EFFECTS OF BALCONIES ON DAYLIGHTING APARTMENT BUILDINGS IN CONTEXT OF DHAKA

By

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Dedication to My Parents

Md. Feeroz Kabir and Mrs. Salma Feeroz

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Abstract

Daylighting is an essential passive strategy which helps to reduce the consumption of electricity or reliability on artificial lighting, and positively enhances wellbeing of building occupants. Inefficient design of buildings, surrounding conditions and presence of natural and manmade obstructions are often the main issues for inadequate daylighting inside the buildings. In addition, the topography, the geographical condition of the site and its regional conditions of weather have direct impact on interior daylight potential. Though inviting daylight in indoor space is a challenge, control of glare is vital in daylighting design. Balcony is a transition space which can invite glare free daylight in indoor space. By exploring balcony design, effective daylighting for interior space could be ensured.

This research has examined the notable impact of balconies on daylighting performance of the balcony adjacent bedrooms of high-rise apartment buildings by using simulation program. Daylight simulation is performed by creating a virtual room with an attached balcony based on information from a real-world apartment building in Dhaka. 3D models are created for computer simulation to calculate the amount of daylight incident on a generated grid point on the work-plane. To generate realistic lighting levels, these models are then exported to RADIANCE Synthetic Imaging software and finally analyzed with DAYSIM simulation program for annual performance evaluation.

The results reveal that the balcony patterns have a significant impact on daylight penetration to the adjacent interior space, as well as the indoor illuminance and luminance distribution. The balcony with 915mm railing height with a drop ended at 2150mm from finished floor level is found to be the most practicable configuration for daylight penetration among the studied configurations. Based on the findings of simulation studies sliding glass openings with a light shelf outer depth equal to balcony depth and an internal depth of 500mm performs better compared to only punched or sliding door on the adjacent wall to the balcony. It is also discovered that when balconies are placed one above another in each floor outperforms the type when balconies are placed in zig-zag pattern on building elevation. After finding the best balcony depth 1370mm, the floor and facade materials were discovered to be silver glossy tiles flooring (reflectance 90) and blue color (reflectance 20) indoor walls. Finally, when these are taken into account, the recessed balcony outperforms over cantilever and semi-recessed balcony types. The study emphasizes the performance of daylight in indoor spaces by altering balcony features design, while also providing a basic framework for judging daylight design principles.

Keywords

Balcony Design, Daylighting, Dhaka City, Facade Treatment, Glare, Apartments, Computer Simulation, Light Shelf.

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List of Abbreviations

ADE	Annual Daylight Exposure
AGS	Architectural Graphic Standards
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BUET	Bangladesh University of Engineering and Technology
CBDM	Climate-Based Daylight Modelling
CIBSE	Chartered Institution of Building Services Engineering
CIE	International Commission on Illumination
CRI	Color Rendering Index
DA	Daylight Autonomy
DF	Daylight Factor
DA_{max}	Maximum Daylight Autonomy
FAR	Floor Area Ratio
IEA	International Energy Agency
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IRC	Internally Reflected Component
ISO	International Organization for Standardization
LRV	Light Reflective Value
Lx	Lux
MGC	Maximum Ground Coverage
NCF	Net Concrete Finish
RAJUK	Rajdhani Unnayan Kartripakhya
UDI	Useful Daylight Index
INB	Imarat Nirman Bidhimala

CHAPTER ONE: INTRODUCTION

1.1 Preamble

Daylight is an essential part of building design. Daylight can influence task management, productiveness (Kilic and Hasirci, 2011; Othman and Mazli, 2012), sense of prosperity, comfort, improved mental and physical conditions, well observation of space, perceptions of organization, emotions, users' nature and experiences (Sufar et al., 2012), and therefore is a crucial aspect in building design (Ahmad and Razon, 2017). Though daylighting is a primary light source of a building but excessive daylight should be avoided to protect against excess heat and glare. Placement of a balcony beside a room could work as shading against excessive daylight and can protect from excessive heat. The balcony also connects individuals with surrounding neighborhoods. By changing the balcony features, the lighting performance of indoor spaces could be enhanced.

One of the major reasons for inadequate daylighting inside buildings is the narrow spacing of surrounding built structures or insufficient gaps between two buildings. Not following the floor area ratio (FAR) rules could also be claimed to get fewer opportunities to invite daylighting inside and it also varies for different floor levels and external obstructions (Xue et al., 2016). Eventually, the intention of accommodating many people in a limited space is also a reason behind poor lighting conditions. Among so many other cities; Dhaka, the capital of Bangladesh is one, where many people use to live for better living conditions and its impact directly hit upon the land. To overcome this scenario alternative ways, have to be find out.

Daylight serves to improve the indoor environment as well as save energy utilization (Ullah, 2014). Dhaka consumes 46% of the total electricity in Bangladesh and residential buildings consume 55% of the total energy in Dhaka (DESCO, 2021). Deprivation of daylight creates additional energy demands by increasing the use of supplementary artificial lighting, which needs to be avoided (Islam, 2011). Several studies show that with advanced lighting sources, design strategies, and controls electrical lighting energy use can be reduced by 25-50% and by 75% with the addition of daylighting (Clanton and Nancy, 2004). Moreover, daylight has many positive influences, on health (e.g., feelings and emotions) which improves body structures besides energy saving. Undoubtedly, natural light is one of the primary components of a healthy atmosphere. With optimum use of natural light, visual comfort can be ensured as well as human requirements, e.g. safety, comfort visibility, health, activity, social contact, aesthetic appreciation, and communication can be fulfilled (Kim and Kim, 2010).

To welcome more daylight penetration through balconies could work effectively. Appropriate design by changing some configurations of balconies, the performance of daylight penetration in indoor space can be improved.

1.2 Problem Statement

In 2001, Dhaka had overloaded with more than 12 million people for the larger contribution and across 6 million inhabitants within the central city area (Islam, 2005). Since the 1970s, the city had faced a housing lack due to the increase in population (Ahmad and Razon, 2017). Thus, the scarcity of land in Dhaka results in closely built apartments on small plots (Kamruzzaman and Ogura, 2007).

Within a short period, the housing culture has changed. The traditional custom houses had been replaced by several types of indigenous origins. Living in multi-storied apartments is a new phenomenon for the community of Bangladesh. The apartments are constructed on smaller plots having lower set-back areas between two adjacent buildings. Most of the existing residential buildings in Dhaka did not follow setback rules and building codes set by RAJUK and also neglected surrounding socio- cultural city effects (Iqbal, N., 2015). Hence, the daylight provision of the interior spaces from the sideways of the buildings is being compromised. Due to coping with poor daylighting, artificial lights are often needed in the daytime which is not a good practice. To minimize the use of electricity conservation, it is necessary to demonstrate such ways that the building's occupants get the maximum glare-free daylight.

Adding a balcony could work as a filtering space for entering daylight and purify the air. Heating and cooling loads can be reduced from indoors by integrating a balcony (Angeraini, 2016). In addition, a balcony could increase planting space and improve visual inception. It can act as an overhang and provide solar shading as well as electricity-saving air-conditioning (Chan et. al., 2010). Moreover, a balcony with a high sliding glass door opening beside the bedroom of apartment buildings is common. It enhances the natural ventilation in indoor spaces by increasing airflow. Hence, by changing the balcony pattern, lighting performance could be improved and some modifications in facade material and the indoor wall beside the balcony could work effectively for better daylight penetration.

As Bangladesh is a tropical country, the summer heat is often uncomfortable. With appropriate balcony design, heat transmission could be moderated and proven as an effective way to get relief from direct solar radiation into indoor spaces. For shading south-facing windows, a simply fixed overhang is effective in summer when sun angles are high but the same horizontal element is ineffective at blocking low afternoon sun entering from west windows during peak heat gain periods in the summer. In previous studies, it was found that in many countries, inappropriate design of balconies increased energy consumption by 200%, while using appropriate design can save energy up to 40% with unheated balconies and up to 28% with heated balconies (Catalina et al.,2022). The Bangladesh Government has also taken many initiatives to encourage builders to integrate more environmental features into building projects and incorporating balconies is one of them. In the residential project development, there is a rule for additional balcony area as a percentage of total floor area and flexibility to exclude the balcony area from the floor area during FAR calculation.

Many investigations are done to find out the advantages of balcony space, conjugate execution of balcony, opening form, diversity, and internal division on the airflow of indoor (Prianto and Depecker, 2003). The reduction of exterior noise and its effect on balcony design by field measurement, scaled model, and computer simulation were investigated (Kim and Kim, 2007; Lee et al, 2007). Some research has also examined the reduction of vertical flame spread due to the presence of a balcony in high-rise apartment fires and varying the geometry of the balcony and depth to an optimum configuration was identified to reduce the spread of vertical fire on the exterior wall of building (Ribeiro,2020). Ribeiro (2020) has also done a review on balcony types available till 2020 and evaluated acoustic comfort, air quality, thermal comfort and visual comfort; however, study on balcony space effect on indoor daylighting of apartments are rare. Under a tropical weather conditions, such as Dhaka, little or no comprehensive research has been done yet for exploring the glare-free daylight penetration by adding a balcony into the apartment building and saving the energy of indoor spaces.

1.3 Aim and Objectives

The research aims to identify daylighting performance inside indoor spaces under different configurations of balconies in the context of Dhaka.

To achieve this aim, following objectives have been developed.

Objective 1: To determine the effectiveness of different balcony types as screening and shading elements to enhance indoor daylighting for apartment buildings in Dhaka.

Objective 2: To investigate the role of various design parameters e.g. railing height, drop level, depth, material, color, placement and types of balconies to enhance the daylight performance in adjacent bedrooms.

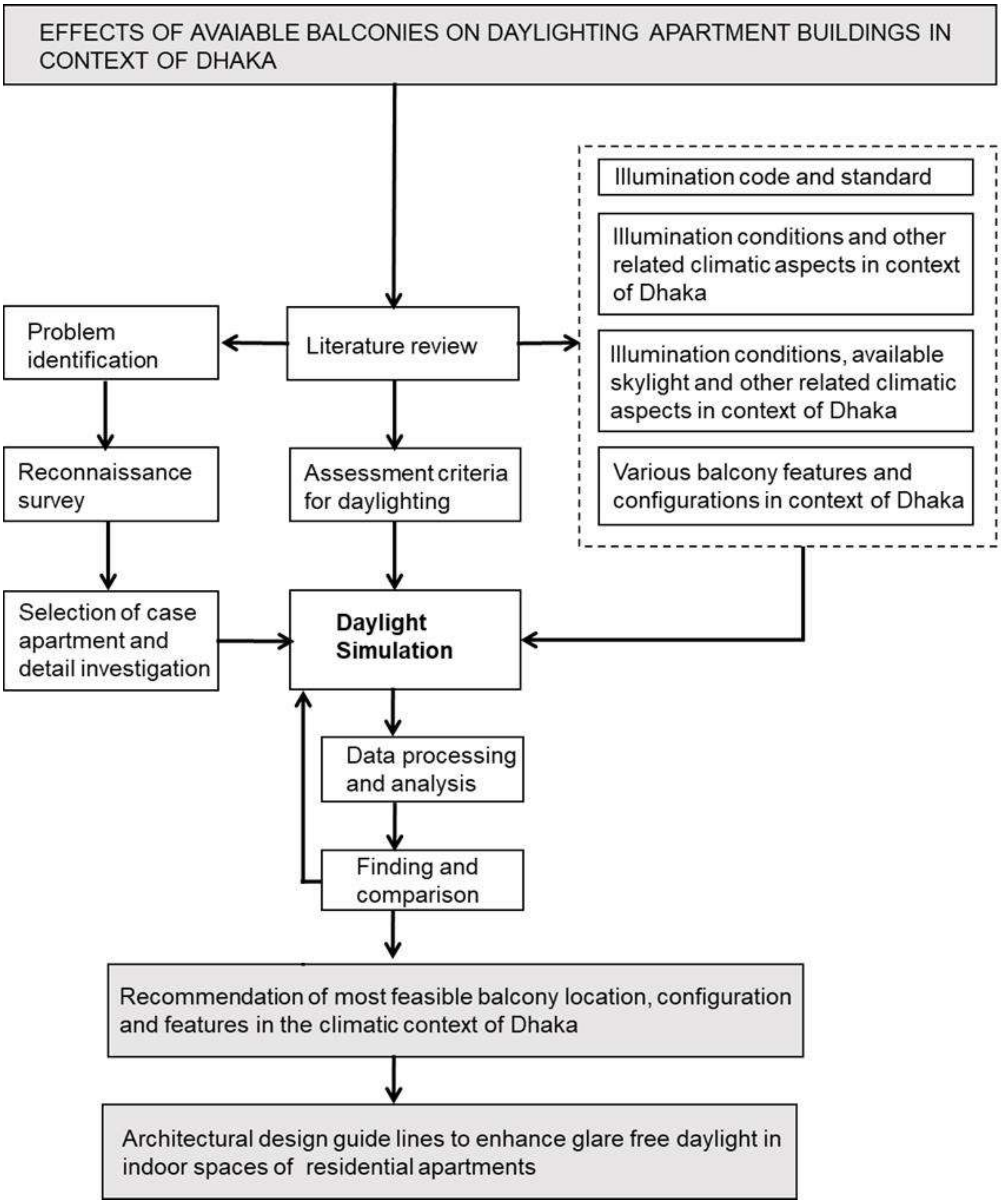
1.4 Overview of the Research Methodology

A detailed description of the research methodology, used for this research, has been discussed in Chapter 3. This section provides a brief overview of the research methodology for the thesis. Figure 1.1 shows a flow diagram of the research process, which integrates the main research methods: literature review, selection of case space and simulation analysis.

To gain knowledge and gather information on balcony patterns of apartment buildings in Dhaka a literature survey is done. Moreover, previous studies on national and international illumination standards; balcony design standards according to the national building code and the climatic context of Dhaka are studied to understand the nature of the expected luminous environment in indoor spaces inside apartments. Literature survey helps to compile the information on the balcony and their features that help to enhance glare-free daylight penetration inside indoor spaces of apartments.

A survey was conducted on apartments mainly focusing on available balcony types which were within 74.32 sqm (800 sft) to 185.8 sqm (2000 sft) floor area apartments. Generally, middle-income people live there. Middle-income people were targeted for study because 58% of the population of Dhaka is in this group (Islam, 2005). Four types of balconies are targeted which are different from each other by pattern and size (Figure 3.11 to 3.14).

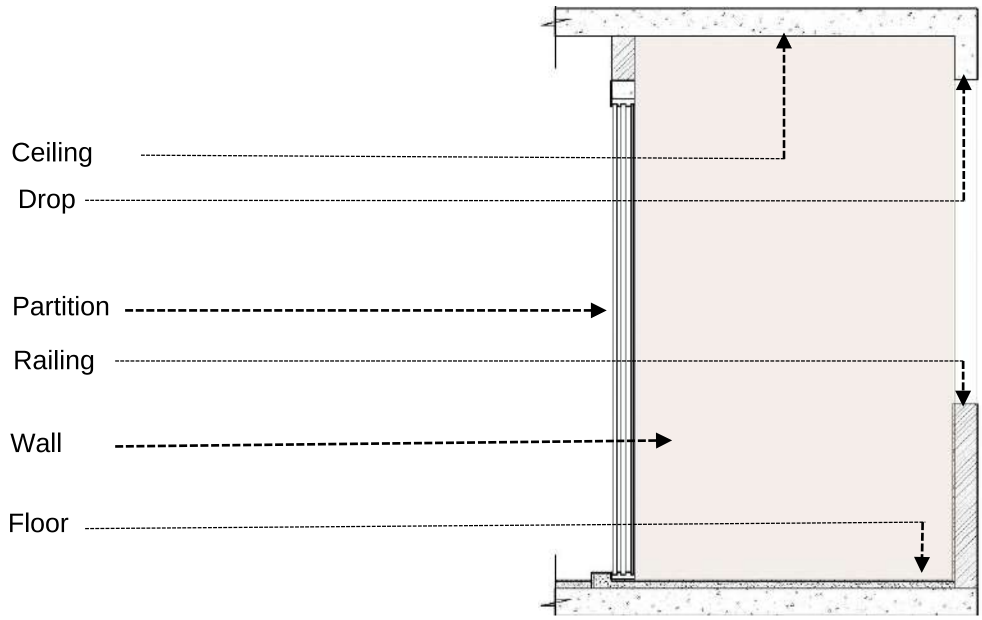
The criteria of case space selection are set from four surveyed apartments based on the available balcony patterns of Dhaka. An apartment with an attached balcony adjacent to the bedroom are selected as a case apartment based on the selection criteria which was used for simulation analysis later.



Figur 1. 1: Flow diagram of the research process

Literature survey helps to collect information on the local types of balconies, their merits, demerits, and the importance of balconies in high-rise apartment buildings. Eight balcony design variables are investigated with different railing heights, drop levels, partition walls, floor depths, floor materials, facade color (Figure 1.2) placements (Figure 4.10) and balcony types (Figure 4.22) by simulation study under the climatic context of Dhaka. Climate Based Daylight Modeling (CBDM) is done by using RADIANCE and DAYSIM software.

Conclusively, the experiences of the simulation study are compiled to recommend architectural design guidelines to ensure glare-free daylighting condition of indoor spaces of apartment buildings through balcony design in the climatic context of Dhaka.



Figur 1. 2: Variables of balcony design

1.5 Scope and Limitation of the Research

This investigation focused on the strategies and recommendations that could be applied by simple modification of existing or newly formed balcony to improve indoor lighting condition of apartment buildings in this tropical region that can be incorporated easily.

Excessive daylight may cause unwanted heat and too much daylight could be a reason for glare. This investigation also keeps fixing the attention to strategies for the prevention of glare. Apart from improving the luminous environment, daylight inclusion is also related to aesthetics, heat loss and gain, energy consumption (electric lighting, mechanical heating and cooling), economies, sound transmission, ventilation, safety, security and subjective concerns of privacy and view. For time restrictions and resource restrained for the research, the consequence of daylight inclusion on mentioned concerns are beyond the scope of this thesis. The present work fix attention mainly on how the balcony features (e.g., railing height, drop level, partition type, floor material, wall color, balcony depth and balcony types) help to ensure effective daylighting in indoor spaces.

1.6 Structure of the Thesis

Five chapters describe this thesis and this section provides an overview of the chapters (Figure 1.2).

Chapter 1 is an introduction to the thesis; describes subjects that might be necessary for understanding this research, problem statement with the aim, objectives, brief methodology, scope of the research and limitations.

Chapter 2 focuses on the outcome of the literature review, based on established research and published sources, to provide a knowledge base for this research, which also helped to fix attention on the concerns on which the simulation is conducted later.

Chapter 3 elaborates the detailed steps of the methodology of this research. It also describes the criteria for the selection of the case space for the simulation study. This chapter also accommodates a general climatic overview of Bangladesh based on published data (e.g., different published books and papers). It considers the case area of this thesis, i.e., Dhaka. The goal is to study an environmental database for simulation study to consider the whole year for dynamic daylight simulation.

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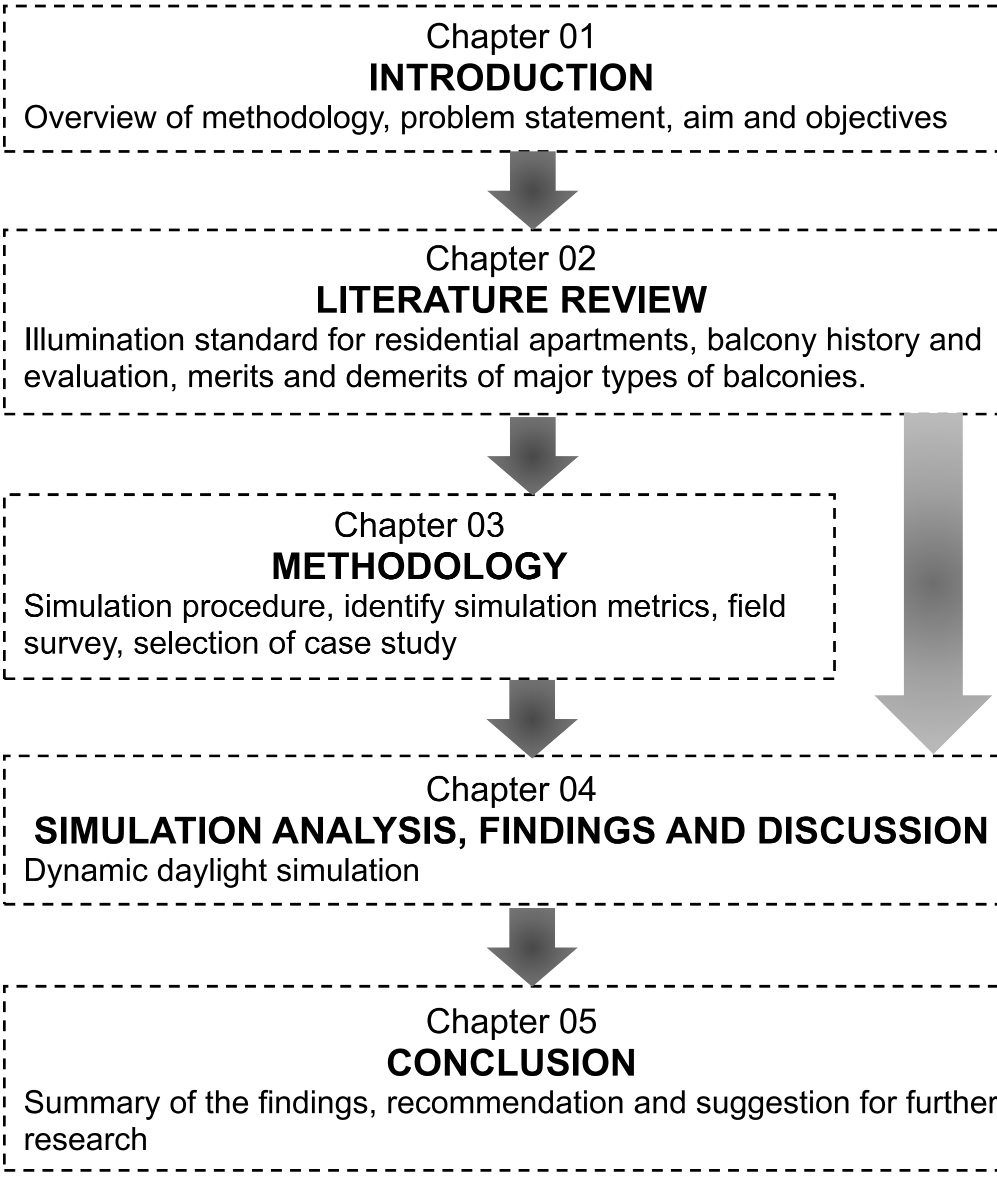


Figure 1. 3: Organization of the chapters and structure of the thesis

Chapter 4 describes the details and output of the simulation exercise in four major parts. At first, simulation is done to evaluate the daylighting performance of different heights of the balcony railing and find out the most feasible one. By fixing the most feasible railing height constant; in the second part, a simulation analysis is conducted with different drop levels for indoor daylighting performance. After fixing the railing and drop levels; in the third part, simulation analysis is conducted by introducing a light shelf with the wall between balcony and adjacent bedroom. In the fifth stage, balcony placement, depth, material for floor and facade color are fixed. After fixing the above in the last phase simulations are conducted to find out the most feasible balcony types for bedrooms facades to accommodate the glare-free daylight penetration in adjacent indoor spaces in Dhaka.

