rest of the simulations.

Some of the key findings from the research is presented in this section-

1.Keeping the west façade perpendicular to true north/south may be beneficial rather than inclining the west façade in plan on elevation. The simulation results showed that even 5^{o} tilt to the plan towards south from north (Figure-5.23 a) or north from south (Figure-5.23 b) would increase energy consumption up to 3.5%-4%. Again tapering the façade to upward or downward direction would also increase the energy usage to 0.40% (Figure-5.25 f) to 5% (Figure-5.25 e).
2. Shading device on 100% glass façade in the west would be more beneficial than window-wall combinations used for simulations as per standard mentioned in Table-5.3 (15-85%, 30-70%, 50-50%, 60-40%, 70-30%). The latter would cut off significant views from west oriented offices.
3. Simulation results show that among all other shading device combinations, horizontal louvers placed at 23 cm gap from each other, 15 cm offset from the glass and perpendicular to the west façade turns out to be most efficient.

There are also some findings regarding users' thermal comfort preference. They are-
1.The preferable indoor temperature range of office occupants is 22℃-26℃
2. Average Relative humidity found from the field data is 35% which is very low compared to the relative humidity standard range to maintain in office buildings as mentioned in Bangladesh Gazette,2021 which is 50%-60%. Therefore, while determining thermal preference from comfort calculator relative humidity has been assumed as 50%.
3.Despite being exposed to non-air conditioned spaces in home and outdoors the users of commercial offices in the study area can adjust well in the internal environment.
4.Most of the users are satisfied with internal environment of the office.

6.4 Outcome of the objectives

The major objective of this research was to find out the relationship between façade treatment and energy efficiency. From the analysis of Chapter-05 it could be clearly identified that façade treatment has impact on energy efficiency.

However direct relationship between thermal preference and energy efficiency could not be determined from this study. It might be connected indirectly which can be highlighted in any other research.

6.5 Limitations

- Due to restrictions on physical movement and proximity, induced by the Corona pandemic, data could not be collected from all case buildings for documentation during the study. The questionnaire survey was restricted to one of the office buildings under the circumstances. It is assumed that this can be a representative model of users' thermal preference in general, as there was no cause to doubt the generalisability of the responses.
- As far as the weather data is concerned due to pandemic situation synoptic data at the specific location could not be gathered. Here the meteoritical data of Tejgaon have been used for simulations as it is very close to Gulshan and it was also compatible with the software used for simulation. If anyone takes data from on spot the results might come different.
- Another limitations that should be mentioned here is that for conducting simulation, gaps between shading devices were kept minimum 8 cm otherwise the software would show error in simulation.
- As far as the depth of the shading device is concerned, it was kept 20 cm for all type of shadings due to availability of this size in the market. Moreover taking different kinds of depth for shading device for simulation would have make the analysis more lengthy and there is no end to it.

6.6 Scope of further research

From the outcome of this research some scope for further research can be established.

1.This study has looked at energy efficiency for commercial buildings. There is scope to study other building typologies using the methodology developed here for a more comprehensive understanding of the energy needs of building stock in general.

2.The study focuses on the thermal environment. Other environmental aspects like daylighting which are part of the office environment can also be studied for a more in depth picture of commercial buildings.

3.For simulation various combinations of shading device have been applied specially following the combinations found in case study but there can be other Hundreds of façade combinations which can be analysed in any other research. This would bring out different results.

Bibliography

1. Ahmed, K S.1995, *Approaches to Bioclimatic Urban Design for the Tropics with special Reference to Dhaka*, *Bangladesh,* Phd. Thesis, (unpublished), Architectural Association, School of Architecture, London, UK. *p. 15,32,47*

2. Ahmed, A. M. Ali, Tarek, M. F. Ahmed 2012, "*Evaluating the Impact of Shading Devices on the Indoor Thermal Comfort of Residential Buildings in Egypt",* Fifth National Conference of IBPSA-USA, Madison, Wisconsin, August 1-3

3. Ahmed, Z. N., "*Assessment of Residential sites in Dhaka with respect to Solar Radiation Gains"*, unpublished PhD Thesis, De Montfort University, UK, p: 95-96, 1994.