Chapter 5 summarizes architectural design strategies for balcony design to achieve a glare-free daylighting condition in balcony adjacent bedrooms (indoor spaces) in the climatic context of Dhaka. This chapter also compile some recommendations and directions to guide future researcher.

1.7 Summary

The research started to overcome some constraints mentioned in Section 1.2. The gradual development of the research from the literature review and incorporation of research findings at each stage made the objectives, methodology and limitations of the research more defined, refined and detailed. A summary of the key findings of the research concerning the objectives, methodologies and concerned chapters are presented in Appendix A.

CHAPTER TWO: LITERATURE REVIEW

2.1 Preamble

The research is introduced in the first chapter. This chapter covers the findings of the literature review in order to provide the foundational knowledge needed to investigate the impact of balconies and balcony features on improving indoor glare-free daylighting in apartment buildings in Dhaka. This chapter is divided into five parts. The first part emphasizes the importance of daylight and its components in integrating successful daylighting into indoor settings and significance of indoor daylight penetration with glare issue. The second part figures out the design strategies for daylighting penetration in indoor areas. The third part elaborates on the positive effects of balconies, their history and usefulness of balconies in tropical areas, i.e. Dhaka. The fourth part figures out the relationship between balcony and energy consumption, and positive effects of a balcony. The last part discusses about the national and international standards for balcony design and daylight illuminance for routine tasks in indoor spaces. At the end of the chapter, the key findings are marked up. The next chapter (Chapter 3) describes the methods for simulation studies and field survey considering the findings from this chapter.

2.2 Daylighting Source and Components

Designing daylight has become a top priority in response to the growing need for healthy and energy-efficient structures. The term "daylight" refers to the mix of direct sunlight and diffuse skylight (Wong, 2017)

One of the main reasons for the desire for sunlight is that it produces sensations of warmth and pleasantness (Hopkinson et al.,1966). The preference for sunshine varies on the climatic conditions. People who live in cooler climates may have a greater demand for sunshine than people who live in milder or warmer climates (Hopkinson et al.,1966).

Numerous surveys conducted around the world have evidenced individuals' preference for daylight in their homes and workplaces (Boubekri, 2004). The nature of daylight sources further complicates standardization. It is dynamic, constantly changing in terms of intensity and color and often unpredictable and unreliable (Boubekri, 2004). With appropriately installed and maintained daylighting systems, daylight has been proved to be beneficial for the health, productivity, and safety of building occupants (Edwards and Torcellini, 2002).

2.2.1 Sources of Daylight

Effective daylight is an important criterion for building design. Daylighting is an essential factor in space design. It is a gift of nature and there are special advantages of daylighting (Hopkinson et al., 1966). The sun is the source of daylight. The sun`s path influences how much sunshine is available at any given building location. The solar altitude and solar azimuth are the two angles that can be used to determine the position of the sun at a given point on the earth's surface (Figure 2.1). The three situations to consider in daylight design are an overcast sky, a clear sky, and a partially cloudy sky, according to the IESNA Lighting

Handbook (IESNA, 2000). The available daylight that can replace artificial light is both direct sunlight and diffuse light from the sky.

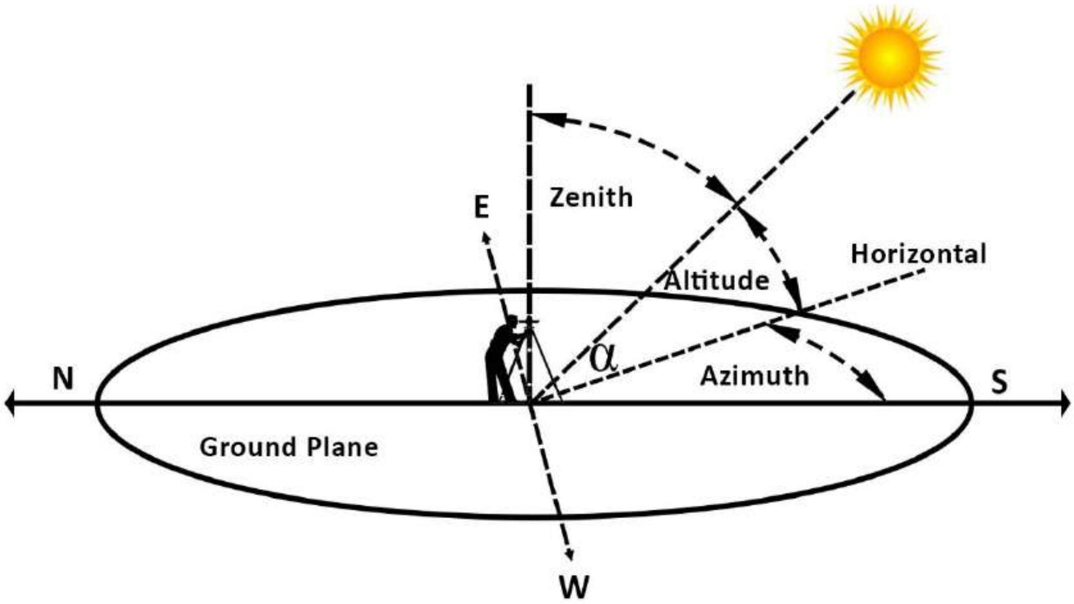


Figure 2. 1: Solar angle of altitude

As the day advances, daylight coming via windows under clear conditions can illuminate an inside spot from five separate sources. The sun, the circum-solar sky, the earth, opposite surfaces, and the blue sky are those to which light enters downwards, upward, and horizontally (Evans, 1980). The amount of light from the sun and the sky for a certain location, time, date, and sky condition is referred to as "daylight availability". The effects of latitude, climate, and building orientation have to be considered during daylight design (IEA, 2000). Since 1991, data on daylight availability has been collected every minute at more than 50 stations around the world and has also been monitored in the Meteosat satellite every half hour from 1996-1997 (under beta testing) (Sharmin, 2011).

2.2.2 Components of Daylight

There are three components of daylight. The light from the sky that reaches a specific position in a room is made up of three separate components, as listed below.

a. Sky component (SC)

b. Externally reflected component (ERC)

c. Internally reflected component (IRC)

These three components are primarily in charge of controlling the amount of daylight in the indoor environment. The following is a detailed discussion of these three components.

a. Sky Component: The sky component (SC) is the illuminance received directly from the sky at a place in the interior of a building. The SC is most commonly used to describe the hazy sky, rather than direct sunlight; i.e., it is not used to describe direct sunlight. The perceived light from this component is smooth and eye soothing. This component requires that the place in the room being considered has a view of the sky. As the point of consideration approaches the window, the view of the sky is larger, and hence it is primarily the sky component that causes the considerable change in light intensity in a side lit room (Figure 2.2). It could work without externally reflected component and internally reflected component.

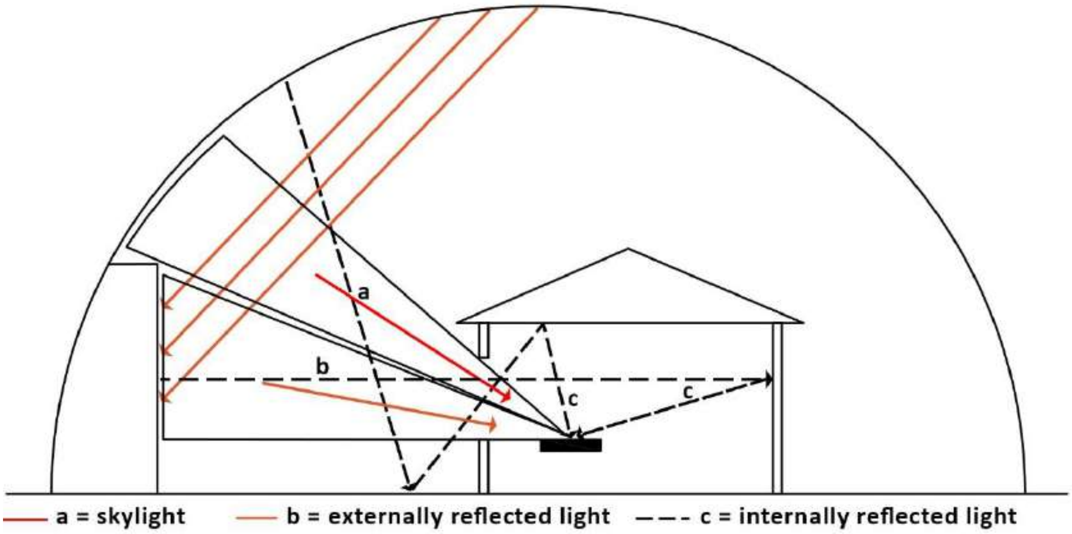


Figure 2. 2: The components of daylight at a point in a room. (after, Koenigsberger, 1975)

b. Externally Reflected Component: The illuminance in the interior caused by light reflected from external barriers is known as the externally reflected component (ERC) (Figure 2.2). The ERC is especially important in densely populated urban areas, where, because of the close proximity of buildings, views of the sky may be limited, if not altogether nonexistent, for all but the most close-to-the-window positions. The ERC will most likely corner at a low angle, close to horizontal. This may penetrate further into the space than the sky component, depending on the reflectivity of the blockage, but it will normally be much weaker due to light absorption by the external obstruction. This component's perceived light is dynamic. It is nearly impossible to visualize anything utilizing only this light without SC.

c. Internally Reflected Component: The illuminance received at a spot is the internally reflected component (IRC), which is made up of light obtained indirectly from daylight that is inter-reflected around the space's internal surfaces (Figure 2.2). Any light reflected from below the horizontal must be reflected a second time on the ceiling or higher walls of the room to illuminate the horizontal (upward-facing) plane, as shown in Figure 2.2, and will therefore end up as the internally reflected component. This component's perceived light is similarly dynamic. It is also hard to visualize anything utilizing only this light without SC.

2.3 Daylighting in Indoor Spaces

In terms of daylighting circumstances in a room and accompanying view connections, the occupant's preference may differ. The colors, nuances and aesthetic elements of the structures buried in the darkness at night are all provided by the light (Abdullayev et al., 2021). The most important luminance interactions when planning daylight is those between the daylight opening and its immediately neighboring surfaces, as well as the surfaces around the work duties. Care must be taken when introducing daylighting to a room; else, unfavorable impacts may result (Tedjokoesoemo, 2015). Furthermore, it can be determined using simple trigonometry that the sun illumination on a horizontal task surface is a sinusoidal function of the sun angle above the horizon. The atmospheric attenuation factor fluctuates with pollution and air moisture content, and these factors affect the level of perceived glare as well. These effects can be overlooked when evaluating how much the set point needs to be changed (Veskovic, 2006).

Individuals' general preferences for the availability of sunlight in their indoor spaces have yet to be translated into building rules that mandate certain amounts of sunlight penetration for specific durations. The dilemma of how to assess the amount of sunshine that enters a structure both quantitively and qualitatively is one of the components that add to the complexity of the problem. The major questions were whether little patches of sunshine (i.e. sparkles) are preferable to massive floods, as well as what the acceptable threshold was. Many architectural elements, such as opening and glazed areas of building envelopes, internal surfaces, and appropriate color use, impact a naturally lighted indoor atmosphere (Tregenza and Wilson, 2013). In internal lighting, the appropriate light will highlight furnishings and accessories, while exterior lighting will reveal our building's values. The type of material utilized, the sort of light it reflects, the angle of this light, and the number of people in the area are all crucial considerations (Abdullayev et al., 2021). While the sort of light utilized in an interior place change depending on the surroundings, individuals' demands may also influence the scenario. As a result, the light reflectance value plays a significant role in the lighting design (Abdullayev et al., 2021). Table 2.1 shows the light reflectance values for interior color. Moreover, consideration of color rendering index (CRI) is also essential for designing indoor space. This is the measurement scale used by color scientists to assess the illumination accuracy of a light. CRI is measured on a scale of 0 to 100, with 100 being the CRI of an incandescent light or natural sunshine, and the higher the CRI, the more accurate or better-quality illumination a light provided. In general, bulbs towards the higher end of the range will create a more accurate color rendition of the items around them. This is useful for things, for example, photography or lighting. It can, however, have an impact on the indoor atmosphere. It is best to use indoor lighting that will make the surroundings clear, bright, and as close to how they would appear in an outdoor, natural setting as possible.

Balance is the key to set visual comfort in indoor environment. To grasp the geometry between the sun, sky, daylight opening and interior space at different times of the day and during the seasons is different. Any opening, such as a window or a balcony, might cause discomfort or glare if the daylighting penetration is not carefully considered. According to logic, a larger aperture will allow more light in, but it will also allow more heat to enter if it is not appropriately insulated. As a result, achieving a suitable balance between views of the outdoors, visual comfort, thermal control, and architectural integrity may be challenging. There may be some overlap between the visual and thermal comfort of the occupants, although this is dependent on the location and season. Direct sunlight may provide warmth in the winter, but it may also cause eye discomfort in the form of distracting patterns on the work surface or even glare.

Table 2. 1: *Light reflectance values for interior colors (Abdullayev et al., 2021)*

Color Wheel	Color Name	Reflectance %	Average %
Warm Colors	Red	18	45.25
	Light Red	35	
	Light Green	60	
	Yellow	68	
Cool Colors	Purple	10	27.5
	Dark Blue	20	
	Dark Green	30	
	Light Blue	50	
Other Colors	Very Black	7	42.4
	Dark Brown	25	
	Dark Grey	35	
	Light Grey	60	
	Very White	85	

2.4 Glare Free Indoor Daylighting

When lighting is balanced appropriately, a design can be effective. This balanced lighting is a key aspect in creating a glare-free atmosphere, depending on the situation. Theoretically, the designer can analyze visual comfort conditions by analyzing brightness ratios and distributions in various lighting settings. Existing lighting design codes and standards primarily rely on illuminance-based recommendations and typically specify horizontal illumination levels, whereas current qualitative thinking is shifting toward luminance-based lighting design as the eye responds to luminance differences, i.e. brightness differences found in the visual field and the space overall. A lack of luminance balance can produce glare, and it's long been known that extreme contrasts and/or high luminance within an occupant's field of view can cause visual discomfort. However, contrast is not a good predictor in and of itself. Indeed, individuals think they know what is going on, but no one can appropriately explain or forecast it in entirely (Schiler, 2000). Because it is harder to forecast whether or not a certain condition will create glare, and if so, how much, the quantitative theory is required to solve the problem of glare.

2.4.1 Definition of Glare

Visual comfort is the primary requirement of any indoor space. Individuals desire daylight in indoor spaces. Excessive daylight, on the other hand, would result in a disaster and an unpleasant indoor environment. The emotional, psychological, and physiological benefits that sunlight provides are frequently at odds with the visual pain that it can inflict. The negative consequences of sunshine, according to

Ne'eman et al (1976), are numerous and primarily focused on the visual and thermal discomforts generated by sunlight. The goal of a good daylight design is to offer enough light for optimal visual performance and to provide a comfortable and pleasing atmosphere that is appropriate for the purpose. The problem of glare is inextricably linked to the comfort component of daylight design (Wienold and Christoffersen, 2006).

Glare, window luminance, and luminance ratios within the field of view affect visual comfort in daylit indoor areas (Wienold and Christoffersen, 2006). When an opening in an indoor space is not planned appropriately and the luminance of the sky and the ground differ, it becomes a non-uniform glare source. Glare is defined as a "vision condition in which discomfort or a loss in the capacity to perceive details or objects is induced by an inadequate distribution or range of brightness, or by severe contrasts" (Mardaljevic et al., 2012). According to Brotas et al. (2014), glare can develop when there is too much light, the brightness range is too wide, and the observer's view angle is too narrow. A bad combination of them can impair a person's ability to accomplish a visual task (Brotas et al., 2014). Glare, on the other hand, is a calculation of light sources in an environment, their subtended or viewed angles, and their surface brightness. The first daylight glare formulas were extrapolations from artificial lighting discomfort glare investigations (Chauvel et al., 1982).

There are two types of glare: disability glare and discomfort glare. Disability glare occurs when stray light reaches the eye, reduce visibility and visual performance; and discomfort glare occurs when stray light reaches the eye, causing discomfort to users, often with less immediately noticeable effects such as headaches or posture-related aches after work (Mardaljevic et al., 2012). Glare has been advantageously separated into two kinds, according to Schiler (2000): discomfort glare and veiling reflections. Discomfort glare is a phenomenon in which the eye seeks to shield itself against the light that may cause retinal damage (Schiler 2000). Extraneous light obscures the intended information in veiling reflection, which is akin to having an extremely low signal-to-noise ratio. The user can often handle veiling reflection, but uncomfortable glare requires strategy, mathematics, and research to overcome.

It is tough to forecast uncomfortable glare because determining the link between subjective assessment and physical characteristics such source brightness, source size, surrounding luminance, and location index is challenging.

2.4.2 Parameters of Glare

Virtual or real-world lighting settings both are possible but depending on the complexity of possible lighting solutions scale models as well as full-size mock-ups may be evaluated. Different performances need different lighting conditions for visual comfort. A clear conception of luminance balance is needed to design. For example, a balcony where possible household chores are to be executed and who is performing them and their requirement of lighting for observing the task. It is the designers' responsibility to be aware of providing the standard luminance balance when designing any space. Individuals appear to be more affected by brightness patterns than by light intensities. Spaces should be identified and the tasks need to be performed under the best luminance balanced light. In general, tasks are different from each other. Where in residence, most of the works are done in indoor spaces so balanced luminance lighting is necessary to design. Glare has four key characteristics that affect the brightness of balanced light. They are discussed as following.

a. The source luminance and adaptation

The source of daylight is an important issue. Direct sunlight or skylight is a necessary point to identify glare. Discomfort glare would most certainly arise when looking at a daylight aperture surface with a brightness of greater than 2500 cd/m^2 (Osterhaus, 2009). Typical guidelines imply a 1:3 ratio between the visual task and its immediate surroundings, a 1:10 ratio between the visual task and other closer surfaces in the visual field, and a 1:20 ratio for the visual field's more distant surfaces. The highest permitted task-to-surface ratio is 1:40 (Osterhaus, 2009).

b. The source size and surface

Visual comfort could be affected by the size of the opening and surfaces that are crucial may show. Discomfort or even impairment glare may arise if prescribed brightness ratios between the task and surrounding surfaces are exceeded. As a result, addressing such problematic brightness ratios through efficient daylighting design becomes critical. Interior wall and ceiling design should be selected carefully. Balcony walls and ceilings with harsh or striated patterns should be avoided. The visual information in a scene should be reinforced by luminance patterns that make sense with respect to the architectural, interior, and lighting design of the space.

c. Surrounding luminance

The lighting luminance differs for the indoor environment. Although the light comes from the same source, the brightness may vary depending on the indoor configuration, such as room surfaces, partitions, furniture, luminaires, and other equipment. To maintain contrast ratios between task and surrounds low, their surface reflectivity should be high, but not glossy. Indoor lighting performance should be examined by competent lighting designers who will regularly offer information to occupants in order to improve lighting performance and enhance visual comfort.

d. Light source's position index

The source angle by which daylight or artificial light is penetrated, as well as the position from which the light is coming, are critical considerations. To avoid glare discomfort, it is important to keep an eye on the illumination brightness and angle. High levels of brightness immediately in the view zone of the fovea are challenging for the human eye to deal with. Osterhaus (2009) proposes brightness limits for various angles of vertical displacement from a horizontal line of sight in daylight interior environments. Though most visual jobs require the occupants to gaze straight ahead or slightly downwards, the high brightness of a vertical surface in or near the center of the visual field is likely to be more uncomfortable than the same magnitude luminance from a horizontal surface at the same location. Luminance limits for glare sources at various angles show in Table 2.2.

Schiler (2000) proposed a simple way to estimate the impact of probable glare sources based on luminance histograms of high dynamic range (HDR) photographs from digital cameras or computer simulations, which was further expanded by Osterhaus (2009). Additional validation experiments are being planned, especially in light of Wienold and Christoffersen's findings (2006).

Table 2. 2: Luminance limits for glare sources at various angles (Osterhaus, W., 2009)

Angle of Vertical Displacement from Horizontal Line of Sight	**Suggested Luminance Limit**
45°	2570 cd/m2
35°	1833 cd/m2
25°	1284 cd/m2
15°	856 cd/m2
5°	582 cd/m2

2.4.3 Enhancing Glare Free Daylight in Indoor

When following passive principles to welcome daylight in indoor spaces, designers try to invite more daylight into indoors and they should consider glare. How and from where the daylight comes from is an important matter to consider. The quantity and quality of light, the degree of flicker, the amount of glare, the contrast, and the shadows all contribute to the lighting. Some simple strategies could work to enhance daylight but also have to consider discomfort glare. Some rules which might help for enhancing glare-free indoor daylight are discussed below.

- To reduce direct sunlight inside rooms, a simply fixed overhang might be beneficial.
- A lack of luminance balance can induce glare, so daylight with a balanced brightness should be welcomed.
- Increasing the illumination from electric light sources in some places could be a strategy to counteract excessive daylight reflectance values or electric lighting.
- To limit glare, it is important to keep the appropriate luminance of vertical surfaces in the field of view near the opening, such as a window or balcony, at a reasonable level. This reduces the risk of uncomfortable glare and promotes user acceptability of a place by generating a pleasant atmosphere (Osterhaus, 2009).
- To maintain contrast ratios between task and surrounds should be low. The indoor material, such as wall surface reflectance, should be high but not glossy.
- Careful consideration should be given to the construction material. Over-glazing should be avoided, and heat-resistant materials should be used in both exterior and interior spaces.

There is mounting evidence that satisfying illuminance alone does not ensure the success of a design solution, and that illuminance should not be the sole factor to consider when evaluating a lighting scenario (Boubekri, 2004). Architects would design their structures, fenestration systems, balcony designs, and interior designs to fulfill these minimum daylight requirements.

2.5 Design Strategies for Daylight Penetration

Daylight is considered as one of the major requirements of individuals when designing a building. When it comes to daylight, it is not just about increasing light levels; it is also about improving the quality of the luminous environment for the people who live there. Control, not just of light levels but also of light direction and distribution, is the important word in daylighting design. Furthermore, inappropriate daylighting technology integration might result in discomfort and unpredictable performance (Sharmin, 2011). The techniques could predict how much glare would bother the inhabitants and how much electric illumination would be required. Without performing any research into the lighting requirements, both sunshine and electric light can cause glare. If the discomfort glare from both lighting systems is within acceptable limits, the combined effect is also likely to be acceptable. Otherwise, the demand for specific sunshine levels inside a room could become a complicated issue. It is now possible to predict both exterior and interior daylight levels using empirical or simulation modeling techniques. Strategies implemented early in the design process could help to avoid unnecessary glare and improve daylight penetration. These challenges should be considered from the beginning of the design process as following.

a. Before design considerations.
b. Daylighting measurement metrics.
c. Design development phase strategies.
d. Refining the design scheme by interpreting design assessment outcomes.
e. Selection of design tools and applying them.

Though the stages are crucial to consider for greater daylight penetration and natural ventilation, the early stages are preferred. Designing daylight has two key focuses: creating a high-quality lighting environment that improves occupants' visual performance, comfort, health, and well-being while also reducing electric lighting and heating or cooling loads for sustainable energy usage.

Daylighting has long been acknowledged as a cost-effective way to save energy while also producing a pleasing aesthetic environment. Daylight is normally the preferred source of light in the indoor setting and sunshine appears to elicit a wide range of psychological responses (Nazzal, 2005). Daylight is the preferred source of illumination, with artificial lighting being used only when and where necessary. Furthermore, tactics make it easier to penetrate daylighting design approaches that emphasize the human visual senses and experiences, as well as the interrelationships between physical representation through quantifiable outputs and the expected qualitative occupant experience.

Designers should devise techniques to accommodate the availability of daylight. By following passive architectural design principles, it could be claimed that passive principles would be a solution to reduce energy consumption from the inside environment, is one of the greatest ways to welcome daylight in indoor space. Because of its ecologically beneficial appropriate ties, there has been a revived interest in passive building design as a feasible solution to the energy issue as well as pollution (Sadineni et al, 2011). Improved building envelope design, enhanced insulation, natural ventilation, shading, and better performing windows and balconies for example, contribute to a highly energy-efficient structure. According to Cheung et al. (2005), there are mainly six passive design strategies on both the annual required cooling energy and peak cooling load on a high-rise apartment building in Hong Kong, namely insulation, thermal mass, glazing type, window size, color of external wall, and external shading devices. Passive Architecture is a phrase used to describe structures that are designed to respond to local climatic conditions in order to provide a comfortable internal environment as organically as feasible (Zaki et al., 2007). The term 'passive' is used to describe a defensive or protective attitude to house design in insulating people from local climate elements, while the term 'architecture' lays this obligation on Architects, who is expected to design comfortable building (Zaki et al., 2008). The next section will explore several daylighting design strategies, as well as some key external aspects to consider when developing passive structures in tropical nations.

2.5.1 The Building Site and Obstruction

To get a successful design and better indoor environment in a building, site considerations are must. The site and surrounding study are a crucial concern for optimal natural ventilation and daylighting penetration design before planning any construction. A designer must consider the level of barrier to the sun and sky from the terrain and nearby structures when choosing daylighting solutions for a building.

The building should be placed with respect to the site and surrounding to optimize daylighting. The floor area ratio (FAR), also affect the building design as there are rules and regulation for each site to maximize the daylighting in building indoor.

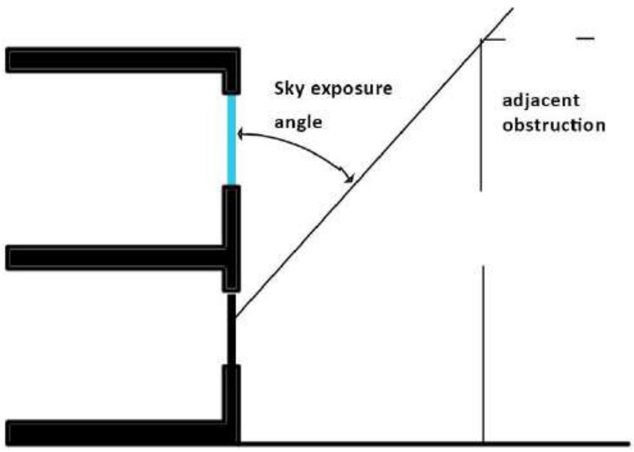


Figure 2. 3: Sky exposure angle (after, Robertson, 2002)

Building orientation is also important and should not be ignored. The neighborhood vegetation, buildings and obstructions should take into consideration. Figure 2.3 shows the relationship between the sky exposer angle and an adjacent obstruction. The extent to which the new construction would obstruct existing buildings, lowering their access to daylight, and/or will reflect sunlight, perhaps causing glare at street level or increasing thermal loads in nearby buildings should be taken into account.

2.5.2 The Building Form and Geometry

In respective climates, a building's widest facades should face north and south rather than east and west (Sharmin, 2011). This is because, even in the summer, the sun is low in the sky in the east and west, making shade difficult, if not impossible, if a view is to be retained. Because of the high angle of the sun when it is in the southern sky, south-facing facades can be readily shaded by minor overhangs (Mou, 2017). South-facing windows should let in winter solar gain, but east and west facing windows should keep low-angle daylight out. Another orientation method is to give shallower spaces on the north side and deeper spaces on the south side to permit varying levels of daylight penetration.

To restrict exposure on the east and west sides, tropical structures are unavoidably rectangular, stretched east-west (Konya, 1980), resulting in a shallow floor layout that supports natural cross ventilation (Tombazis et. al.,2001). If possible, the perimeter zone to total floor area ratio should be increased. The amount of daylighting in the indoor floor area is determined by the skin-to-volume ratio; the higher the skin-to-volume ratio, the greater the percentage of daylight in the indoor floor space.

Up to a point, long and narrow footprints are preferable to square ones. The size of a room has a practical limit beyond which traditional window systems are inefficient (A.G.S, 2000). The deeper the room, the weaker the consistency of daylighting (Sharmin, 2011).

2.5.3 Fenestration Design

A good fenestration design could invite glare-free daylight in the building's interior. Fenestration design (Figure 2.4) should consider in the conceptual design phase to avoid discomfort glare in an indoor environment. Building fenestration is mainly divided into two parts: top-lighting systems and side lighting systems (Sharmin, 2011).

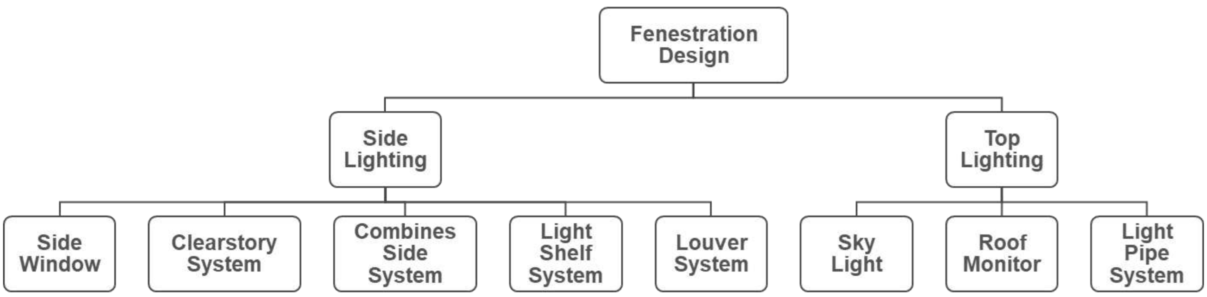


Figure 2. 4: Fenestration design chart

Side-lighting Systems

The goal of side-lighting is to disperse daylight across the depth of space, providing adequate light to complete a job in the room while minimizing glare and permitting a view of the outside. Because these devices can deflect the light away from the window wall and towards the back of the room, adding light shelves, prisms, or mirrored louvers to the window glazing provides a potential side-lighting solution.

i) Side Window

In a hot and humid region, window openings should be large enough to capture the prevailing breeze, and rooms should be organized in a single bank to allow cross ventilation (Konya, 2013). This is also true for Dhaka's environment, where single-sided ventilation promotes stifling conditions, according to studies (Ahmed, 2002). Traditional side windows, especially if the space is large, tend to provide too light near the windows and dimmer conditions elsewhere. A side window beside the balcony wall plays a vital role in a good indoor environment. Furthermore, depending on the sky conditions, the orientation of the window, its location within the wall and in relation to the activity zones and the rest of the room, the effective height of the window (from the sill to the upper limit of the window), and its width all influence the spread and depth of daylight penetration. Because of the contrast between the brightness of the window and the darker background surrounding the window aperture, a single side window can generate a lot of uncomfortable glares (Sharmin, 2011.)

ii) Clerestory System

It is a kind of side window, but it is not the same as a conventional one. This is frequently contained in a structure that rises above the roof line (Figure 2.5). While it does not provide views of the outside, it does allow for more daylight penetration into the space than a normal side window. Moreover, when a light shelf is used on a balcony, a clearstory window creates in the middle space between the ceiling and light shelf and provide a better illuminance. In the northern hemisphere, a typical side window with a south-facing clerestory will provide more daylighting than one with a north-facing clerestory.

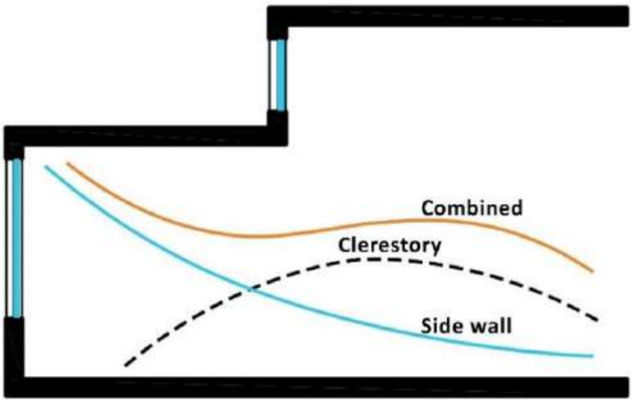


Figure 2. 5: The combination of a vertical clerestory and a side window allow uniform daylight (after, Boubekri, 2008).

East and west facing clerestories have the same issues as east and west facing windows: problematic shading and especially when west facing, possibly substantial heat gains. The daylighting zone is determined by the clerestory's mounting height (the distance from the finished floor to the bottom of the aperture) as well as the width and length of the clerestory. The higher the mounting height, the larger the daylight zone.

iii) Light shelf System

A light shelf is a horizontal or nearly horizontal baffle that is installed halfway up a window to manage and redistribute incoming daylight (Littlefair, 1995). It is a gadget that captures sunshine, especially sunlight, and reroutes it to the back of the room by bouncing it off the ceiling. Figure 2.6 shows that with a light shelf, daylight penetration is better than without one. A light shelf, installed in front of a window, divide the glazing into two sections: a view window underneath the shelf and a clerestory window above it. Both exterior and interior light shelves are possible. The outside of the window will be shaded by an outside light shelf, minimizing solar gain in the room (Lam, 1986). At intermediate depths within the room, an internal shelf provides superior visual protection from sun glare (Littlefair, 1995).

For greater glare free lighting, the building should include a light shelf. The size and depth of the light shelf are determined by the size of the window and the orientation of the facade. The room layout will determine the placement.

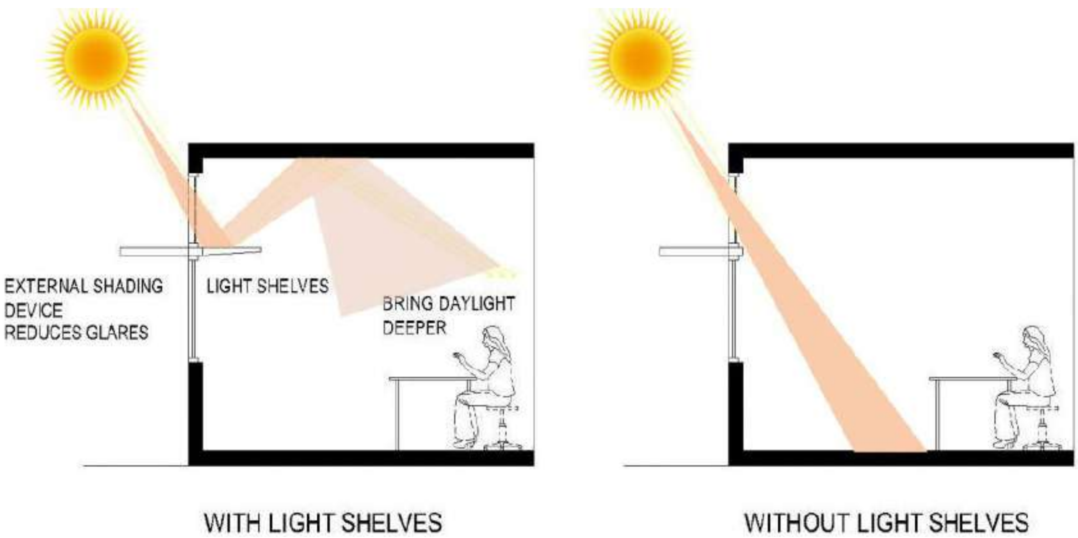


Figure 2. 6: Daylight penetration in a room with and without light shelf

Lower height of the light shelf may cause more glare. Figure 2.7 shows the performance of a light shelf in summer and winter environments. With a light shelf, sunlight penetration is greatest in the winter and least in the summer (Littlefair, 1995). In a tropical country such as Bangladesh, putting a light shelf at any height results in a loss of total illumination on the work plane across the interior space. In terms of enhancing daylighting quality in the interior space, light shelves at a height of 2m above floor level inside 3m high ceilings from finished floor level will perform better than other places. (Joarder et al., 2009).

For external light shelf, according to the Dhaka Metropolitan Building Construction Rule 2008, a maximum overhang of 0.5m is allowed over mandatory open spaces (clause no. 50.6G).

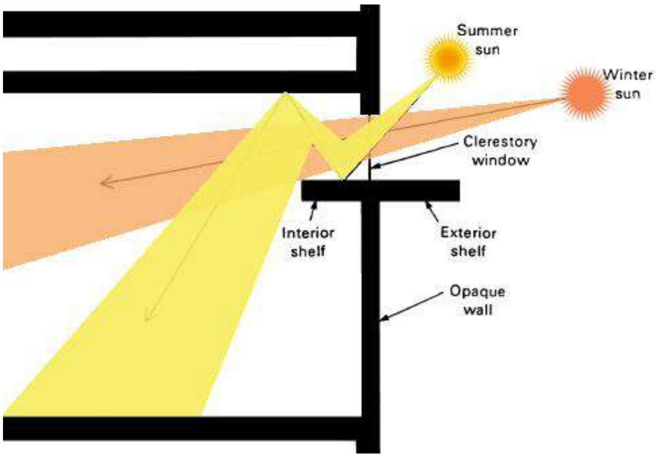


Figure 2. 7: Daylight penetration angles through light shelf

2.5.4 Window- to- Wall Ratio (WWR)

The WWR, which is defined as the ratio of the total area of windows to the overall gross external wall area including windows, is a standard way to quantify effectiveness of window area with respect to daylighting (Seraj, 2018). Visual pain is caused by uncomfortable glare. Glare might be caused by windows that are not in appropriate size (Muneer et al., 2000). The influence of window size on sunlight presence and glare was researched by Boubekri and Boyer (1992), who found that the unpleasant glare of sunlight can compete with the good psychological effects of sunlight. The size of the window accounts for less than 30% of the variation in the perceived glare (Boubekri and Boyer, 1992). When the perceived glare value exceeds a value of 4, occupants become uncomfortable and visual pain is caused by it. Except when the window size is 40—55 percent of the wall area, perceived glare is within acceptable limits (Muneer et al., 2000). The following are the basic characteristics of window sizes and glare conditions (Muneer et al., 2000).

Small windows - the dazzling source is minimal, and the experience is unobtrusive.

Medium windows - have a greater perceived glare intensity due to the high contrast between the glare source and the surrounding adjacent walls.

Large windows - despite the fact that the glare source is large, the contrast between it and the surroundings is limited, increasing the eye's adaption level and minimizing glare sensation and discomfort.

2.5.5 Window- to- Floor Ratio (WFR)

The WFR is calculated by dividing the entire size of the window by the floor area of the same room (Mou, 2017). The efficiency of air movement in a house is determined by the window size and location concerning the floor area and the building's direction. WFR accounts for daylight penetration into space, in addition to other design characteristics such as ceiling height, internal reflectance, and room depth (Capeluto, 2003). For example, Smith (2007) stated that in non-domestic structures, a WFR of 20% can give sufficient daylighting up to a depth of approximately 1.5 times the height of the window lintel (Ibrahim et. al., 2011). The WFR rule of thumb is frequently used in architectural and building code literature. Legislation in Malaysia and Singapore stipulates that any room (residential, commercial, or whatever) intended for daylighting needs must have a minimum of 10% WFR (Nedhal et al., 2016).

2.5.6 Finishing, Furnishing and Space Activities

The majority of sunshine-redirecting strategies direct daylight to a room's ceiling. The way daylight is dispersed is influenced by the ceiling's reflectance qualities. The reflectance of walls, floors, and furniture has a big impact on the overall perception of a space. Light-colored blinds or drapes, as well as walls with matching reflectance, should be used. The wall adjacent to the windows should have very high non-specular reflectance to avoid excessive brightness ratios between the windows and the wall surface. Because the ceiling is the most crucial in reflecting light downward, it should be much more highly reflective (white) and non-specular. The floor reflectance should be as high as possible utilizing widely available floor covering materials, with a reflectance of around 25% being the goal. Although the reflectance of the floor is not as important as that of other room surfaces, it does contribute to the ambiance of the area and should not be disregarded.

Passive design solutions, which can moderate internal temperatures and hence minimize building energy consumption by changing the building to match local climatic factors, have been generally overlooked by local building designers (Cheung et al., 2005). Early actions should be taken to ensure that the passive design criteria are carefully followed. Although a lot of people currently live in mechanically ventilated structures, constructing buildings with sustainable architecture and excellent natural ventilation lowers the use of mechanical systems, resulting in lower energy usage.

2.6 Balcony as an Aparture for Useful Daylighting

A balcony, according to Oxford Dictionary (2000), is a platform contained by a wall with a balustrade or railing extending outside or inside the building's walls (Ayokunle, 2015). According to Chau et al. (2004), a balcony is a recommended "green" solution that serves as an integrated "environmental filter" for reducing road noise, providing planting space, and improving energy efficiency.

The act of inhabiting and connecting individuals with nature and other individuals is an important central human behavior. Balconies make it easier for people to connect from building to building and nature. It is one approach for reducing heat gain while also improving the living quality of the occupants by providing access to outside views and a soothing function. Having a private outdoor space in a dwelling is one of the finest spaces for people during lockdown time, especially in pendamic settuation (i.e. COVID-19 crisis). Apart from pandemic, various architecture projects in recent decades have investigated the possibilities of adding intermediate spaces to buildings (Rivkin, 2015), not only to meet this spatial requirement but also to improve indoor environmental conditions (Ramos and Colen, 2020).