4. Ahmed, Z. N., *"Sustainability in the Built Environment of Bangladesh: Participation of Architects; Environmental Sustainability Concerns"*, Eds. M.M.Rahman, M.J.B. Alam, M.M.Ali, A.B.M.Badruzzaman and I.Smout; EEM BUET,CERM-BUET, ITN-BUET, WEDC; September 2006; pp133-144, 2006.

5. Ahmed, Z.N., Howarth, A.T. and Zunde, J.M,1990; "*Thermal comfort studies and applications for Dhaka",* Building Services Engineering Research and Technology, 11(3), pp.105-108.

6. Ahmed, Z.N.1987; *"The Effects of Climate on the design and Location of Windows for Buildings in Bangladesh"*, unpublished MPhil thesis, Sheffield City Polytechnic, Chapter 2, October 1987

7. Ahsan, T., 2009; "*Passive Design Features for Energy-Efficient Residential Buildings in Tropical Climates: The Context of Dhaka, Bangladesh"*, Unpublished M. Arch Thesis, KTH, Department of Urban Planning and Environment Division of Environmental Strategies Research.

8. Ahsan R.M.; 1991; Changing Pattern of the Commercial Area of Dhaka City; Dhaka Past,Present & Future; in Ahmed.S.U. (Ed.);The Asiatic Society of Bangladesh.

9. Al-Masrani, S.M., Al-Obaidi, K.M., Zalin, N.A. and Isma, M.A., 2018; Design optimization of solar shading systems for tropical office buildings: Challenges and future trends. *Solar Energy*, *170*, pp.849-872.
10. Aman, J., 2017. Impact of windows for daylighting on thermal comfort in architecture design studios in Dhaka (M.Arch. Thesis). Bangladesh University of Engineering and Technology, Dhaka. http://lib.buet.ac.bd:8080/xmlui/handle/123456789/4835
11. Amin, A. 2019, *"Façade design for energy-efficient buildings: analysis of architectural façades through functionality and simplified forms approach",* The Architectural Science Association (ANZAScA).
12. Beizaee, A., Firth, S., Vadodaria, K. and Loveday, D., 2012, "*Assessing the ability of PMV model in predicting thermal sensation in naturally ventilated buildings in UK".*
13. Betancur, J., 2017. Multitasking façade: how to combine BIPV with passive solar mitigation strategies in a high-rise curtain wall system. *International Journal of High-Rise Buildings*, *6*(4), *pp.307-313*.
14. Change, N. G. C.(2020). Causes of Climate Change
15. De Dear, R. and Brager, G.S., 1998. Developing an adaptive model of thermal comfort and preference.
16. *Dhaka Building Construction Act, 2008*, Government of Bangladesh, Ministry of Housing and public works, Dhaka
17. Double-Skin Façade System: Materials, Advantages & Examples. (2017, November 9). Retrieved from https://study.com/academy/lesson/double-skin-fa-ade-system-materials-advantages-examples.html.
18. Faisal, G., & Aldy, P. (2016, April). Typology of building shading elements on Jalan Sudirman corridor in Pekanbaru. In *IOP Conference Series: Materials Science and Engineering* (Vol. 128, No. 1, p. 012029). IOP Publishing.
19. Feriadi, H. 2003, *"Thermal comfort for natural ventilated residential buildings in the tropical climate"*, Unpublished PhD Dissertation, National University of Singapore.

20. Haase .M.Amato, 2006; *"A Sustainable Facade Design for Zero Energy Buildings in the Tropics"*, presented at 23rd Conference on Passive and Low Energy Architecture(PLEA) , Geneva, Switzerland.