The balcony is a platform that is projected from a building's external wall, supported by columns, brackets, or cantilevered and encircled by a balustrade. Over the years, balconies have played an important role as beautiful yet functional architectural features on buildings over the world. As a result of its location on the building's outside facade and functions, it is also an important feature of the structure. A balcony could also be incorporated into the structure as a green element. View enjoyment, improved ventilation, and expanded planting space are the main benefits of balconies, but the adjacent room is also protected from sun and glare. A balcony can operate as an overhang, providing solar shading and reducing the amount of energy used by the air conditioning system. In addition, this overhanging balcony could help to reduce indoor air pollution and traffic noise. Griffiths (1999) views a balcony to be an integrated "environmental filter" from an environmental standpoint. In a nutshell, a balcony is a vital feature of a building's front.

2.6.1 History and Emergence

"A house is not only a physical space in which people live but also a space where social interactions and rituals take place" (Zin et al., 2012). From the very beginning of house design, the provision of extra space was mandatory where people could seat in their leisure time and do casual discussions. In early houses, this space is called `Peera' as a local word. Day by day houses are modified into buildings and Peera modifies into balcony. Figure 2.8 shows the main features of 'Peera' with respect to courtyard and surrounding rooms in a Bangladeshi rural house.

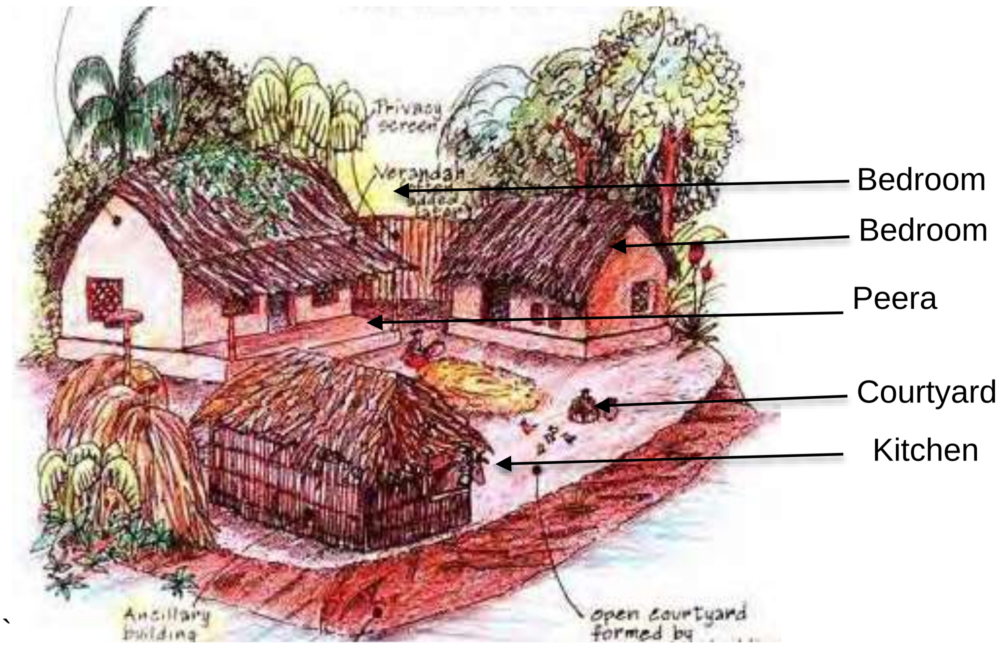


Figure 2. 8: Main features of a courtyard in a Bangladeshi rural house (Source: Ahmed, 2006)

Balcony and jalousie are examples of Dutch Colonial design adaptations to tropical regions (Ribeiro, 2020). In contrast, the morphology of Dhaka's urban homes has evolved at the beginning in the 13th century with the pre-Mughal period (Seraj,2018). From the beginning, the rural pattern was adopted in the spatial structure of Dhaka's urban dwellings, which steadily evolved with time and societal changes. The 'Peera' served as both a private inner front space for various activities and a temporary semi-public threshold zone between inhabited rooms

Table 2. 3: Chronology of balcony changes with house patterns in Dhaka

Period	**Pre Mughal Period**	**Colonial Period**	**Post Colonial Period (after 1957)**	**After Liberation War 1971**
House Layout Type	Introvert type	Extrovert type	Consolidated type	Consolidated type
Common Characteristics of houses	a. Introvert courtyard pattern houses . b. Inner court, outer court and courtyard were the main features. c. The inner court served private family purposes d. Courtyard was the central space of all activities e. All the rooms, kitchen, toilets were separate from each other but connected through courtyard.	a. Detached Bungalow pattern houses. b. Follows European styles c. buildings were free standing d. Courtyard less detached service structure at the back. e. Service remained isolated from the main mass but connected by a stair. f. Kitchen, toilets were separated from the main house. g. Some houses of Dhaka were also found with European facade treatment but a local courtyard type layout which was blended with the European bungalow pattern.	a. Multi-storied walk-up buildings. b. One stair serving two units. c. House was separated into three zones, formal, informal and service zones. d. A corridor space run through the center e. Dining or family living as linking space. f. Bedrooms, kitchen, drawing ,dining and balcony were present.	a. Multi-storied High-rise building b. Compact apartments c. Compact space arrangements d. Staircase and lift core e. Smaller rooms f. Dining as connecting space g. Bedrooms, kitchen, drawing ,dining and balconies were present
Example	Early village houses.	Chummery House, Dhaka.	Dhakeswari Quarters (single storied row houses), Azimpur Estate (medium rise multi-storied walk-ups).	Vasantek Housing.
Presence of Balcony	No significant space as balcony but Courtyard acted as communicating space.	One or more balcony are present .	Several balcony are present.	One or more balcony are present in a unit.

(private domain) and the living room (public domain). It was a semi-open space that provided daylight to the nearby spaces.

Everything changes with time. The educational and occupational sectors have altered as a result of changing lifestyles and family structures, and this has led to changes in home types (Rahman et al., 2001). Since 1576, the Europeans have created a new house form- detached/ Bungalow of extrovert nature, which reflects more of their life style than the local lifestyle of this region. Outward-facing buildings with a detached service structure at the back and no courtyards, were common. A central hall connected the surrounding spaces in these types of structures. Two balconies on opposing sides of the hall were attached to it. One balcony was immediately attached to the building's main entrance. The central hall received light from these two balconies (Seraj, 2018).

In recent times, migration, territorial expansion and natural growth are the main reason behind the quick population growth of Dhaka City. In the early '70s, there were few buildings in Dhaka that were more than two stories high. With a rising population housing demands are also increasing. The horizontal expansion of the city is limited as Dhaka is hemmed by a network of rivers that makes outward expansion difficult and only vertical expansion was made to accommodate the growing numbers of residents. The increasing housing demands are being fulfilled essentially by multi-storied apartments (Kamruzzaman et al., 2007).

Several types of multi-storied high-rise apartments have been seen in Dhaka nowadays. With the changing of house patterns from introvert type to extrovert type, extrovert to consolidate type, balcony patterns also changed. From pre-Mughal to present balcony patterns are different. Where in the pre-Mughal period, there were no significant spaces as a balcony but in the Colonial period, the houses were built with one or two separated balcony spaces. Similarly, in the post-Colonial period and after the Liberation war, buildings were built in respect to connecting the neighborhood with two or more balconies. Table 2.3 shows the chronology of balcony changes in house from in Dhaka.

Now-a-days, in twenty centuries, several types, shapes and sustainable design of balconies are seen in Dhaka to make it cozier and more comfortable has become a challenge for architects to design. Light, foldable, and bright-colored furniture are found which adds beauty and sophistication to the outdoor space in the balcony. Moreover, a lush display of greenery has found on most of the balconies.

2.6.2 Types of Balconies

Balconies are classified into three categories, according to Leigh, Bae, and Ryu (2004): open balcony, enclosed balcony, and extended balcony (Figure 2.9). According to them, a courtyard is one of the forms of balconies that fall within the category of enclosed balconies (Leigh et al., 2004). The local types of balconies could be categorized under open balconies because of their availability in the sub continent and tropical countries.Figure 2.10 shows international and local balcony categories.

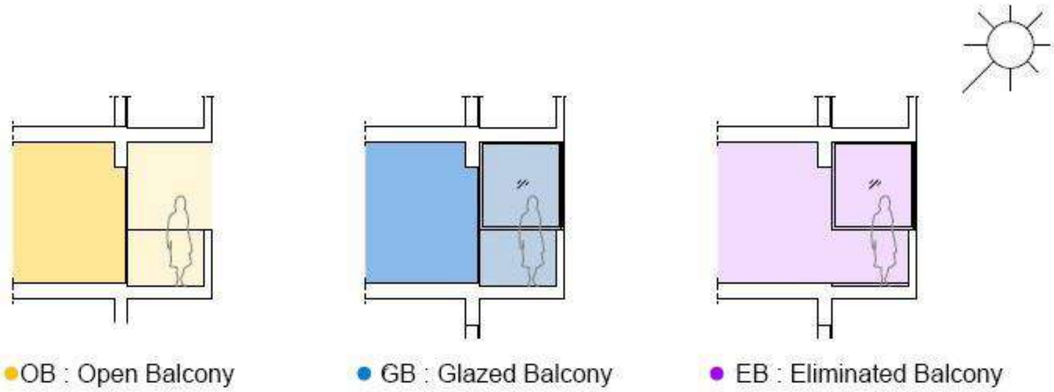


Figure 2. 9: Types of balconies according to morphology and boundary system (after, Riberio,2020)

Figure 2. 10: Images of balcony spaces based on their shape and border system

Ribeiro (2020) defined three categories of balcony spaces based on their shape and border system, which are detailed below.

Open Balcony (OB): Projected balconies, loggias, mashrabiya (balconies protected by carved wood lattice structure, associated with Islamic culture) (Fatty, 2006), balconies with shading systems (brise-soleil, blinds, curtains) (Requena-Ruiz, 2012), and green balconies with vegetation) are examples of open systems to the outside (Besir et al., 2018). According to their structural system, open balconies can be classified into three varieties (Figure 2.11). As follows, these categories are highly widespread in sub-continental and tropical countries.

i. **Recessed Balcony:** This type of balcony has overhead shade of upper floor balconies.
ii. **Semi-recessed Balcony:** This type of balcony has half or some portion overhead shade of upper floor balconies.
iii. **Cantiliver Balcony:** This type of balcony have no overhead shade.

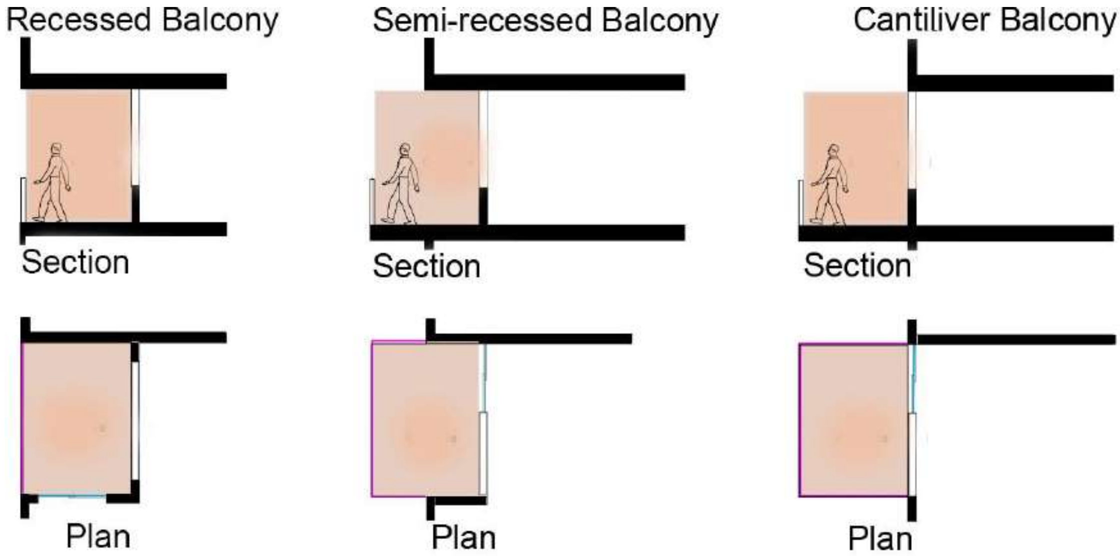


Figure 2. 11: Local types of balconies popular in sub-continent countries with tropical climate (after, Riberio,2020)

Glazed Balcony (GB): A closed system with a barrier between inside and outside space, balconies with glass on the outside edge (Wilson et al., 2000), also known as "sunspace" (Mihalakakou, 2002), or winter gardens (Wilson et al., 2000).

Eliminated Balcony (EB): Former balconies have been removed and merged into the internal living area, creating an open system to the indoor space (Kim and Kim, 2010).

The balcony kinds are highlighted in terms of climatic conditions. As previously stated, studies on open balconies (OB) have a significant impact on high-density cities and were present mostly in warm locations with tropical and subtropical temperatures, as well as the harsh environmental circumstances of the Middle East. Due to their ability to cope with the desire for seclusion (Saleh, 2015) and the harsh climatic circumstances, the references to open balconies protected by shading systems were mostly associated with Muslim nations. According to recent studies, several of these countries have reduced their cooling energy demands by 60–70% (Touma and Ouahrani, 2018), which justifies the reinterpretation of traditional shade methods in balconies to minimize energy consumption in residences.

Glazed balconies (GB) are more common in cold regions and nations with higher latitudes, where the sun angle in the winter, just before and during the night period, allows for a large amount of heat to be supplied on cold sunny days (Ribeiro, 2020). Despite some studies stating that it should not be a recommended practice from the analysis of energy consumption (Saleh, 2015), the placement of glass on the edge of balconies was primarily motivated by a desire to increase living space (Hilliaho et. al., 2015) and a reduction in traffic noise and air pollution (Kennedy et al., 2015).

2.7 Balcony Effectiveness and Essentiality in Tropical Climates

Natural ventilation and balconies are two of the most desirable features of a living space in subtropical climates where the spring season is short, humid and sometimes foggy. The temperature varies a lot from one day to the next and the weather is mostly tropical between May and September, which means hot and humid with the occasional showers or thunderstorms. As a result, the balcony can be defined as one of the main factors in establishing a sustainable building design, particularly in Bangladesh. Natural ventilation in high-rise apartment buildings is of vital importance. Here a balcony, in addition to traditional window openings, is another architectural element that allows for controlled ventilation in a naturally ventilated high-rise apartment. From an architectural standpoint, the usage of balconies in structures contributes to the shape and articulation of the building; hence, with different design methods in mind, balconies could contribute to the usefulness of a building as a significant architectural element (Ayokunle, 2015). Three types of local balconies have some shared benefits and drawbacks. To sum up, it could be said that the balcony is a valuable element of any building. They could be described as following.

- A magnificent addition to the structure that adds more living space.
- An important space for social interaction.
- Can be used for urban gardening or urban farming.
- Reduce heat gain to the adjacent room and workspace as a buffer.
- If the width is significant, it reduces the level of daylight in surrounding places.
- It reduces energy consumption by natural ventilation.
- Works as a shading device for the floor just below.

According to Chan, certain lower-level residential flats may receive significant shading from nearby flats in the same building block, resulting in a negligible shading impact from a balcony (Chan, 2015).

2.8 Relation between Balcony and Energy Consumption

The primary objectives of sustainable design are to provide healthy and comfortable environments. Through the balconies, glare-free daylight penetration may reach the deeper/central parts of the apartment. Integrating a balcony into a multi-story residential building can lower heating loads and be an effective approach to allowing glare-free sunshine into inside rooms (Angeraini et al., 2016; Xue et al., 2016). It not only allows glare-free sunshine into inside spaces but also reduces energy consumption by minimizing heat gain through natural ventilation. Due to its roles, this architectural element has the potential to be adapted in facade design, improving energy efficiency and maintaining local design efforts (Tedjokoesoemo, 2014). Due to the shade effect of the balconies, residential flats facing various orientations (N, E, S, W, NE, SE, SW, and NW) can offer significant energy savings in air-conditioning systems. The building with the southwest-facing balcony and clear glass glazed window had the largest yearly air-conditioning consumption savings of 12.3 percent in Hong Kong (Chan et al., 2010).

2.9 Different Studies on the Effectiveness of Balconies

Building's geometry can modify the airflow pattern surrounding buildings. The geometry of the balcony is the most influencing aspect in producing balcony design solutions. The airflow pattern within and outside a building can be drastically altered by a balcony. It has the potential to improve indoor comfort by improving the homogeneity of air dispersion (Ghadikolaei et al., 2020). It's the most effective feature in terms of modifying the entering wind and airflow pattern and, as a result, providing natural ventilation (Mirabi et al., 2020). In the tropics, the cross-ventilation method is an ideal kind of natural ventilation, but it can only be used in certain situations when at least two openings are present on two different external walls (Ghadikolaei et al., 2020). A balcony with sliding glass and a window inside the room works here as the two elements for cross ventilation. Where the size, kind, location and the number of openings, as well as the distance between them, are the most important elements impacting interior airflow in relation to openings (Mohamed et al., 2011). Balconies can change the pressure distribution on opposing building faces, resulting in a greater or lesser pressure difference between them. This difference might cause a dramatic shift in air flow towards interior spaces. The most important factor impacting natural ventilation is the difference in wind-induced pressure on windward and leeward facades. The apertures on facades allow wind to enter and depart structures. As a result, a balcony can be thought of as a scoop that funnels outdoor air into indoor rooms (Mirabi et al, 2020). A novel notion of wing wall, on the other hand, might be included in balcony design. When two openings are placed close to the partition walls in each corner of the balcony, the ventilation performance is nearly four times better than when only one opening is used with a flat facade. In this situation, the partition walls serve as the building's wing wall. The provision of a balcony with wing walls, according to Ghadikolaei et al. (2020), can be a facade design solution to improve indoor ventilation and possibly reduce energy consumption in buildings (Ghadikolaei et al., 2020).

The wider the balcony area, the less sun discomfort and glare come through the nearby indoor spaces, and the deeper the balcony, the lower the air velocity. Although an open balustrade balcony can help with inside ventilation, the balcony's partition walls reduce the velocity along the wall by about a fifth. It can be described as an effective wind box that serves as a thermal management element in a structure by reducing heat gain into interior rooms while also maximizing heat loss (Yeang, 1991).

If correctly planned to take full advantage of the local environment and overheating is treated by passive means, a balcony can be an acceptable and effective system of natural ventilation for the whole year (Aelenei et al., 2014). Because of its effectiveness in minimizing negative external environmental effects, it has an implied value (Chau et al., 2004). According to Angeraini (2016), the most critical factor influencing daylighting conditions in surrounding spaces is geometry of the building. Another important factor that affects energy savings is user behavior, which is influenced by the user's availability and understanding of how to control balcony use by adjusting ventilation openings, doors, and shading devices to meet the necessary comfort needs and available conditions.

2.10 National and Regional Cases, Standards and Legislations

The purpose of building rules and regulations is to protect the health, safety, and welfare of building inhabitants (Boubekri, 2004). Legislation governing daylighting has taken a variety of forms, varying from one country to the next (Boubekri, 2004; Julian, 1998; Seraj, 2018).

2.10.1 Standard and Legislation for Balconies

a. Regional Standards and Legislation for Balconies

In South China and Southeast Asia, verandas were a typical design element of colonial buildings, providing outdoor living space with natural ventilation. Verandahs were not present in Chinese architecture. Chinese city streets were too narrow, and as John Henry Grey noted in Guangzhou in the 1870s, the homes and businesses were neither raised to the same height nor yet placed in a straight line (Gray, 1875)

Yeoh describes an 1820s-era colonial policy that emphasized the use of verandahs as "walkways". In his discussion of the development of upper floors in private buildings that were extended into the airspace of government-built thoroughfares throughout the twentieth-century urban planning process. The descriptions of multi-floor buildings inhabited by Chinese people in China and Southeast Asia, where the ground floor was frequently used for business (mostly as shops), the upper floors were residential, and the upper-floor extension of the verandah contributed to a roof that covered the pavement skirting the building. Such structures became known as "Chinese tenements" in Hong Kong, the capital of China. These structures added to a feature of the Southern Chinese and Southeast Asian metropolis, complete with business signboards hanging out of the verandahs and the columns supporting them. The majority of studies on verandahs focus on their native Chinese character, but administrative decisions taken by the colonial government of Hong Kong made the verandah an approved architectural feature in urban settings.

Verandah is an upward extension of a building over a sidewalk along the side of the road and it was used to describe the building extension on the higher floor or floors in Hong Kong (Faure, 2021).The verandah was successfully traded by the Hong Kong government for a space for ventilation at the back of the home and it was a tradeoff provided to real estate developers by the colonial administration of Hong Kong in exchange for better ventilation (Faure, 2021).

Guangzhou is a sprawling port city of China. In a period of 1910s and 1920s, there were significant road widening in Guangzhou. In addition to being intended to modernize and reshape the city, road widening also functioned to generate cash. These two objectives were achieved in 1918 when the city walls were destroyed. However, the walls were insufficiently thick to provide the necessary width for the road, necessitating the demolition of 3,500 homes to provide more space. To settle with the business owners over the compensation, the government loosened the restrictions on verandahs. In areas where the road was 100 feet broad and 80 feet across, property owners were permitted to construct verandahs that extended 20 feet over the pavement and 15 feet over those areas. A permit was needed to construct the verandah, but it was given away without charge to landowners who had given up an equivalent amount of land for road widening. The area that the verandah added to the property became known as "verandah land" (qilou di), which was taxable. The context for the qilou verandah building was created by Hong Kong's encroachment on public space, compensation for the loss of private space, usage of reinforced concrete, and taller structures.

According to Yeoh in Singapore, verandahs are five-foot "covered walkways" that have been a condition of building leases awarded by the colonial administration from the country's early years of history. Even while propriatety owners considered these sidewalks to be rightful and legal parts of their appropriate ties, the government demanded that they be kept free from blockage. Given that verandahs were listed as subject to all property rights of homeowners under the 1872 Summary Criminal Jurisdiction Ordinance, it would appear that private ownership of verandahs was recognized by the law. Here, a verandah was defined under the building ordinance as "any projection over crown land, whether verandah, oriel, portico, flying balcony or other building", rather than as a passageway as it was recognized in Singapore (Hong Kong Government Gazette, 1889).

The five-foot way was regarded as private property in Singapore, from the beginning of the Japanese colonial occupation. However, starting in 1933, building regulations exempted the area covered by the five-foot way from the plot size requirement in consideration of the built-up plot ratio. At a time when verandahs were being constructed and homes were being erected, that may have been a partial concession for ventilation space.

In Korea residential flats generally have balconies on both the front and back sides. The balcony sections are not thermally conditioned, but serve as a buffer zone to reduce heating/cooling loads and environmental consequences such as exterior noise (Clarke et al., 2008). Balcony enclosure has been permitted here since January 2006. Additionally, each dwelling contract in developments produced after this date has a column where a balcony enclosure can be selected. However, a balcony enclosure may entail one or more of the following steps by Korean building regulations: installing the exterior glass sash; removing the inside glass sash; and installing floor cladding that is the same material and height as the interior of the home. Figure 2.12 shows the three types of sash on Korean balconies. Only in the event of (1) may judgments be made on an individual basis in accordance with the law, and balcony enclosure would be considered a formal adaptation (Costa et al.,2014).

Figure 2. 12: Korean balcony enclosure with sash removal, enclosure with random window frames and enclosure without sash removal (left to right)

b. National Standards and Legislations for Balconies

Similar to other countries, there are some rules and regulations in Bangladesh for buildings construction. It is called BNBC (2020) which is a national-level legally binding document in Bangladesh. BNBC is the country's standard for building design, construction, and maintenance, while RAJUK is the planning authority for Dhaka, the country's capital. RAJUK requirements for various types of buildings, based on the BNBC, are made down with the details in a document named as "Imarat Nirman Bidhimala" 2008 (INB, 2008). Different aspects considered by the regulations include the location of a building concerning neighboring streets, its height concerning adjacent buildings, maximum permissible floor area ratios (FAR), and the space around buildings to ensure free air circulation, admission of light and access for service purposes, as well as engineering considerations are indicated in BNBC (Seraj, 2018).

Some balcony related rules are highlighted below according to BNBC (2020).

- Balcony is a covered and hanging platform at a height of minimum 2.286 m from the plinth level of a building and having access from any floor level and which is laterally open to outer air by three sides up to 2.06 m in height and edges are protected with guards.
- Balconies at levels higher than 6 m may project into the mandatory open space by not more than 0.9 m provided that a clearance complying the separation distances between the edge of the balcony and the property line.
- At least one side of all habitable rooms shall be exposed to an exterior or an interior open space or to a balcony or verandah exposed to an open space.
- The minimum width of individual balcony shall be 0.9 m.
- Every room, bathroom and kitchen shall have windows in an external wall opening on a courtyard, a balcony not wider than 2.5 m, or the exterior.
- A barrier erected along exposed edges of an open side, floor opening, wall opening, ramp, platform or catwalk or balcony to prevent the fall of persons.
- Verandah portions of a building at any level which have ceiling or roof and at least one side open up to 2.15 m height to the outside air.

INB (2008) is a set of laws that establishes various set-back and height constraints for different occupancy classes. Building set-back from the site boundary, building height (with relation to the width of the road and set-back in front of the site), and maximum allowable covered space are restricted based on these considerations. According to INB (2008) there are three types of balconies in residential buildings and apartments (Figure 2.13) as following.

a. Front Balcony (FB)

b. Side Balcony (SB)

c. Other Balcony (OB)

Front Balcony

- Projected from the front side of the building.
- The allowed railing height of the FB area is max. 1.2 mm
- This balcony area cannot be extended in the setback area.

- 30% of the front length area are MGC excluded for front balcony where the width has to be one meter.

MGC excluded FB area calculation for total building as:

FB = 1/3 x LF or (30% of LF)

=1/3 x BL x 1m W x Number of floors (LF= BL x 1m W x Number of floors)

Where, LF-Length of front area; W-Wide; BL- Balcony Length

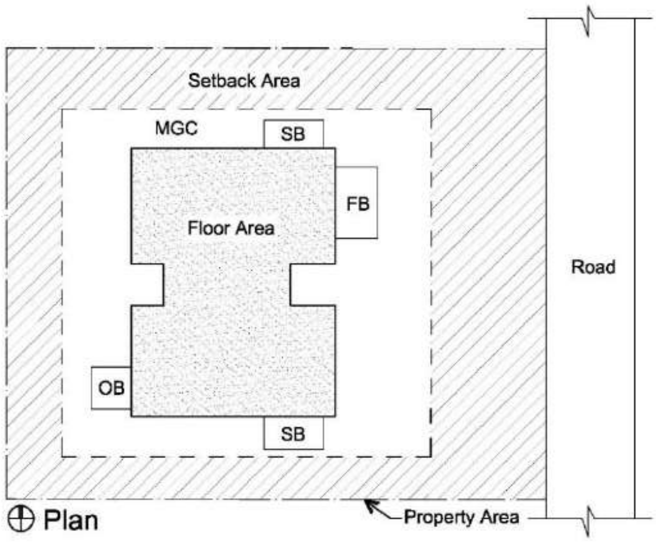


Figure 2. 13: Types of balconies according to INB (2008)

Figure 2.14 shows plan view and section of front balcony. The FB depth for each floor can be more than 1m or less than 1m and the placement can also be irregular but all area has to count in MGC except the calculated area which has found by the calculation.

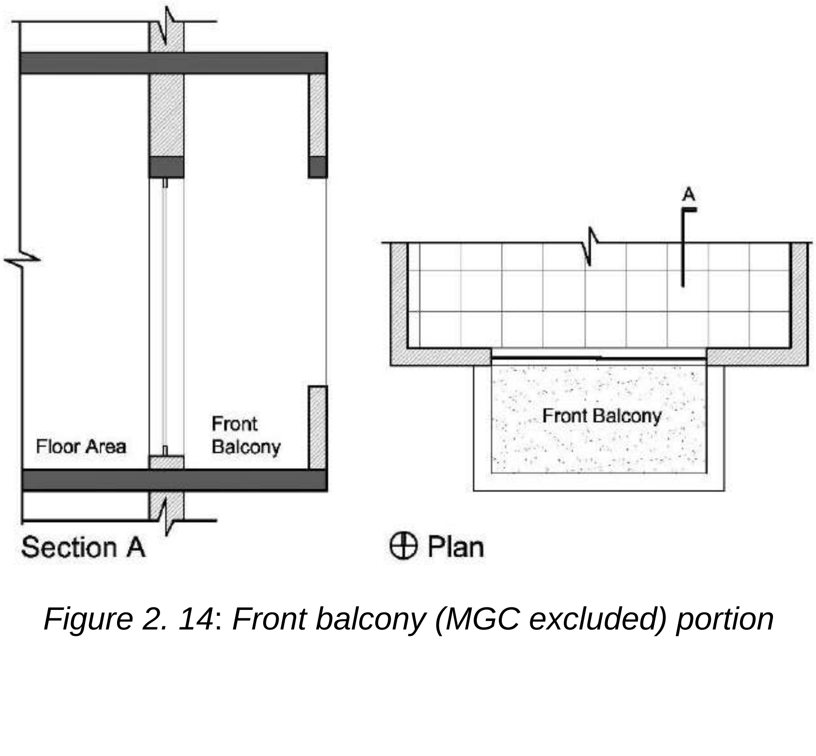


Figure 2. 14: *Front balcony (MGC excluded) portion*

Side Balcony

- Projected from the side of the building.
- 2.5% of total floor area is FAR excluded area if more area needed than that would be count as FAR included area (Figure 2.15)
- The allowed railing height of the SB area is max. 1.2 mm.
- This area cannot be extended in setback area.

Other Balcony

- Projected from the side or back of the building.
- The allowed railing height of the OB area is max. 1.2 mm.
- This area cannot be extended in setback area.
- The total area of OB is MGC included.

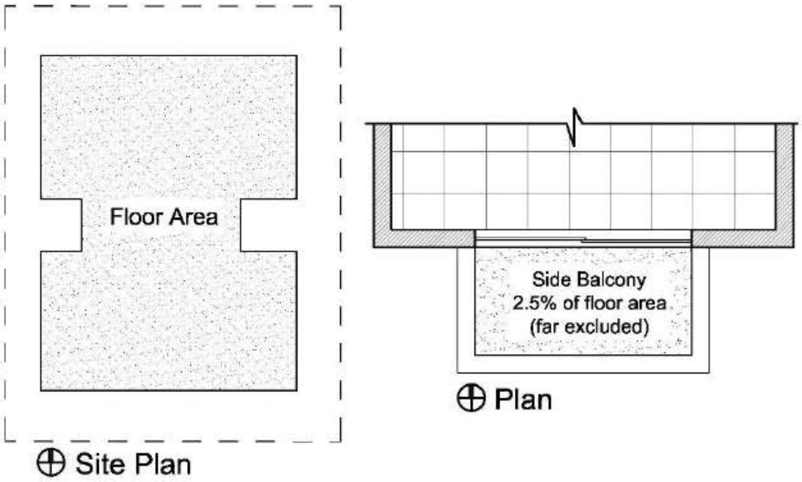


Figure 2. 15: Side balcony (MGC excluded) portion

Nevertheless, for child protection, certain precautions should be taken, such as installing a grill on every door/window. Aside from that, horizontal sunshades on the south, east, and west windows and balconies could be provided, as well as vertical shading devices on the west.

2.10.2 Illuminance and Daylight Factor based Standards

On a clear day, if the outdoor light level is approximately 10,000 lux. In buildings, the light level can be decreased to around 1,000 lux in the area nearest to windows. It could be as low as 25 to 50 lux in the middle (Levels, 2015). To compensate for the low levels, additional lighting equipment is frequently required. The term "illumination-based regulation" refers to the process of determining the minimum illuminance required to execute various visual tasks.

a) International Standards

The Illuminating Engineering Society of North America (IESNA) has recommended a four-step design procedure that includes: defining visual tasks in the proposed design, selecting an illuminance category; determining the amount of lighting required; and determining a target illuminance value for design. The IESNA provides a comprehensive list of standard lighting settings for various room types and activities in residential structures. Where working spaces, such as interior counters (fixed sitting counter beside bedroom, balcony) and bathroom vanities, are installed, these values are reported as horizontal and vertical illuminances. Vertical illuminance can be measured at a height of 5 feet and horizontal illuminance at a work surface of about 3 feet; the values are appropriate for the occupant age range of 25 to 65. (DiLaura et al., 2011; Holton, 2012). Table 2.5 shows the recommended illuminance values for household lighting.

Table 2. 5 Residential Illuminance Recommendations (DiLaura et al., 2011).

Room	Area/ Task	Horizontal Illuminance (FC)	Vertical Illuminance (FC)
Bedroom	General (dressing)	5 (53.82 lux)	3 (32.3 lux)

In Hong Kong, the Practice Notes for Authorized Persons (PNAP, 278) stipulate that livable rooms must have a minimum vertical Daylight Factor (VDF) of 4% (Building Department, 2009). Given that domestic settings are not nearly as a desk and display screen oriented as business buildings, a larger upper limit for Useful Daylight Illuminance (UDI) is achievable in residential areas than in offices (Mardaljevic, 2008). UDI 100 to 2000 lux is recommended for the work plane throughout the year, since it is neither excessively dark (>100 lux) nor too bright (2000 lux) for the occupants (Seraj, 2018).

b) National Standards

BNBC (2020) narrated that where work takes place over the entire utilizable area of a room, the general illumination over that area should be reasonably uniform, and the diversity ratio of minimum to maximum illumination should not be less than 0.7, the illumination of work areas within a building should be a minimum of 150 lux.

Table 2. 6 Based on activities, the recommended illumination levels for residential buildings (BNBC, 2020)

Room	Area/Activity	Illuminance (Lux)
Bedroom	General	50
	Bed-Head, Dressing Table	150

Table 2.6 lists the recommended lighting levels for residential structures based on activities. The fact that illuminance will surely decrease below this value by the conclusion of the cleaning and replacing period, the beginning illuminance should be higher than the recommended amount. To avoid or decrease glare discomfort, a gradual (rather than a rapid) transfer in brightness from one region of the field of vision to another is recommended.

2.11 Key- findings

This section presents a few selected issues which helped to establish and set parameters for methodology of simulation study.

- The recommended illumination levels for bedrooms are generally 50 lux in residential buildings and for bedroom dressing tables, bed-head space is 150 lux (BNBC 2020)
- A light shelf could be included in the structure to achieve glare-free illumination. The size and depth of the light shelf are dictated by the window's size and the facade's orientation.
- Although an external light shelf reduces solar gain in the room (Lam, 1986), an inside light shelf provides greater optical shielding from sun glare at intermediate depths in the room (Littlefair, 1995).
- In terms of enhancing daylighting quality in the interior space, light shelves at a height of 2m above floor level inside 3m high ceilings perform better than other places (Joarder et al., 2009).
- A maximum overhang of 0.5m is allowed over mandatory open spaces according to the Dhaka Metropolitan Building Construction Rule 2008 (Clause no. 50.6G).
- A balcony can be an acceptable and effective system of natural ventilation all year (Aelenei et al., 2014) and can work as a key aspect that influences energy savings by modifying ventilation openings, doors and shading devices to match the essential comfort demands and available circumstances (Angeraini,2016).
- A balcony can work as a shading device (Chan, 2015).
- The broader the balcony, the less glare and sun discomfort in surrounding indoor areas, and the deeper the balcony, the lower the air velocity. Although an open balustrade balcony can aid with internal ventilation, the partition walls of the balcony lower the velocity along the wall by roughly a fifth (Yeang, 1991).
- The balcony area cannot be extended in the setback area (INB, 2008).
- 30% front length area are MGC excluded for front balcony where the width has to be one meter (INB, 2008).
- For the side balcony, 2.5% of the total floor area is MGC excluded (INB,2008).

2.12 Summary

This chapter assessed the effectiveness of various balcony types as screening and shading features to improve indoor daylighting in apartment buildings in the context of Dhaka. The evolution of balcony space in Dhaka's urban apartments, as well as possible daylighting solutions to improve the lighting quality in balcony adjacent indoor areas, are discussed in this chapter. In addition, based on past research and published sources, the elements impacting daylight and standard illumination for residential spaces have been examined in this chapter. The chapter's findings aided in the selection of issues for which the simulation study's phases were established in Chapter 3.

CHAPTER THREE: METHODOLOGY

3.1 Preamble

Chapter 2 illustrates some information to start the simulation procedure. The detailed steps of the methodology of the simulation exercise are described in this chapter. The quantity and quality of daylight penetration can be identified by using an advanced lighting simulation tool, i.e., DAYSIM. In a physical experiment, it is difficult to isolate the impacts of one single aspect, and its variations due to synchronous influences of a wide range of conditions. Keeping other variants constant, simulation allows investigation of the impact of changes in one aspect. The lighting performances could be checked by changing the balcony patterns, balcony depths, railing heights, drop heights and could be evaluated for rooms beside balconies from the point of view of useful daylight inclusion.

The outcome of this chapter has a prime role to understand and evaluate different balcony types, features, patterns and their performances to get glare-free daylight inside indoor spaces. In addition, it includes the method of field survey investigation on balcony types and their effects on daylighting, criteria of case apartment selection and selection of different parameters for the case apartment and simulation tools. The simulation methodology used is described in depth in this chapter, along with the parameters and specific blind configurations. The process aids in assessing how well various designs perform in terms of illumination intensity inside residential structures. The next chapter will compare the annual CBDM simulation results of different balcony features in terms of daylight photometric based on the suggested methodology established in this chapter.

3.2 Methodology

Simulation analysis is chosen to analyze the design parameters of balcony features to improve the indoor luminous environment of the apartment. The flow diagram Figure 3.1 presents the steps of the simulation process of this research.

3.2.1 Microclimate of Dhaka

The microclimate plays a vital role in the city's overall climatic condition. Urban open spaces, fields, playgrounds, streets and courtyards typically cover about two-thirds of a city's total area and keep an impact on the atmosphere (Souch and Grimmond, 2006). In a consequence of its geographic location, Dhaka city experiences a hot, wet and humid tropical climate. It lies between latitudes 23º40'N and 23º55'N, longitude 90º20'E and 90º30'E. Three distinct seasons rule over the climate of the city, – the hot dry (March-May), the hot humid (June-November) and the cool dry season (December-February) (Ahmed, 1995). This city has a distinct monsoonal season. The annual average temperature is 27.5°C (81.5°F). While the summer is long and wet in the meantime cool dry season is short. April is the hottest month with an average temperature of 30.7ºC and January is the coldest month with an average temperature of 16.2ºC. Average radiation on a horizontal surface is 5.00 kWh/ m^2 and air flow is 4.1 m/s (Ahmed, 1996). High radiation influx is the main reason behind contributing to the difference in temperature observed in the hot dry season (March to May). Therefore, the Koppen climate classification stated Dhaka as a tropical savanna climate (Roth,2007).

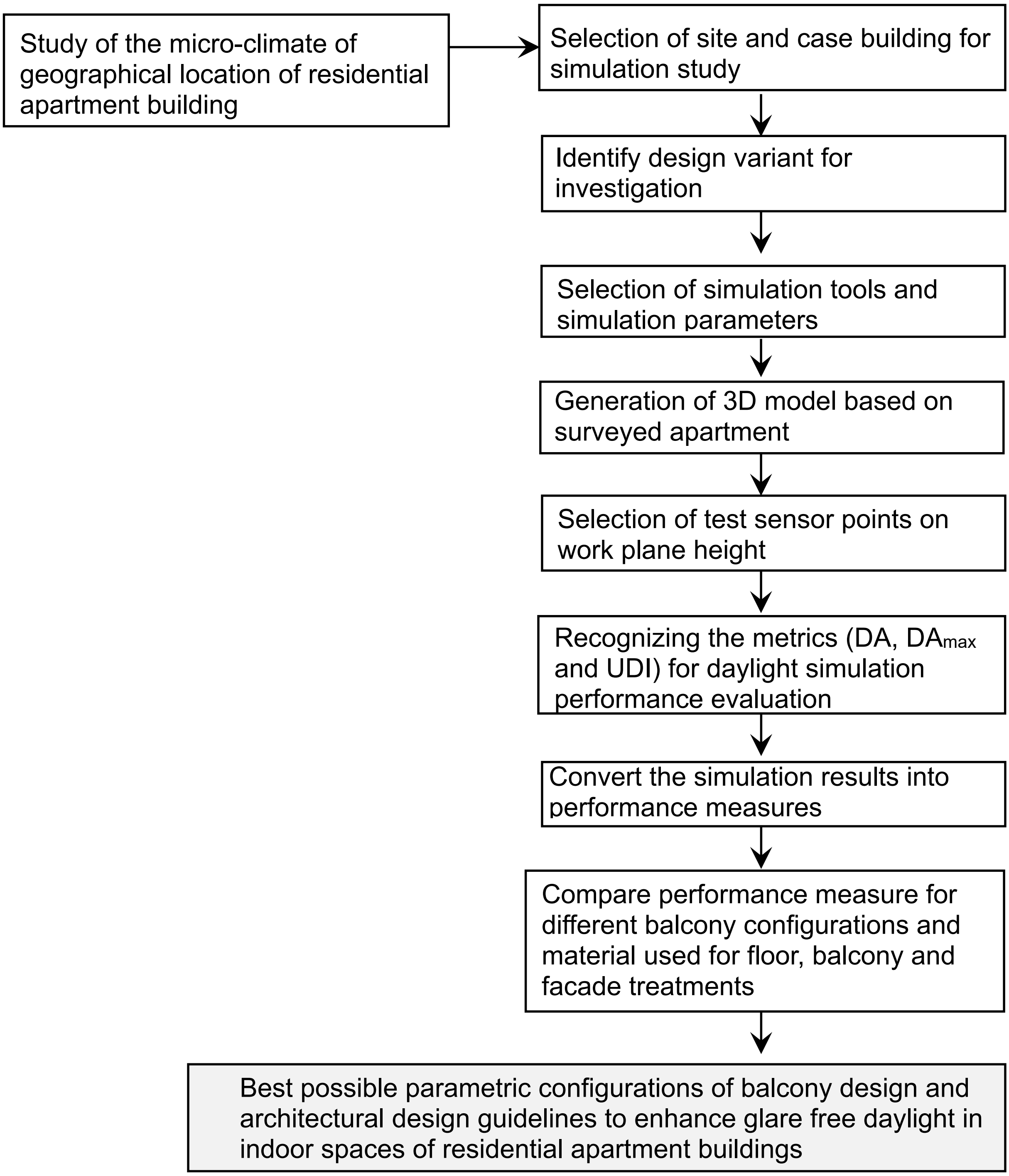


Figure 3. 1: Flow diagram (step by step) of the simulation process (after, Joarder 2011)

Dhaka city is marked by an increased built density and reduction of public open space, resulting from such a magnitude of urbanization, which has been reported to produce inadvertent modification of Dhaka's climate (Hussain and Sultan,1991). This is the reason behind over warming of Dhaka City. Figure 3. 2 shows the monthly average sun shine hours in Dhaka.