21. Hossain, N.; 2001; The Socio-Spatial Structure of Spontaneous" Retail Development in Dhaka City; Unpublished PHD Dissertation; Faculty of the Built Environment; Bartlett School of Graduate Studies, UCL; London, UK.

22. Islam, N.; (1996); Dhaka from city to megacity ; Urban Studies Programme ; Department of Geography; University of Dhaka.

23. Izzet Yüksek and Tülay Tikansak Karadayi, 2017; "*Energy-Efficient Building Design in the Context of Building Life Cycle, Energy Efficient Buildings*," Eng Hwa Yap, IntechOpen , DOI: 10.5772/66670. Available from: https://www.intechopen.com/chapters/53557 (January 18th 2017)

24. Kim, E.B. and Park, J.K., 2014. Proposal for a heat balance model tailored to the Korean Peninsula. *Asia-Pacific Journal of Atmospheric Sciences*, *50*(1), pp.657-667.

25. Koenigsberger, O.H., Ingersoll, TG.; Mayhew, A., Szokolay, S.V.,1973; *Manual of Tropical Housing and Building Design*, Part 1, Orient Long man. *p. 23*

26. Lee, E., Selkowitz, S., Bazjanac, V., Inkarojrit, V. and Kohler, C., 2002. *High-performance commercial building façades*.

27. Leung, T.C., Rajagopalan, P. and Fuller, R., 2013. Performance of a daylight guiding system in an office building. *Solar Energy*, *94*, pp.253-265.

28. M.A.Alghoul, 2011; *"Perspectives of double skin façade systems in buildings and energy saving"*, Renewable and Sustainable Energy Reviews, Vol.15, Issue 3, pp. 1468-1475.

29. M. A. Humphreys and J. F. Nicol, 2002; "*The validity of ISOPMV for predicting comfort votes in every-day thermal environments."* Energy and Buildings 34(6), 667-684

30. Ma, L., Shao, N., Zhang, J. and Zhao, T., 2015. "*The influence of doors and windows on the indoor temperature in rural house*." Procedia Engineering, 121, *pp.621-627.*

31. Markus T A and Morris E N, 1980, “*Buildings, climate and energy* (Pitman)”p 37

32. Ministry of Housing and Public Works, Government of Bangladesh. Building Construction Act, 2008

33. Nikolaou, T., Kolokotsa, D., Stavrakakis, G., Apostolou, A. and Munteanu, C., 2015 ; “*Managing indoor environments and energy in buildings with integrated intelligent systems.”* Springer International Publishing.

34. Oesterle, Lieb, Lutz, Heusler. 2001, *Double-Skin Facades:Integrated planning* , Munich: Prestal Verlag.

35. Oh, S.H., 2020. Curtain wall facades on the new generation of supertall buildings present and future directions. *International Journal of High-Rise Buildings*, *9*(2), *pp.124*

36. Parkinson, T. and de Dear, R., 2017. Thermal pleasure in built environments: spatial alliesthesia from air movement. *Building Research & Information*, *45*(3), pp.320-335.

37. P.O. Fanger.,1970.; *“Thermal Comfort: Analysis and Applications in Environmental Engineering.”* Newyork: McGraw-Hill Book Company.

38. Rahman, A. 2007*; Performance evaluation of shading devices used in tall buildings of Dhaka city*, M.Arch thesis, Department of Architecture, BUET, *p. 9.*

39. Santamouris, M, dan Asimakopoulos, D. 1996; “*Passive Cooling of Buildings*”, James & James, Universitas Michigan

40. Syma . H . Trisha, ZN Ahmed, 2016; *“Light Zones vs. HVAC Loads: evaluating energy efficiency for shading devices in commercial buildings”*, in 32nd International Conference on Passive and Low Energy Architecture (PLEA) Los An.geles, Cities , Buildings , People: Towards Regenerative Environments, Vol. 1

41. Tariq, S.H., 2016;” *Investigation on energy consumption for thermal comfort with respect to plan layout of residential apartment buildings in Dhaka”,* lib.buet.ac.bd.