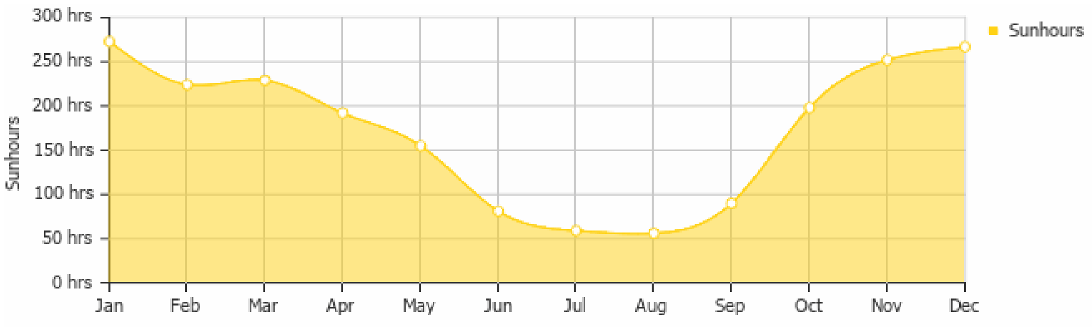


Figure 3. 2: Monthly average sun shine hours in Dhaka, year 2020 (Data source: Bangladesh Meteorological Department, Dhaka- 2017)

With high solar radiation March to May observed high air temperature and from June to October high humidity is associated with high air temperature (Joarder, 2007). To minimize the over-warming condition, solar radiation can be moderated from March to May while maximizing wind flow over warming can be minimized from June to October. Two prime climatic factors, sunshine hours and sky conditions are determining the quantity and quality of daylight and the luminous environment is also related to the variation of these two factors.

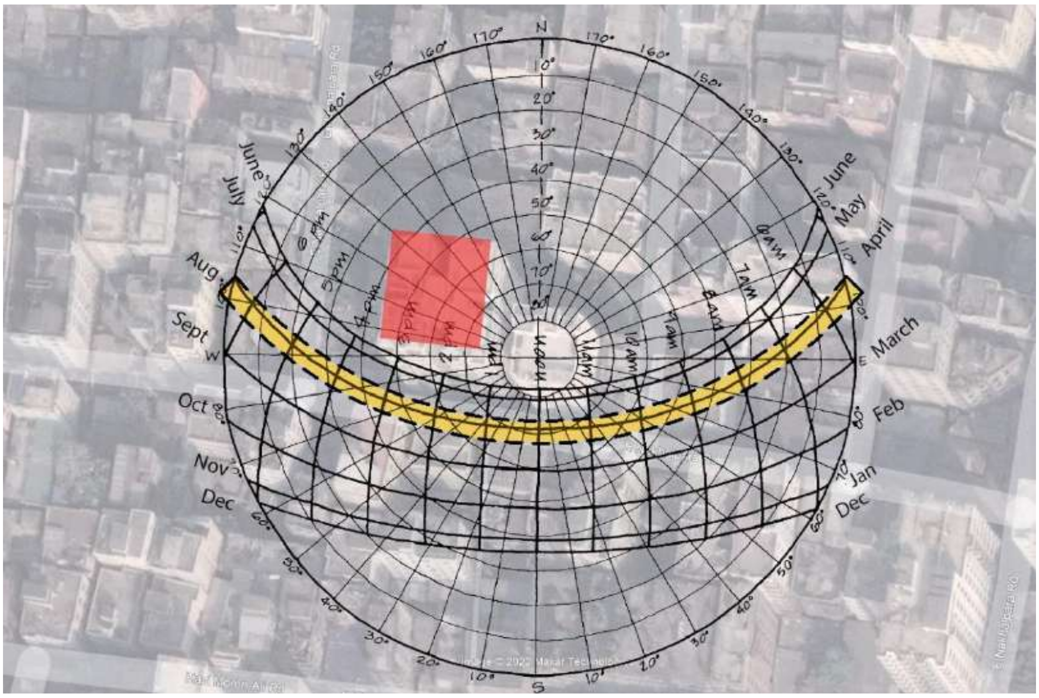


Figure 3. 3: Sunpath diagram of the month of August

Weather patterns and latitude are directly related to daylight. Latitude and weather patterns are the key factor in perceivable daylighting of any area (AGS, 2000). During a cool period, Dhaka perceived more than 200 sunshine hours per month. But due to cloud cover, monsoon months (warm-humid season) come down below 150 hours per month (Joarder, 2007).

During July to November the atmospheric condition of the diffused component of the daylight is substantially high. During this time sky remains cloudy. Due to this condition, the sun path diagram of Dhaka shows wide from July to November. Figure 3.3 shows the sun path diagram of Dhaka, Bangladesh.

a. Sky Condition

A composite climate remains over Dhaka. Here overcast, partly overcast and clear skies are perceived over the year (Figure 3.4), That's why planners have to be cautious to design for different sky conditions (Ahmed, 1987).

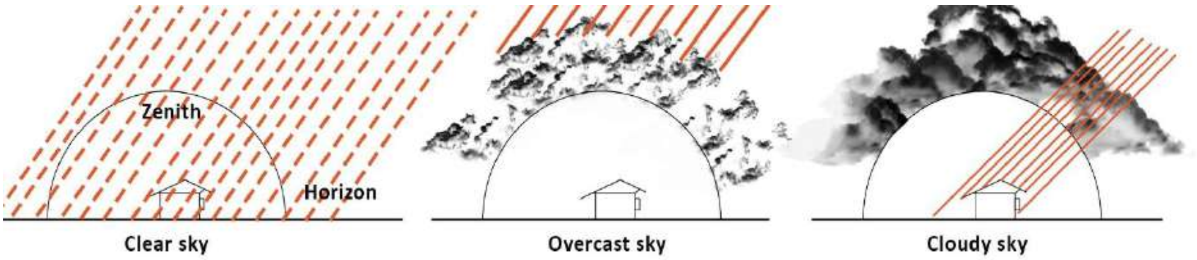


Figure 3. 4: Diversified sky conditions of Dhaka (after ,Hossain, 2011)

According to the sun's position changes throughout the day (up to 1,00,000 lux), the direct sunlight is substantially intense and varies. Daylight from a clear sky can be 10% to 25 % of the intensity of direct sunlight (10000-25000 lux). Daylight under partly cloudy conditions can be highly variable; daylight under full overcast conditions can be 5% to 10% of sun conditions (5000- 10000 lux) (Joarder, 2007).

Table 3. 1: Sky condition over a year round (after,Khatun, Rashid and Hygen, 2016)

Type of sky	Pre-monsoon (March-May)	Monsoon (Jun-Sept)	Post-Monsoon (Oct-Nov)	Cool Dry (Dec-Feb)	Total (day)
Clear sky	62	38	39	77	215
Overcast sky	30	84	22	14	150
Total sky	92	122	61	90	365

In context of Dhaka, the sky remains clear and overcast in different parts of various seasons. During summer (Hot Dry), the sky remains both clear (sunny with sun) and overcast. During the warm-humid (March-November) period, the sky remains overcast considerably. During monsoon (June-September) which is one third of the whole year the sky remains significantly overcast. During the winter (December-February) the sky mostly remains clear. While during the rest of the year, both clear and overcast conditions are observed (Joarder et al., 2009;) Concerning cloud cover over a year sky conditions of Dhaka city are shown in Table 3.1.

Table 3. 2: Illumination from a design sky on a horizontal unobstructed surface on different latitude and solar altitude

Suggested values for overcast sky	**lux (lumen/m2)**
Latitude 50-60 ^{O}	5,000
Latitude 40-50^{O}	5,000-6,000
Latitude 30-40^{O}	5,000- 8,000
Latitude 20-30^{O}	8,000-10,000
Latitude 10-20^{O}	10,000-15,000
Suggested values for overcast sky	**lux (lumen/m2)**
All latitude	5,000
Solar altitude 15^{O}	14,000
Solar altitude 30^{O}	36,000
Solar altitude 45^{O}	58,000
Solar altitude 60^{O}	75,000
Solar altitude 75^{O}	83,000
Solar altitude 90^{O}	94,000 to 110,000

b. Design Skies

Many researchers over the world agree that in temperate climates, daylight design should be considered for a design sky; not the worst situation possible, as this would be unrealistic, but for a situation when illumination is exceeded for about 85% - 90% of the daylight hours. By statistical evaluation of long-term illumination records, a design sky illumination value can be established for a particular location. In lower latitudes, the sky is much brighter than in the higher latitudes. Published data on outdoor design sky illuminance specifies a value of approximately 10,000 – 12,000 lux for Dhaka latitudes (Iqbal, 2015). Table 3.2 presents the outdoor illumination that is bettered 85% of total daylight hours for this location.

With reference to Dhaka, in warm-humid climatic context shows that for reducing the eight-hour time frame, an average of about 16,500 lux can be considered as outdoor design sky illuminance (Iqbal, 2015).

3.2.2 Field Survey

For this study, the residential buildings of Dhaka are taken into consideration. After selecting a target group, a field survey is conducted upon some of the buildings to find out commonly used balcony types beside bedrooms. Some common types of balconies are searched at first. Among those balconies, different types and depths of balconies are analyzed. Primarily four balconies beside the bedroom are selected. Among them, one is considered for furtherer work according to specific selection criteria.

a. Target Group

Dhaka, being surrounded by the Buriganga river, is a metropolis of many possibilities. It has one of South Asia's largest metropolises, with 45 percent of the population in the middle and upper middle-income bracket (Islam, 2005). Based on economic expenditure or consumption level, the middle-income group can be characterized in relative or absolute terms (Seraj, 2018). Lower-middle (5,000-10,000 BDT per month), middle-middle (10,000-20,000 BDT per month), and upper-middle (25,000-50,000 BDT per month) income groups are the subgroups of middle income (Jahan, 2012). As a result, the target demographic for this research is Dhaka's middle-income population and their preferred location needs to be understood. Moreover, the required apartment size has to be recognized. After those suitable buildings with preferred balconies have to be selected for further work.

b. Preferred Building Type and Unit Size

Middle-income people make up a large section of Dhaka's population. This is why, during the last few decades, high-rise apartments in Dhaka have become increasingly popular as a means of meeting housing needs (Ahsan et. al., 2014). In Dhaka, the trend is to create high-rise residential buildings with 12-20 stories (Kamruzzaman and Ogura, 2007).

Most developers choose Malibagh, Shantinagar, Shamoly, Mirpur, Farmgate, Tejgaon, Tejkunipara, Kalabagan, Monipuripara, and Uttara as middle-income regions since land prices in these areas are lower than in other planned areas such as Gulshan, Banani, and Dhanmondi (Seraj, 2018). According to a study, the medium income group wants flats between 92.9 and 139.4 m^2, while developers claim that areas between 69.7 and 111.5 m^2 are within the range of the middle-income group in Dhaka (Seraj, 2018). According to another field survey, 69 percent of apartment units selected sizes between 65 and 148.6 m^2 (Seraj, 2018). Figure 3.5 depicts mid-income groups' preference for apartment unit sizes.

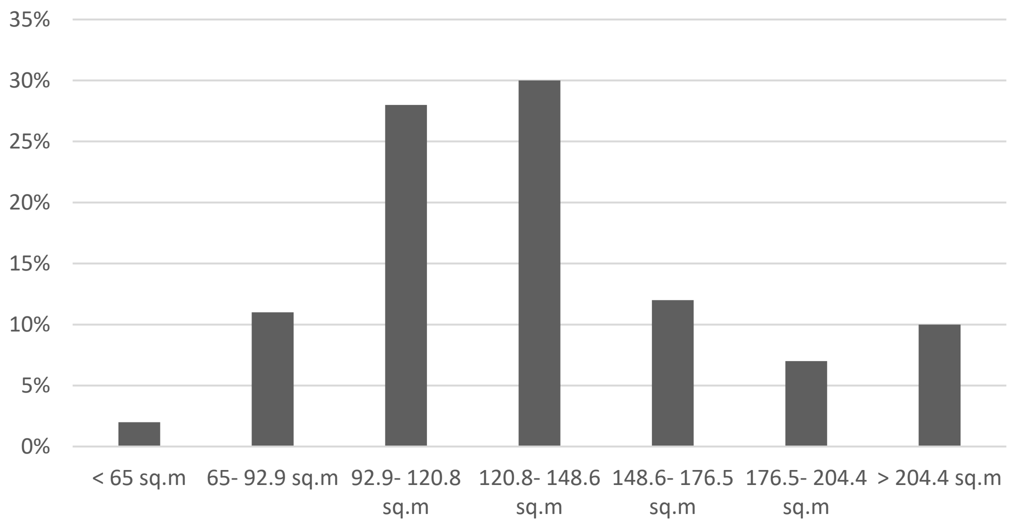


Figure 3. 5: Size preference for apartment unit of mid-income people (after,Seraj,2018)

c. Preferred Site and Buildings

The criteria for the site and building selection are that it would be in an urban context and the same micro-climate because of avoiding the complication of daylighting levels for different areas. A 6m front road would be required along with the building and also a roadside balcony for investigation. According to the above criteria, the Tejgaon area is chosen, because it is a populated area. Mainly middle-income family size units are found. Moreover, many residential buildings are present and it is located almost at the center point of Dhaka. Monitoring the above criteria total of four buildings were selected with different balcony patterns. Figure 3.6 shows the location map and google map of the four surveyed buildings. According to balcony depth (D) they are coded as D 600, D 760, D 915 and D 1065. Figure 3.7 shows the location map, road network and topography of D 600 and D 915. Figure 3.8 and Figure 3.9 show the location map, road network and topography of D 760 and D 1065.

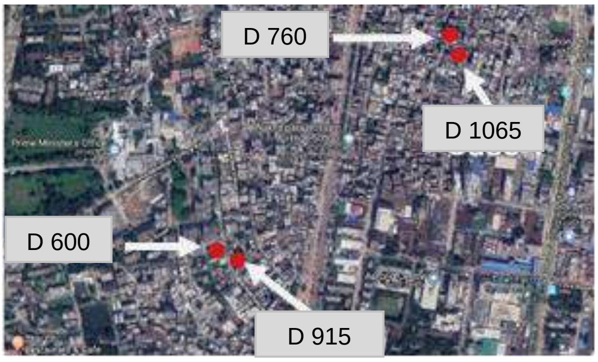


Figure 3. 6: Location map and google map of surveyed buildings

Figure 3. 7: Location map, road network and topography of D600 and D915

Figure 3. 8: Location map, road network and topography of D760

Figure 3. 9: Location map, road network and topography of D1065

d. Field Measurement and Case Spaces

Primarily four types of balconies from different buildings are chosen from the same area under the same microclimate at Tejgaon. These four types of balconies are mostly found within mid-income affordable unit sizes. Selected four buildings have 6m front roads and roadside bedrooms with attached balconies. The balcony types, patterns and sizes are different.

Figure 3. 10: Exterior view of D 600, D 760, D915 , D 1200 (left to right)

On a sunny morning, on 7th August 2019 the survey of D 600 and D 915 and on 8th August 2019 the survey of D 760 and D 1065 were done. At first, the bedroom sizes, heights, balcony sizes, balcony heights were measured by using a measuring tape. Figure 3.8 shows the building exterior views and Table 3.3 shows the building previews. Figure 3.11, 3.12, 3.13 and 3.14 show the floor plans and interior views of the buildings.

Table 3. 3: Buildings' preview of the four surveyed buildings

Building Preview	D 600	D 760	D 915	D 1200
Building Type	Residential	Residential	Apartment	Apartment
Location	Nakhalpara	Tejkunipara	Nakhalpara	Tejkunipara
Building Height	21336 mm (70')	9144 mm (30')	27432 mm (90')	27432 mm (90')
Selected Floor	1st Floor	2nd Floor	1st Floor	2nd Floor
Bedroom Size	(3048 x 3658) mm	(3048 x 3658) mm	(3048 x3 658) mm	(3048 x 3658) mm
Bedroom height	2896 mm (9'6")	2896 mm (9'6")	2896 mm (9'6")	2896 mm (9'6")
Balcony Size	(600 x 6600) mm	(760 x 3500) mm	(915x 2100) mm	(1200 x 1500) mm
Balcony Pattern	L shaped	Rectangle	Rectangle	Rectangle
Balcony Type	Recessed	Cantilever	Cantilever	Cantilever
Window in Bedroom	1	1	1	1
Door in Bedroom	2	2	2	2

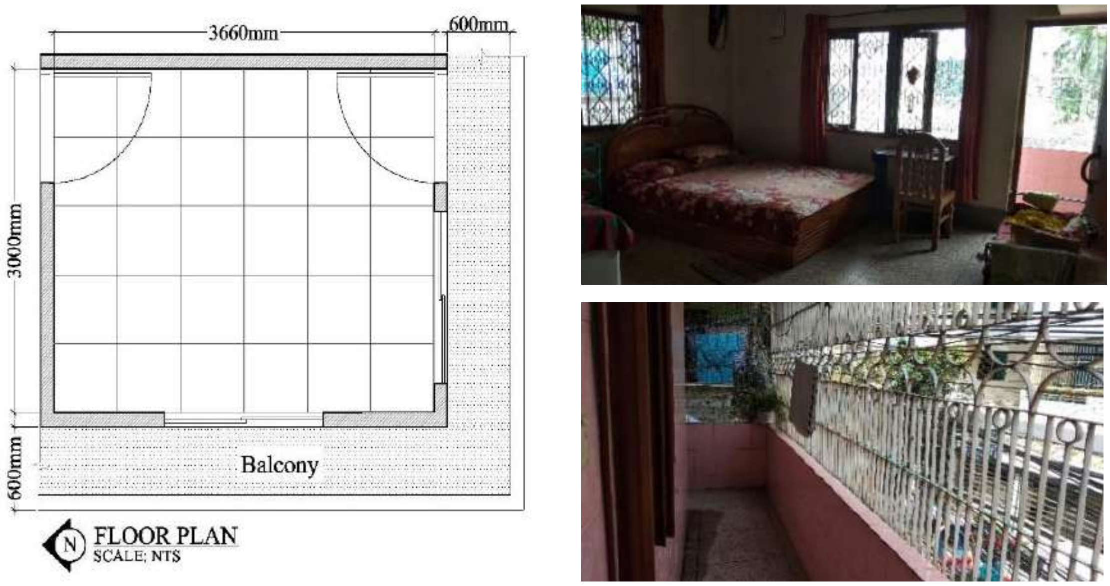


Figure 3. 11: D 600 bedroom plan; bedroom and balcony interior photos

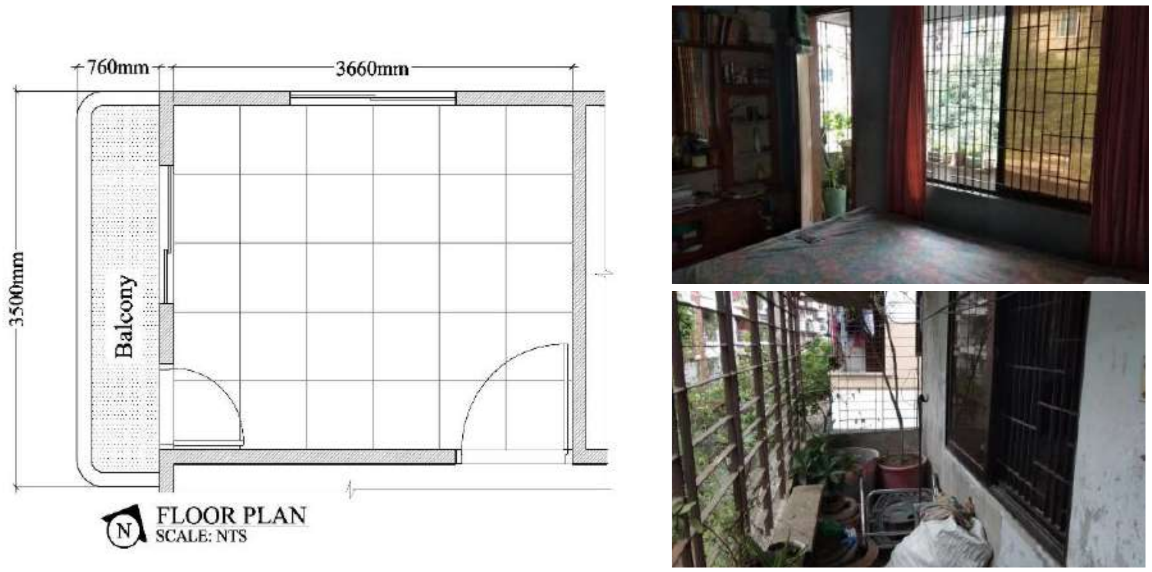


Figure 3. 12: D 760 bedroom plan; bedroom and balcony interior photos

The details of the buildings were studied carefully and the measurements are taken. The detail measurement of window sill levels and balcony drop levels were taken. The partition wall between balcony and bedroom were checked and detail measurements were taken. Moreover, the room materials were observed and noted down. The selected four cases were found with similar construction materials and finishing. Table 3.4 shows the material attributes discovered during field survey.

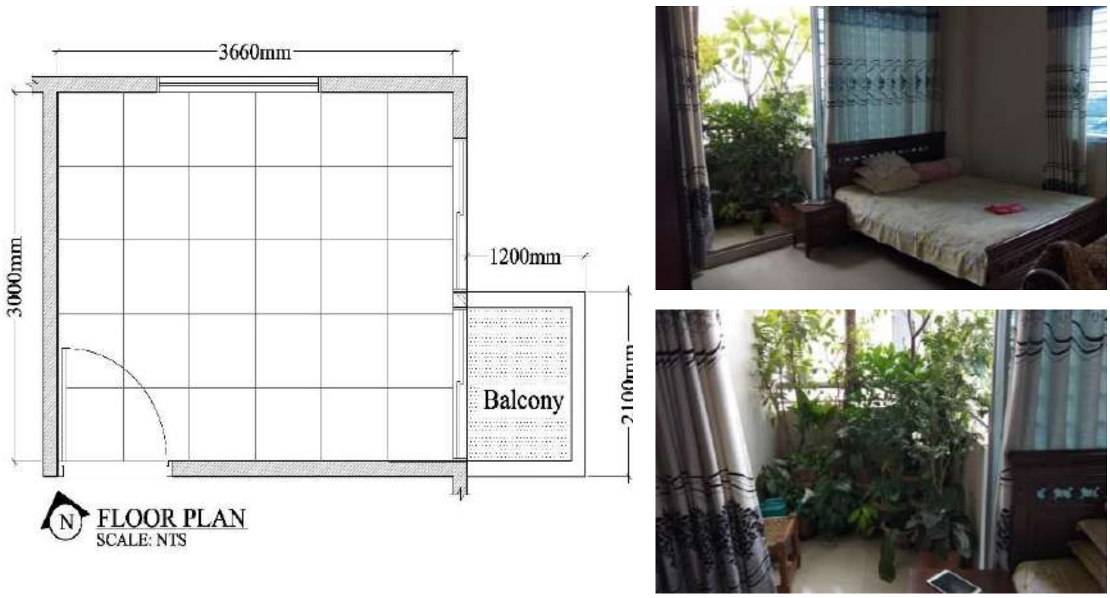


Figure 3. 13: D 915 bedroom plan; bedroom and balcony interior photos

Figure 3. 14: D 1200 bedroom plan; bedroom and balcony interior photos

Table 3. 4: Material attributes discovered during field survey

Building Element	Material Description	Material Properties
Ceiling	Concrete with white paint	a diffuse reflection 40%
Walls	Brick with plaster, both side	a diffuse reflection of 70%
Floor	Tiles finished	a diffuse reflection of 50%
Mullions	Aluminium	a diffuse reflectance 50%
Window	Single glazed low aluminium frame	90 % of transmission
		0.70 pollution factor
		0.90 Framing Factor
		0.85 Maintenance Factor

Lux meter measurements were obtained every 600 meters for 2 minutes and found the maximum and minimum ranges from the lux meter screen. Afterward, an average rate was calculated, which is shown in Table 3.5 along with the final illuminance level in lux.

Table 3. 5: Illuminance (Lux) of four surveyed building

Illuminance level of four surveyed building							
Depth	Date	Time	Distance from balcony (mm)	Minimum (Lux)	Maximum (Lux)	Average (Lux)	Room Average (Lux)
D 600	27.08.2019	From 10 am to 11:30 am	600	1107	1799	1645	595
			1200	450	1250	671	
			1800	422	779	575	
			2400	258	321	281	
			3000	224	237	228	
			3600	140	234	173	
D 760	28.08.2019	From 12 pm to 1:30 pm	600	93	143	136	77
			1200	41	90	106	
			1800	27	74	90	
			2400	24	47	82	
			3000	14	35	35	
			3600	12	30	15	
D 915	27.08.2019	From 10 am to 11:30 am	600	345	4047	2048	561
			1200	308	1020	532	
			1800	279	318	296	
			2400	198	237	226	
			3000	48	290	148	
			3600	30	419	118	
D 1200	28.08.2019	From 12 pm to 1:30 pm	600	345	4047	253	144
			1200	308	1020	244	
			1800	279	318	164	
			2400	198	237	86	
			3000	48	290	74	
			3600	30	419	44	

e. Case Building Selection

Following selection criteria were considered while selecting the case building and site.

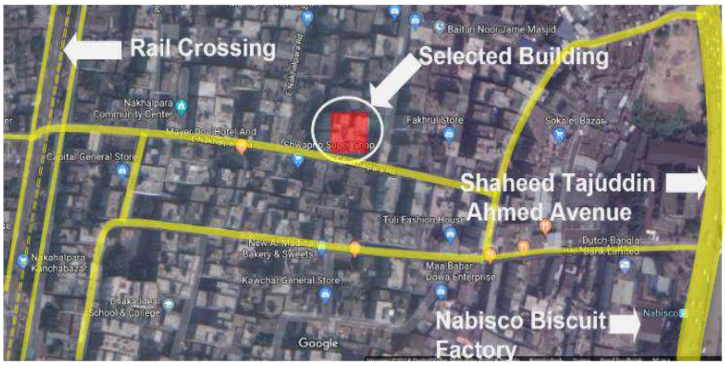
a. The building has to be apartment type.
b. The building must be located within an urban context.
c. The building design has to comply with BNBC standard.
d. 6m front road would be required along with the building.

e. The building also required road side balcony beside the bedroom.
f. Balcony must be open on at least one side with a full sliding door/window to receive ample daylight from the side.
g. The balcony beside the bedroom should have at least one window.
h. The internal arrangement should allow ample daylight penetration and dispersion.

Table 3. 6: Surveyed four buildings with correspondence to selection criteria

Criteria	D 609	D 762	D 915	D 1065
a	x	X	√	√
b	√	√	√	√
c	x	X	√	√
d	√	√	√	√
e	√	√	√	√
f	X	X	√	√
g	√	√	√	√
h	√	√	√	√

Location Map of Tejgaon



Location Map of the area Nakhalpara

Figure 3. 15: Case building location map

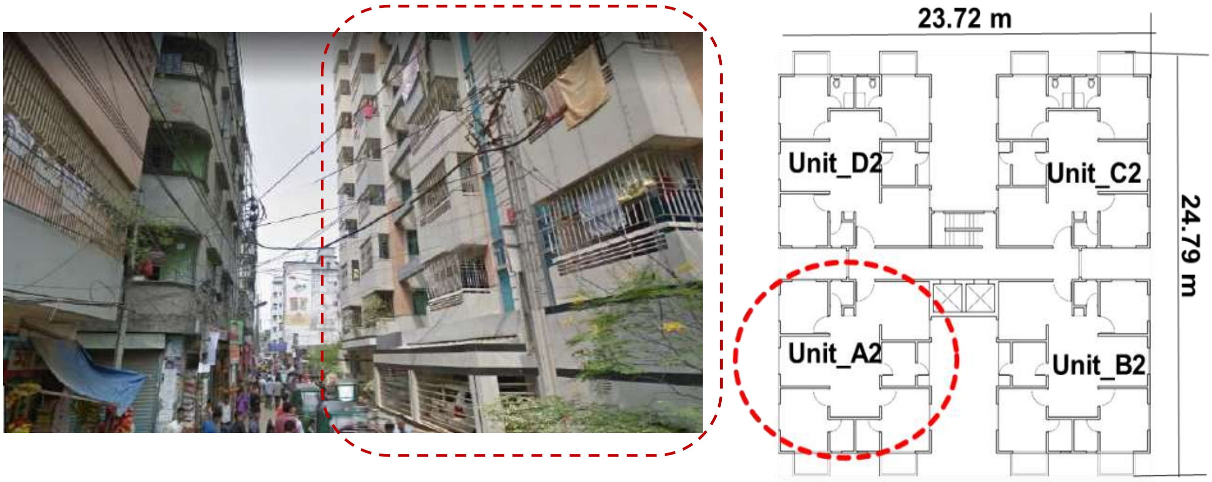


Figure 3. 16: Front view and unit plan of the case building

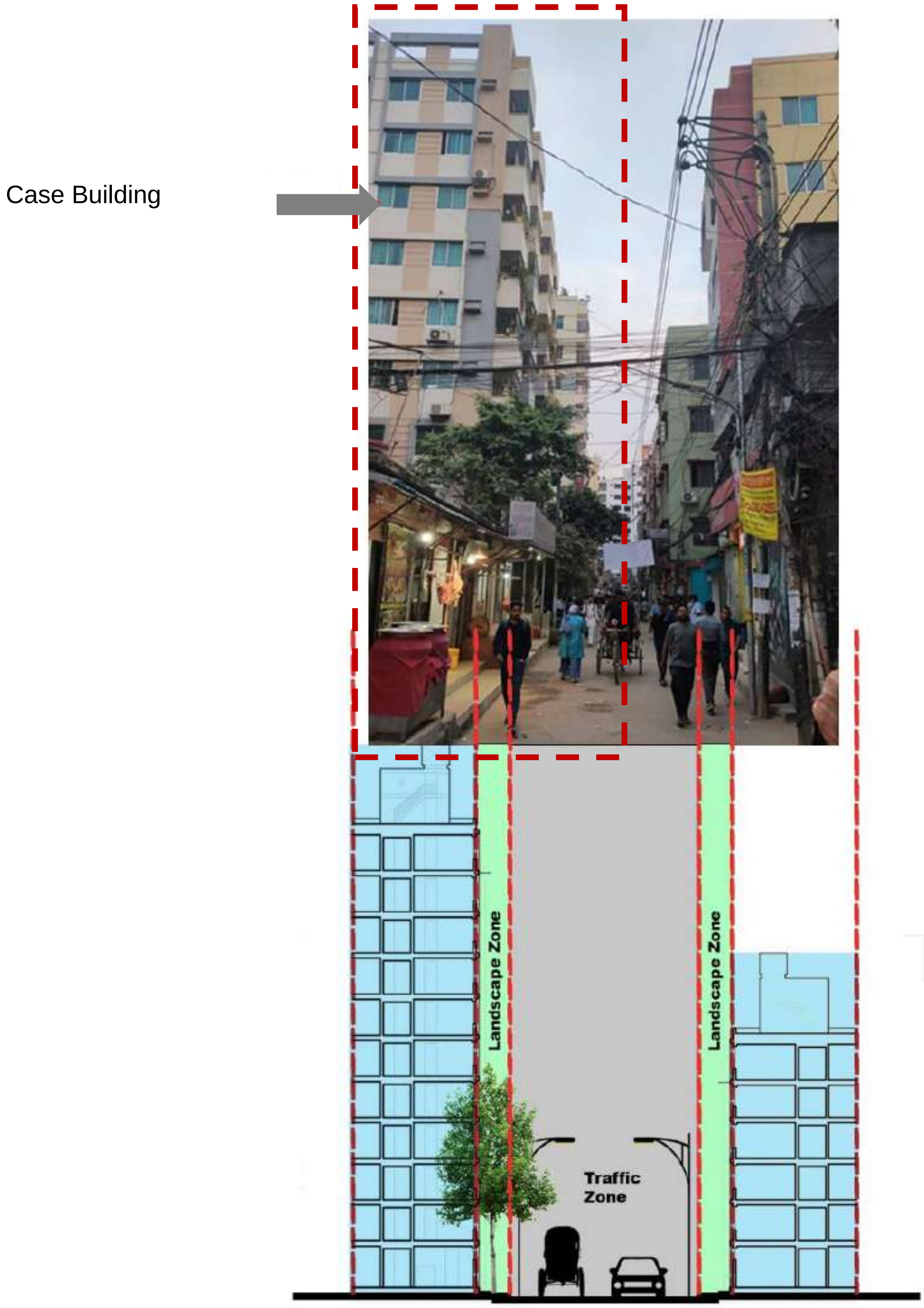


Figure 3. 17: Site surrounding parameter of the case building

Table 3.6 shows selection criteria. Among the four buildings from the field survey, one apartment building was selected as the case apartment that better satisfied the selection criteria with better daylight illuminance measured by lux meter. The nine-storied building at Nakhalpara (D 915) in the Tejgaon area was selected for examination and simulation study as the case building. Figure 3.15 shows thelocation map and the google map of the case apartment building. Figure 3.16 shows the front view and unit plan. Figure 3.17 shows the site surrounding parameter of the building.

The selected case building is a nine storied with a 6m wide front road with square shape having typical floor plans. The apartment has four units on each floor and has a vast opportunity for daylight exposure through balconies and facades. One roadside unit of apartment A2 is selected as a case apartment and a bedroom with an attached balcony was selected for the study. The bedroom is 3048x3658 mm with a clear ceiling height of 2896 mm and a 915 x 2134 mm balcony is attached to the bedroom. The floor area ratio of the balcony to the bedroom is estimated to be around 4:1.

3.2.3 Design Variants for Investigation

In this research, the initial simulation model is built using the ECOTECT V5.0 tool. Balcony configurations and locations were examined to get the best result of glare-free daylight in bedrooms beside the balconies. Here the window of the bedroom is considered open. The experiment was done in eight different phases and the phases progressed with previous findings.

In the first phase, five different railing heights were placed alternatively at the balcony to get the best result of glare-free daylight to the adjacent bedroom. By taking the best option from phase one, in phase two, six different balcony drop levels are studied alternatively. With this best option, in phase three, two alternative designs of walls between the balcony and bedroom were analyzed to get the best performance. Considering the best performed one, in phase four, the balcony was placed in two alternative ways. Keeping the best result constant in the next phase five different balcony floor depths were studied and after getting the best result, four-floor materials and six façade colors were checked one after one. Finally, by keeping the best parameters three local types of balconies are checked.

The outdoor and indoor conditions and parameters discovered during the physical survey were kept constant for other parameters. The height of the work plane was 750mm. As seen in Section 3.2.5, the grid arrangement is built into the work plane height.

The potential scenarios were simulated using dynamic simulation metrics that include 8760 (24x365) hours of a year's worth of sky models. The hours of the day from 6:00 to 18:00 were considered in this study. Figure 3.18 shows the balcony performance evaluation process.

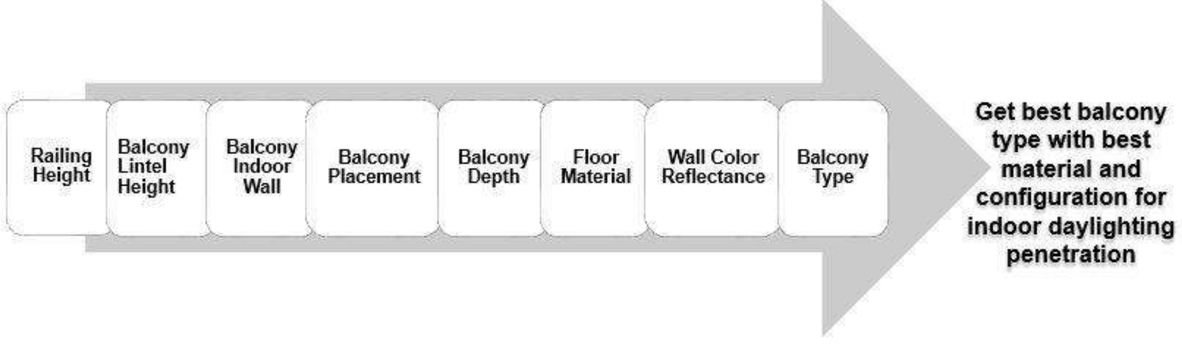


Figure 3. 18 : Balcony performance evaluation process

3.2.4 Selection of Simulation Tools

Several methods of daylighting analysis have been generated and developed in the past. Researchers, designers, and consultants are using these from physical modeling to computer-based simulations and analysis methods and make it possible to predict the performance of daylighting systems even when a building is not constructed. The quantifiable values, as well as illuminance levels, can be measured by using these methods. Several types of lighting simulation tools are available in the market. The Tools Directory of Building Energy Software (US-DOE, updated on August 26, 2020) listed 48 tools under the —Lighting System category, among them 21 were advertising daylighting as a key feature. Round Robin Ranking is a creative thinking tool allowing to compare different options in pairs, rank, prioritize and make a decision. However, to get an accurate result is not easy, it is predictable, or often even matching values between techniques due to the multitude of variables, including sky selection. So, the prediction accuracy and modeling capacities have several levels based on listed computer-based tools. For example, LUMEN MICRO (Baty, 1996) and SUPERLITE (Modest, 1982) can compute daylight under strict boundary limitations, whereas, some other software can compute complex model geometry and arbitrary environments, such as LIGHTSCAPE (Khodulev et al., 1996) and RADIANCE (Ward, 1998), with photorealistic rendering capacity to evaluate the quality of lighting in 3D space. A suitable simulation tool is required for the evaluation of the daylighting concept to ensure effective daylighting (Joarder, 2011), which

- has high prediction capability for indoor daylight distribution;
- can model simple to complex geometry with surrounding environments; and
- can provide climate-based daylight metrics as output (e.g. DA and UDI).

However, it is difficult to analyze accurately by using software but not impossible to do. So, when choosing between different sky representations, the users have to understand the implications of their selections. In contrast, RADIANCE, a backward raytracing software package for lighting simulation, is validated for accurate prediction of the distribution of indoor daylight environments by many researchers, for example, Du et al. (2009), Ibarra et al. (2009), Bryan et al. (2002) and Reinhart et al. (2001). Though RADIANCE can predict light levels for complex geometry accurately, RADIANCE does not have any built-in graphical interface to generate a physical model, however, it is possible to use other software as a modeling interface for RADIANCE, e.g. AUTOCAD and ECOTECT. Among the RADIANCE-based ray tracer, a limited number of softwares are able to calculate climate-based metrics as final output, such as 3D SOLAR, GENELUX, LIGHTSWITCH WIZARD, S.P.O.T, LIGHT SOLVE and DAYSIM.

In this research, DAYSIM is selected for daylight simulation analysis which also satisfied the above-mentioned three criteria. Daylight Autonomy (DA%), maximum Daylight Autonomy (DA_{max}%), Useful Daylight Illuminance ($UDI_{<100\%}$, $UDI_{100\text{-}2000\%}$, $UDI_{>2000}$%) and illumination on a specific point can be calculated by using the DAYSIM simulation program. DAYSIM uses a RADIANCE (backward) raytracer combined with a daylight coefficient approach. DAYSIM considers Perez all weather sky luminance models (Perez et al, 1990; 1993) and can provide more than 365 x 24 = 8760 hours of data for each sensor point. DAYSIM has been validated comprehensively and successfully for daylighting analysis (Reinhart et al., 2007).

3.2.5 Construction of a Three-dimensional Model for Computer Simulation

Following the field survey information, a building model is first created. The chosen unit is on the first floor, and it is used in the simulation computation. Researchers can use daylight simulation to explore the impact of one variable while keeping the others persistent. Here, daylight penetration will be checked into the bedrooms beside balconies by changing railing height, balcony drop levels, using a light shelf in the balcony, wall between balcony and bedroom, balcony position, balcony depth, floor material, wall material and local balcony types one after one.

The case apartment walls are plastered brick walls with white paint on the internal and external surfaces, with a clear floor-to-ceiling height of 2875mm, a wall thickness of 125 mm, and a ceiling thickness of 125mm plastered and white painted (inner surface) RCC.

Table 3. 7: Parameters for simulation modeling

Sl.	Parameters	Specification
1	Total area of the apartment	102.19 sqm
2	Total area of the bedroom beside balcony	11.45 sqm
3	Balcony area	2.16 sqm
4	Balcony ceiling height	2.9 m (White painted)
5	The bedroom work plane height	0.75 m
6	Bedroom ceiling height	2.9 m (White painted)
7	Floor	White glazed tiles
8	Wall	Plastered and white-painted 0.125 mm thick
9	No of window in bedroom	01
10	Window sill level height	0.75 m
11	Glazing for windows	A single clear glass panel with an aluminum frame
12	Balcony drop level	Ended at 2.1 meter from finished floor level
13	No of sliding door	01
14	Sliding door material	Single panel of clear glass with aluminum frame
15	Ceiling material	Concrete with white paint finish
16	Shading device	Plastered concrete with white paint finish

According to RAJUK guidelines, the width of a shading device is 500mm that is allowed in mandatory open spaces (BNBC, 2020). The interior area is simulated as empty, devoid of any furniture, to avoid the effects of such surfaces, which may disguise the differences in the consequences of the various studied parameter. The modeling parameters for the simulation investigation are shown in Table 3.7.

3.2.6 Identifying the Sensor Points

The initial step in the daylight simulation is to choose the number and position of sensor points after creating the model. Defining a grid of illuminance sensors that stretches throughout a lighting zone is a frequent strategy (Reinhart et al., 2006). Depending on the space, some sensor sites can be designated as "core work plane sensors", which are sensors positioned close to where the inhabitants are usually found. For simulation purposes, the entire bedroom floor is gridded with 12 intersecting sensor points. Figure 3.19 shows the core and test sensor points. Figure 3.20 shows a schematic cross section of the bedroom. These 12 sensor locations are placed at a height of 750mm from the finished floor level, which represents the work plane height in Dhaka's residential areas (BNBC, 2020). At work plane height, a standard grid dimension of 915 mm X 600 mm is maintained.