42. Tartarini, F., Schiavon, S., Cheung, T. and Hoyt, T., 2020. CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX*, *12*, p.100563.
43. Trisha, S. H. 2015, *"Assessment of HVAC load in light zones to determine energy efficient shading for tall office buildings of Dhaka"*, M. Arch. Thesis, (unpublished), Department of Architecture, Bangladesh University of Engineering and Technology, Dhaka.
44. United Nations Environment Program, 2009;*"Buildings and climate change-summary for decision makers"*, UNEP DTIE, Sustainable Consumption & Production Branch, France.
45. Yeang, K., 1997; "*Designing the Green Skyscraper";* In Proceedings of the Third International Conference on Conquest of Vertical Space in the 21st Century, London *p. 12-18*
46. Yeang, K. , 1990; *"Designing the Green Skyscraper",* In Proceedings of the Fourth World Congress on Tall Buildings: 2000 and Beyond, Council for Tall Buildings and Urban Habitat, Hong Kong. *p. 113-115*
47. Zain, Z.M., Taib, M.N. & Baki, S.M.S , 2007, "*Hot and Humid Climate: Prospect for Thermal Comfort in Residential Building"*, *Desalination*, 209(1-3): 261-268.

Appendices

Appendix A: Key Terms and Concepts

Terminology of Glass Properties

Transmittance -Transmittance (T) is the fraction of incident light which is transmitted. In other words, it's the amount of light that "successfully" passes through the substance and comes out the other side. It is defined as T = I/Io, where I = transmitted light ("output") and Io = incident light ("input").

U-Value-One of the most important glass performance measures is U-value—also known as U-factor—which measures the insulating characteristics of the glass, or how much heat flow or heat loss occurs through the glass due to the difference between indoor and outdoor temperatures. U-values measure how effective a material is an insulator. The lower the U-value is, the better the material is as a heat insulator.

Reflectance-The reflectance of a material is the ability of the material to reflect the energy incident on its surface. The reflectance of a material is determined when light and solar radiation is incident on the surface of the material. This value can be used to describe the nature of a surface in terms of the surface finish. Reflectance may also be known as reflectivity.

Solar heat gain co-efficient- Solar heat gain coefficient (SHGC) is the fraction of solar radiation admitted through a window, door, or skylight -- either transmitted directly and/or absorbed, and subsequently released as heat inside a home. The lower the SHGC, the less solar heat it transmits and the greater its shading ability.

Shading coefficient-Shading coefficient (SC) is a measure of thermal performance of a glass unit (panel or window) in a building. It is the ratio of solar gain (due to direct sunlight) passing through a glass unit to the solar energy which passes through 3mm Clear Float Glass. (Source Wikipedia)

Appendix B: Meteorological data of Dhaka

B1: Monthly Normal Humidity, 2019

Monthly Normal Humidity (%)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka	71	64	62	71	76	82	83	82	83	78	73	73
Tangail	80	74	69	74	79	84	85	85	85	83	80	81
Mymensingh	77	72	71	77	81	86	87	86	86	83	79	79
Faridpur	77	72	67	72	79	85	87	85	85	82	78	78
Madaripur	77	72	70	74	79	84	86	85	85	82	78	78
Srimangal	80	73	70	75	80	84	85	85	85	85	82	81
Sylhet	75	68	68	76	81	87	87	86	86	83	77	75
Bogra	77	70	66	72	78	84	86	85	86	82	77	77
Dinajpur	79	70	63	68	76	82	84	84	85	82	78	78
Ishurdi	76	70	63	66	75	83	86	85	85	82	77	77
Rajshahi	78	71	63	65	75	83	87	86	86	83	78	78
Rangpur	82	75	68	74	81	85	86	85	87	84	80	81
Sayedpur	78	70	63	70	77	82	83	83	83	80	75	76
Chuadanga	78	72	65	68	74	83	86	86	86	83	78	78
Jessore	77	72	69	72	77	84	87	86	86	83	79	78
Khulna	78	74	73	76	79	85	87	86	87	84	80	79
Mongla	75	73	73	77	80	86	88	88	88	85	80	77
Satkhira	74	71	69	72	75	82	85	85	86	82	77	75
Barisal	81	78	76	80	83	88	90	89	89	87	84	83
Bhola	81	77	77	81	84	88	90	89	89	86	83	82
Khepupara	76	75	76	79	81	86	88	87	87	85	81	78
Patuakhali	78	76	76	81	83	88	90	89	89	86	82	80
Chandpur	78	73	73	77	80	85	86	85	85	82	78	78
Ambagan(Ctg)	73	66	70	77	80	86	87	86	85	84	79	77
Chittagong	73	70	74	77	79	83	85	85	83	81	78	75
Comilla	77	75	77	81	82	86	87	86	86	84	80	79
Cox's Bazar	72	71	75	78	80	87	89	88	86	82	77	74
Feni	76	73	74	79	81	85	87	86	86	84	80	78
Hatiya	76	74	76	79	82	87	89	88	86	84	80	79
Kutubdia	75	75	80	81	81	86	88	87	85	83	79	76
Maijdi Court	79	76	76	78	81	86	88	87	86	83	80	80
Rangamati	77	69	67	72	78	84	85	85	85	84	82	81
Sandwip	79	77	79	82	84	88	90	89	88	85	82	81
Sitakunda	75	72	74	78	81	85	87	86	85	83	80	78
Teknaf	69	68	73	77	81	88	90	89	87	83	77	71
Country	76	72	71	75	79	85	86	86	85	83	79	77

Bangladesh
Meteorological
Department

Appendix C: Simulation Raw Data

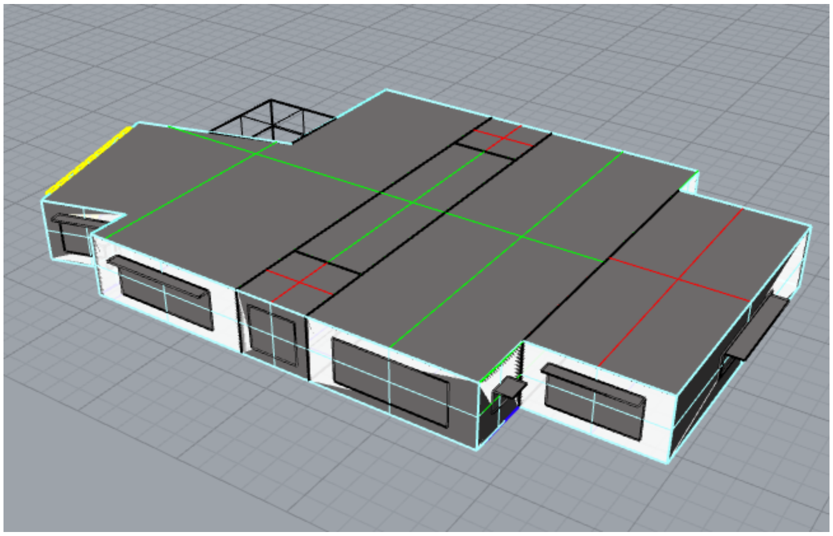


Figure-A1: 3D modelling of Existing casing building using software

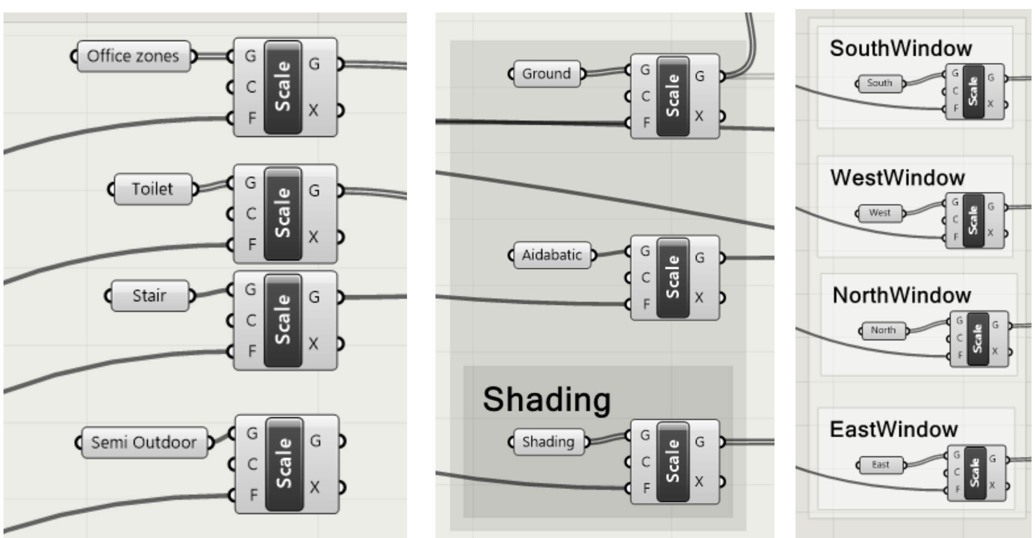


Figure-A2: Different zone setup using software

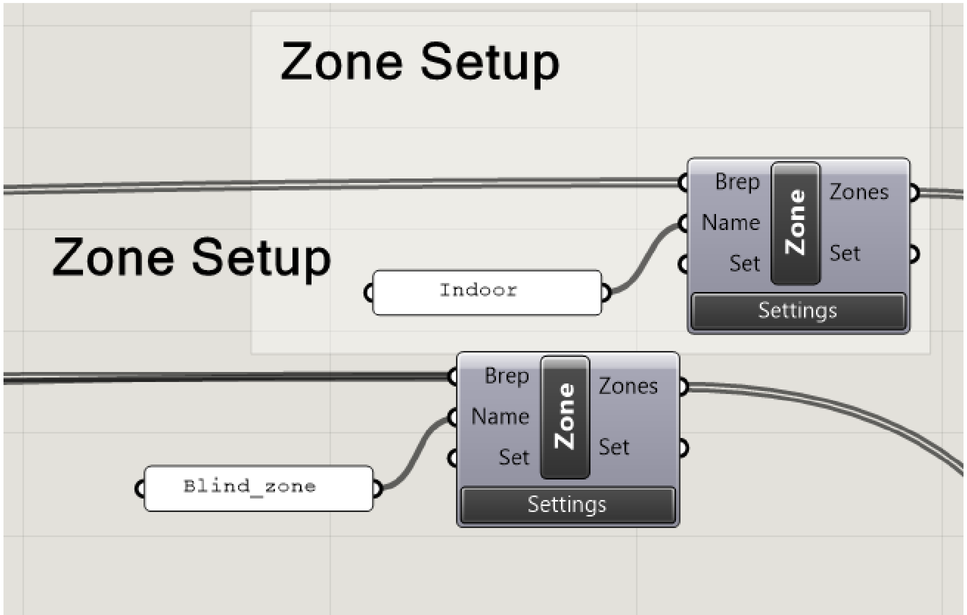


Figure-A3: Zone setup according to type and use (using software)

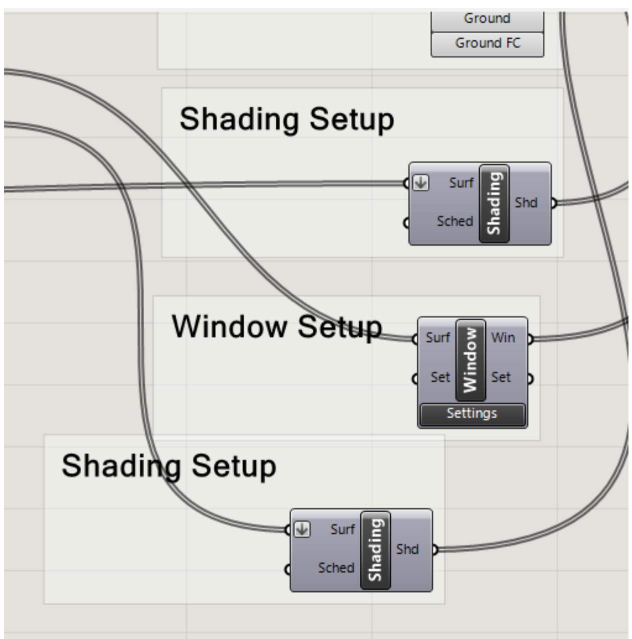


Figure-A4: Designed Shading Output (using software)

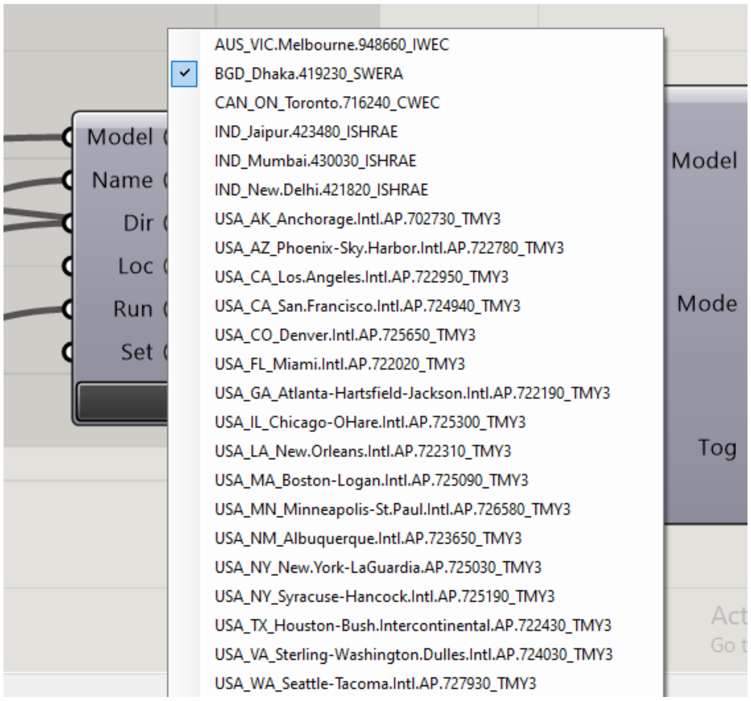


Figure-A5: Weather data for input in software

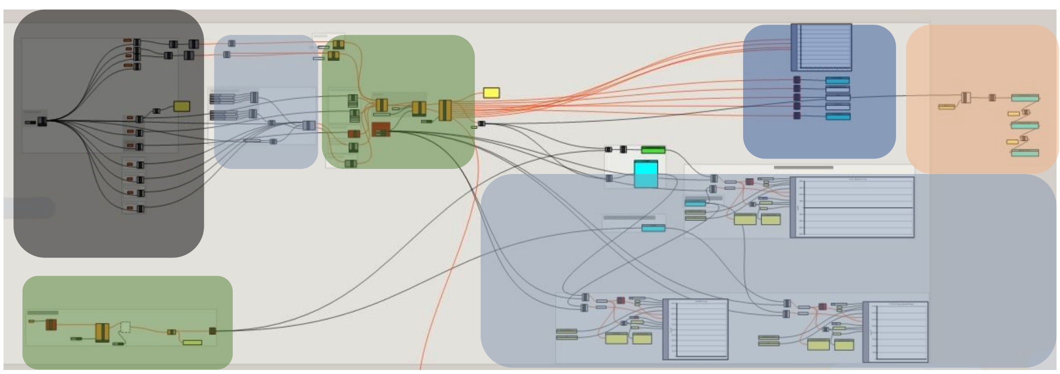


Figure-A6: Diagram showing all data connected after input for simulation

Appendix D : Sample questionnaire

Questionnaire Survey to assess thermal preference of users' of west facing offices in Dhaka

Name:
Gender:
Age:
Date:
Time:

Location of Floor:
Type Of opening : Fixed/Operable
Orientation:

Put a tick mark on the correct box.

1.How many years have you been working in this building?

☐ Less than 1year ☐ 1-2y ears

☐ 3-5years ☐ More than 5years

2.**Which of the following do you use to adjust or control your office environment? (You may tick more than one option)**

☐ Window blinds or shades

☐ Room air-conditioning unit ☐ Portable fan

☐ Ceiling fan ☐ Other

☐ Windows

If other please describe____

5.Which of the following ventilation system does the office support?

☐ Natural Ventilation ☐ Mechanical Ventilation ☐ Mixed-mode(combination of natural and mechanical system)

If your office has mixed-mode system then select your preferable means of cooling:

☐ Ceiling fan and Air-conditioner ☐ Ceiling Fan and windows open

☐ Only Air-conditioner ☐ Only ceiling Fan

7.Is the air-conditioning unit always on?

☐ **Yes** ☐ **No**

8.What is your preferable temperature range when the air-conditioner is on?

☐ **18°-22°C** ☐ **22°-26°C** ☐ **above 26°C**

9.Do you often pull the blinds during the working hours?

☐ **Yes** ☐ **No**

10.How would you describe the weather outside today?

☐ Clear skies/sunny ☐ Overcast

☐ Partly cloudy

11.How satisfied are you with the temperature in your office today?

Very Satisfied ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very Dissatisfied

If you are dissatisfied, how would you best describe the source of your discomfort?

☐ Too much air movement ☐ Not enough air movement ☐ In coming sun

☐ Drafts from windows ☐ Drafts from vents

☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)

☐ Heating/cooling system does not respond quickly enough to the thermostat

☐ Other. Please Describe:____

12.Clothing: Please place a check by the articles of clothing that you are wearing

☐ ShortSleeveShirt and pant ☐ Sharee

☐ LongSleeveShirt and pant ☐ Others

☐ SweaterVest and pant

☐ SuitVest and pant

☐ Salwar Suit

☐ Jeans and tops

☐ T-shirt and pant

13.Do you feel hot due to your clothing?

☐ **Yes** ☐ **No**

14.How would you describe your activity level just prior to completing this survey?

☐ SeatedQuiet ☐ StandingRelaxed ☐ Light Activity,Standing

☐ Medium Activity,Standing☐ HighActivity

15.In the winter months, how satisfied are you with the temperature in your office?

VerySatisfied ☐ ☐ ☐ ☐ ☐ ☐ ☐ VeryDissatisfied

If you are dissatisfied, how would you best describe the source of your discomfort? (check all that apply)

☐ Too muchair movement ☐ Not enoughairmovement ☐ Incomingsun

☐ Draftsfrom windows ☐ Drafts fromvents

☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)

☐ Heating/cooling system does not respond quickly enough to the thermostat

☐ Uneven temperature (some parts always hot while others always cold)

☐ Other. PleaseDescribe:____

16.**In the summer months, how satisfied are you with the temperature in your office?**

VerySatisfied ☐ ☐ ☐ ☐ ☐ ☐ ☐ VeryDissatisfied

If you are dissatisfied, how would you best describe the source of your discomfort? (check all that apply)

☐ Too muchair movement ☐ Not enoughairmovement ☐ Incomingsun

☐ Draftsfrom windows ☐ Drafts fromvents

☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)

☐ Heating/cooling system does not respond quickly enough to the thermostat

☐ Uneven temperature (some parts always hot while others always cold)

☐ Other. PleaseDescribe:____

17.Give suggestions how can the indoor thermal condition can be improved for better working output?

____

____

____

____