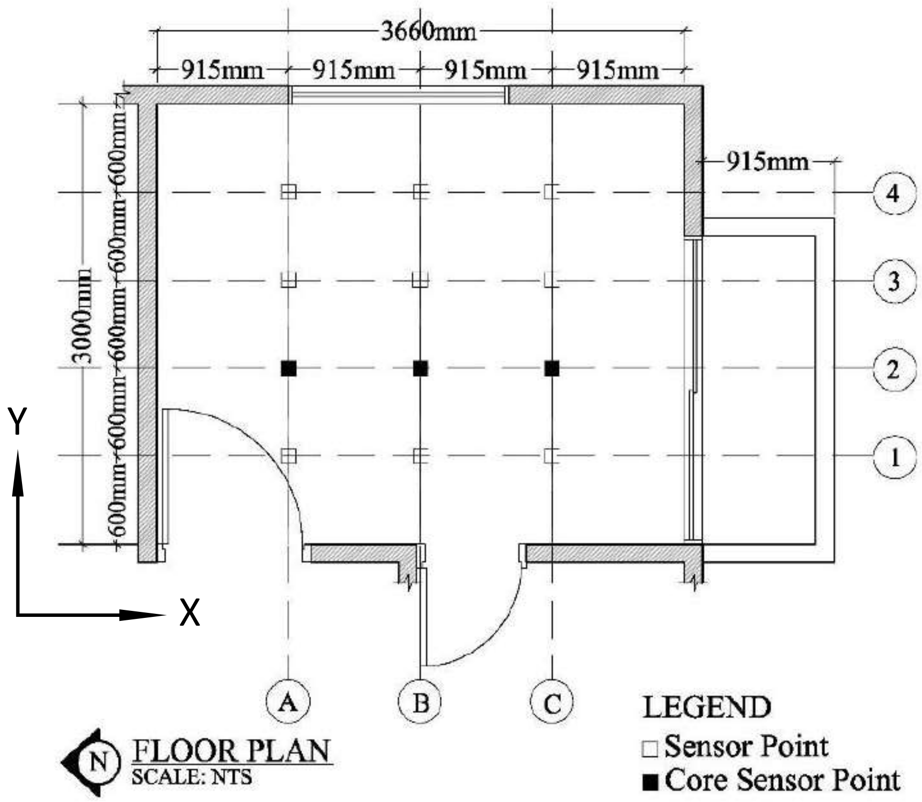


Figure 3. 19: Location of the sensor points in bedroom plan

Table 3. 8: Points of intersection for simulation

Number	A	B	C
1	1A	1B	1C
2	**2A**	**2B**	**2C**
3	3A	3B	3C
4	4A	4B	4C

In the 'X' direction, there are three sensor axis lines with an equal distance of 915 mm between them and four in the 'Y' direction with an equal distance of 600 mm between them (Figure 3.19). The location of the core sensor points is examined on the 'X' axis and in the north-south direction, from the balcony to the inside. Visible Node: 12; Core Sensor Point: 03.Core sensor points are 2A,2B and 2C. The intersection grid locations are coded using the letter and number method indicated in Table 3.8.

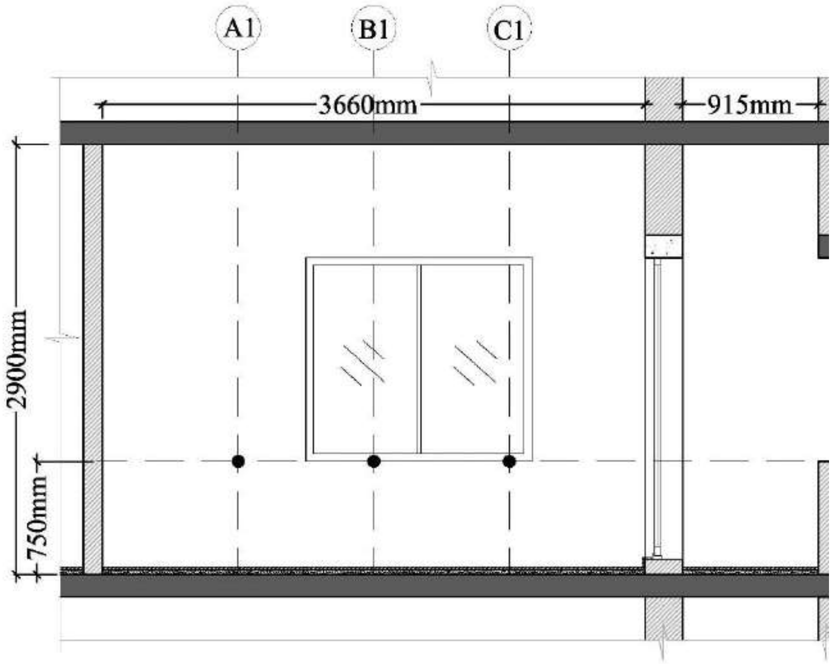


Figure 3. 20: Heights of the sensor points in bedroom section

3.2.7 Defining a Time- Basis and Additional Simulation Parameters

In a yearly CBDM simulation approach, hourly illumination is calculated at intersecting grid points for the entire year. According to BNBC (2020), the minimum illuminance level for a bedroom (general area) should be 150 lux.

Table 3. 9: Simulation parameters for daylighting analysis

Sl. No	Parameters	Specifications
1.	Location	Dhaka
2.	Longitude	90.40° N
3.	Latitude	23.80° E
4.	Local Terrain	Urban
5.	Precision	High
7.	Time Zone	+6 GMT
8.	Simulation Time	6.00 to 18.00
9.	Date	Whole year
10.	Sky Illumination Model	Perez all possible sky model round the year (Appendix- B)
11.	Unit of Dimension	SI metric (m, cm, mm)
		Photometric dimension: SI (Lux, cd/m^2)
12.	The window glazing portion's light qualities	90% transmission
		Pollution factor: 0.70
		Framing factor: 0.90
		Maintenance factor: 0.85

Table 3.9 lists the dynamic daylight simulation parameters and Table 3.10 shows the material used for simulation. DAYSIM calculate illuminance at discrete sensors, the simulation parameters needed to be modified slightly. Higher parameter settings will result in longer process time. Therefore, the art is to use parameters that are sufficiently high but not too high. The parameters in DAYSIM non-default RADIANCE simulation parameters for the simulation analysis for complex geometry are shown in Table 3.11 (definitions in Appendix C). DAYSIM uses the same raytracer used to generate RADIANCE rendering.

Table 3. 10: Material properties for daylighting simulation

Building element	Material Characteristics
Wall	115mm brick with a 10mm plaster finish on both sides. 2.620 U Value 0.418 solar absorption Decrement in temperature: 0.7
Window	A single pane of glass with an aluminum frame is used (no thermal break). 6.000 U Value 0.94 solar absorption Decrement in temperature: 1.74 (refractive index of glass)
Floor	On the ground, there is a 100mm thick concrete slab. 0.880 is the U value. 0.467 solar absorption Decrement in temperature: 0.3
Shading device	0.896 is the U value. 0.9 solar absorption Decrement in temperature: 0.58
Roof	Roof is made of concrete with a plaster finish.

Table 3. 11: DAYSIM simulation parameters (Reinhart et al., 2006)

Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient Resolution	Specular threshold	Direct sampling
5	1000	20	0.01	300	0.15	0.0

3.2.8 Defining the Performance Metrics for Daylight Simulation

Several studies on daylight simulation have demonstrated that annual dynamic daylight metric approaches can be utilized to reliably determine the time series of illuminance and brightness in buildings (Reinhart and Andersen, 2006; Reinhart, 2001; Reinhart and Walkenhorst, 2001; Mardaljevic, 2000). These time series can then be used to calculate annual dynamic daylight performance metrics e.g., DA and UDI to quantify the daylight quality of a given building design (Reinhart et al. 2006; Nabil and Mardaljevic, 2005), as well as annual energy savings from reduced electric lighting use (Reinhart et al. 2006; Nabil and Mardaljevic, 2005; Iqbal, 2015). Details can be found in Appendix B. The criteria used to assess whether the daylight situation at a sensor is 'sufficient' at any given moment are chosen. Several criteria have been proposed, including the ones listed below.

The results for dynamic daylight simulation are generated for the core sensor points and presented in the form of a table (e.g. Table 4.1). The values for different performance metrics are then calculated from the table to get the annual output for the case space. The following criteria are used to assess overall lighting.

- Average annual DA percent of core sensors
- Average annual DA_{max} percent of core sensors
- Values of the core sensor points' average yearly UDI percent ($UDI_{<100}$, $UDI_{100-2000}$ and $UDI_{>2000}$)

3.2.9 Convert Result into performance Measure

For dynamic performance measures, various sorts of overall rating systems have been utilized in the past. Reinhart (2006) employed a method for daylight performance evaluation in which key sensor points were centered on a central axis. Sensors are placed throughout the space layout in this study. The performance measures' average values are then shown in a table, and rating points are allocated based on their performance. Because three separate parameters are investigated in this study, a wide range of parametric settings for each step is investigated. Different rating points are assigned at different levels. The highest point (for example, 7 points) denotes the best performance among the choices analyzed, while the lowest point (for example, 1 point) shows the worst performance. The ultimate score is calculated by adding the scores of each performance metric.

3.3 Summary

This chapter explains the methodology of the research including the selection of a case apartment. In Chapter 4, numerous aspects, such as balcony railing heights, balcony drop levels, balcony locations, balcony depths, floor materials, wall materials, and balcony types, are analyzed by changing different elements.

CHAPTER FOUR: SIMULATION STUDY

4.1 Preamble

This chapter incorporates the analysis based on the outputs of the simulation exercise and methodology developed in the previous chapter. Eight major aspects have been explored in this chapter. The first part elaborates on the dynamic simulation outcome with different railing heights of the balcony. The second part presents the outcome of different drop levels of the balcony. The third part presents the results of wall configurations between the balcony and bedroom. The fourth part elaborates on the outcome of different balcony placements. The fifth part elaborates on the outcome of different balcony floor depths. The sixth part elaborates on the outcome of different balcony floor materials. The seventh part elaborates on the outcome of different balcony wall materials and finally in eighth part elaborates on the dynamic simulation outcome of different local balcony types. Chapter 5 concludes the research by presenting the key findings and the strategies based on the activities that have been done under this research.

4.2 Dynamic Daylight Simulation

Considering the core work plane sensor approach, the summary results of annual dynamic simulations are shown in this section. To refer, the alternative options are coded according to height level and position as following.

i. The studied five balcony railing heights are coded according to height level as BR750, BR600, BR450, BR300 and BR150. Where BR750 represents a railing height of 750mm from finished floor level and so on.

ii. The studied six balcony drop levels are coded according to height level as BL2150, BL2300, BL2450, BL2600, BL2750, and BL2900. Where BL2150 represents a balcony drop ended at 2150 mm from finished floor level and so on.

iii. The studied three wall types between balcony and bedroom (sliding with glass; 500 mm deep light shelf in both interior and exterior of the bedroom; 500 mm deep light shelf in interior and exterior lightshelf depth equal to balcony floor depth) are coded as SG, LS and FC accordingly.

iv. The studied two balcony placements, i.e. when balconies are placed one above another in each floor and the type when balconies are placed in zig-zag pattern on building elevation are coded as BA and BZ.

v. The studied five balcony floor depths are coded as BD915, BD1065, BD1220, BD1370 and BD1525. Where BD915 represents a balcony depth of 915mm and so on.

vi. The studied five balcony floor materials, i.e. silver glossy tiles, epoxy floor, timber floor, concrete floor and mat tiles floor are coded according to their reflectance as GT90, EF80, TF60, CF40 and MT20.

vii. The six-wall colors, i.e. white, black, red, yellow, blue and green are coded according to their reflectance as RW, RK, RR, RY, RB and RG.

viii. Three local types of balconies,i.e., recessed, semi-recessed and cantilever are coded as R, SR and C.

4.2.1 Balcony Railing Height

It is easier to interpret the rating between the balcony railing using the dynamic metrics (Reinhart et al., 2006). After analyzing the mean value of dynamic metrics of core sensor points for each railing height, the rating system is executed. Here perceived the highest point as 7 points to least 1 point as the configurations from 1st to 7th place.

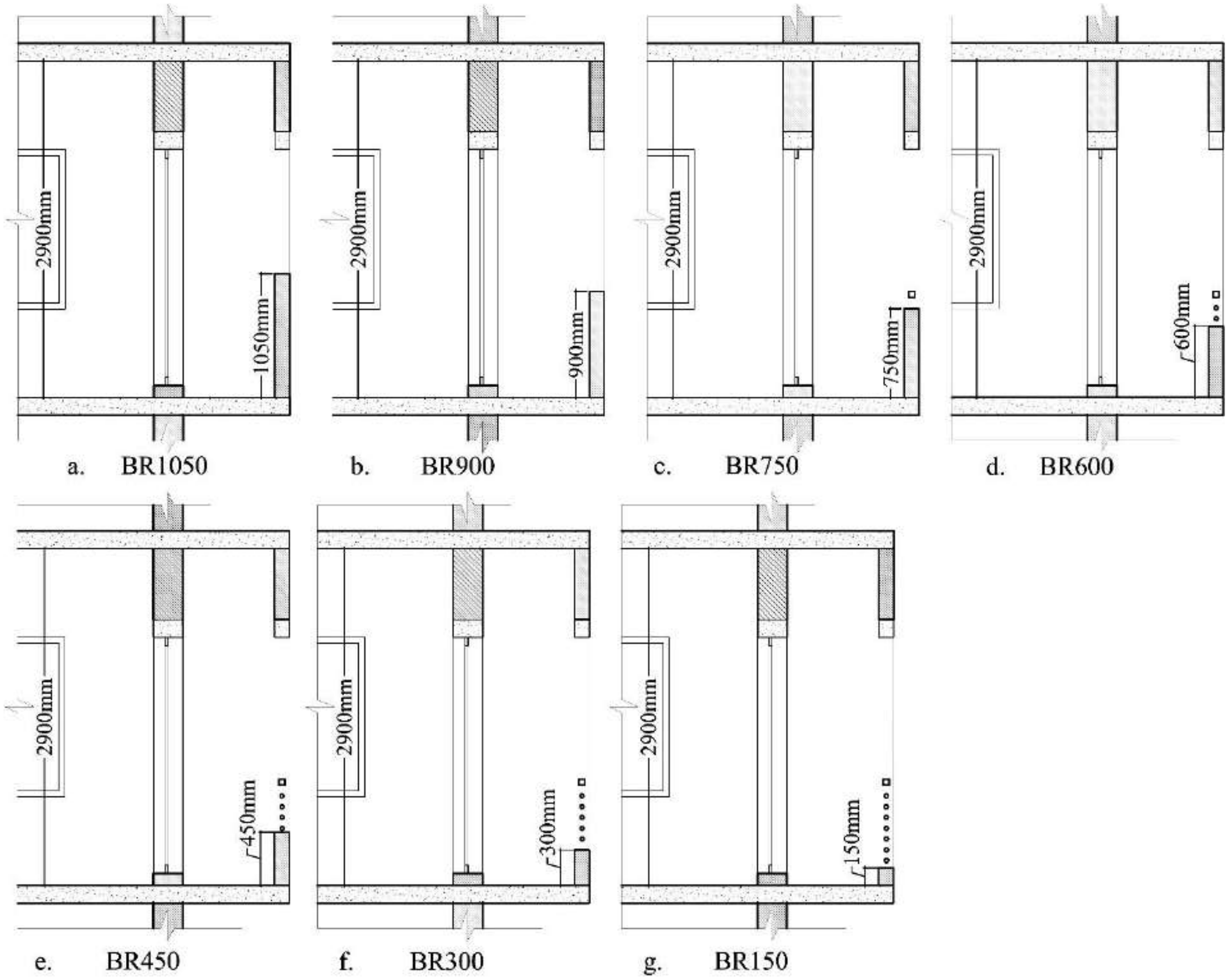


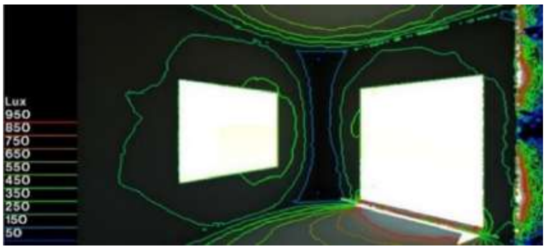
Figure 4. 1: Balcony railing heights for performance evaluation

Figure 4.1 shows the studied balcony railing heights. Table 4.1 shows a summary of annual CBDM simulation output with rating points and a ranking of recommended seven types of railing height configurations for balconies.

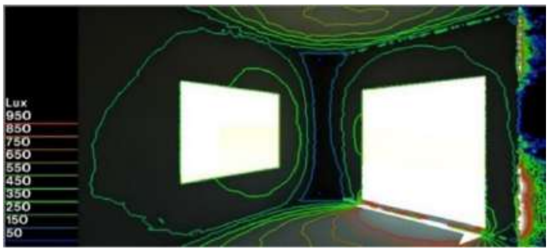
Considering DA, BR300 performs better compared to other railing heights. The value range of DA_{max} is highest at BR150 which may cause glare and heat in the case space. On the other hand, BR450 and BR150 have the same value of DA. In addition, BR1050 and BR900 both have the same value of DA_{max} but BR900 has better value in DA. For $UDI_{100-200}$ and $UDI_{>2000}$, BR1066 performed the best score.

Table 4. 1: Annual CBDM simulation outputs with rating points and ranking of different balcony railing heights

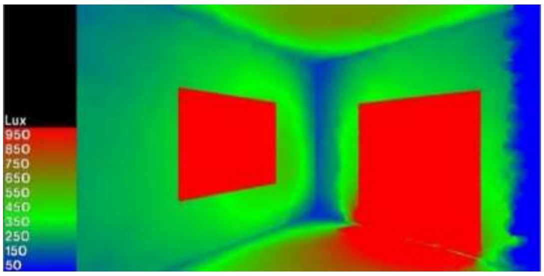
Balcony Railing Height (mm)	Value and Rating points (RP)	DA (%)	DA max (%)	UDI<100 (%)	UDI 100-2000 (%)	UDI>2000 (%)	Total RP	Ranks
BR1050	Value	70.33	3.33	24.33	66.33	9.33	29	1
	RP	3	7	5	7	7		
BR900	Value	70.67	3.33	24	66	10	29	1
	RP	4	7	6	6	6		
BR750	Value	70.67	4	24	65	10.67	25	3
	RP	4	6	6	4	5		
BR600	Value	71	4.33	24	65.33	10.67	26	2
	RP	5	5	6	5	5		
BR450	Value	71.33	4	24	64.67	11.67	25	3
	RP	6	6	6	3	4		
BR300	Value	71.67	4.33	23.67	64.33	12	24	4
	RP	7	5	7	2	3		
BR150	Value	71.33	4.67	23.67	64	12.33	20	5
	RP	6	4	7	1	2		



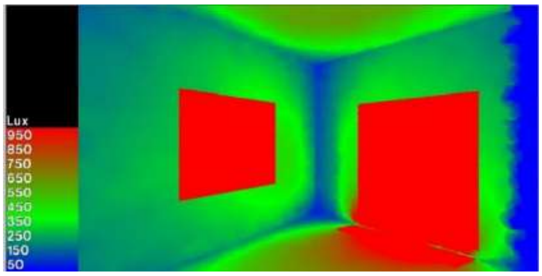
a) Existing BR750 daylight contour map;



b) BR900 daylight contour map



c) Existing BR750 daylight false colour map;



d) BR900 daylight false colour map

Figure 4. 2: Daylight contour and false colour map at bedroom for BR750 and BR900 type balcony

Considering the rating points BR1050 and BR900 score the highest and ensure a uniform distribution of daylight, compared to other types of balcony railing heights. However, both ranked 1st place based on a point but according to far rules, railing height should be 800-900mm. For a special reason, an extra rail could be added at up or down. (BNBC 2020). Therefore, for further work BL900 will be fixed as the working railing height. Figure 4.2 shows the daylight contour and the false color maps of the BR900 and existing BR750. Figure 4.3 shows the DA and $UDI_{100-2000}$ patterns at bedroom for BR900 type balcony.

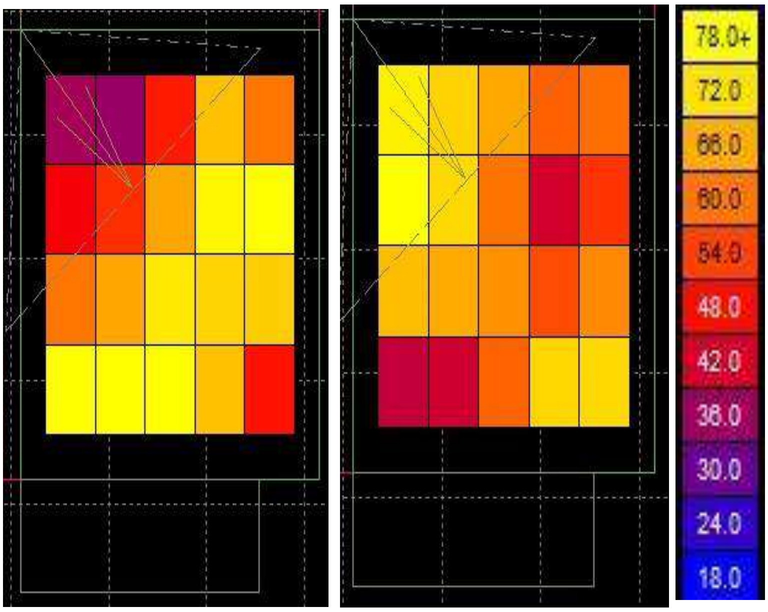


Figure 4. 3: DA (left) and $UDI_{100-200}$ (right) patterns at bedroom for BR900 type balcony

4.2.2 Balcony Drop Level

After finding the best option for balcony railing height; in phase two, balcony drops ended at six different levels from finished floor are placed alternatively keeping the balcony railing height fixed to BR915 as found best in Section 4.2.1. Figure 4.4 shows different balcony drops ended at six different levels from finished floor and Table 4.2 shows a summary of annual CBDM simulation results for the six types. Considering DA, BL2750 and BL2900 perform the best to other configuration types but the value range of DA_{max} is the highest for BL2900 which may cause glare. Considering DA_{max}, $UDI_{100-200}$ and $UDI_{>2000}$, BL2150 performs the best but BL2750 and BL2900 perform an average. On the other hand, BL2300 and BL2450 have the same value of DA and average value in the other fields. BL2150 has not scored the best result in DA_{max}, $UDI_{100-2000}$, $UDI_{>2000}$ categories and an average in other categories.

However, performed an average in the studied categories and become the higher scorer. Here perceived the highest point as 6 points to least 1 point as the configurations from 1st to 6th place considering the fact as Table 4.2. Considering the rating points BL2150 scored the highest and ensure a uniform distribution of daylight, compared to other types of balcony drops. It ranked 1st place according to the result.

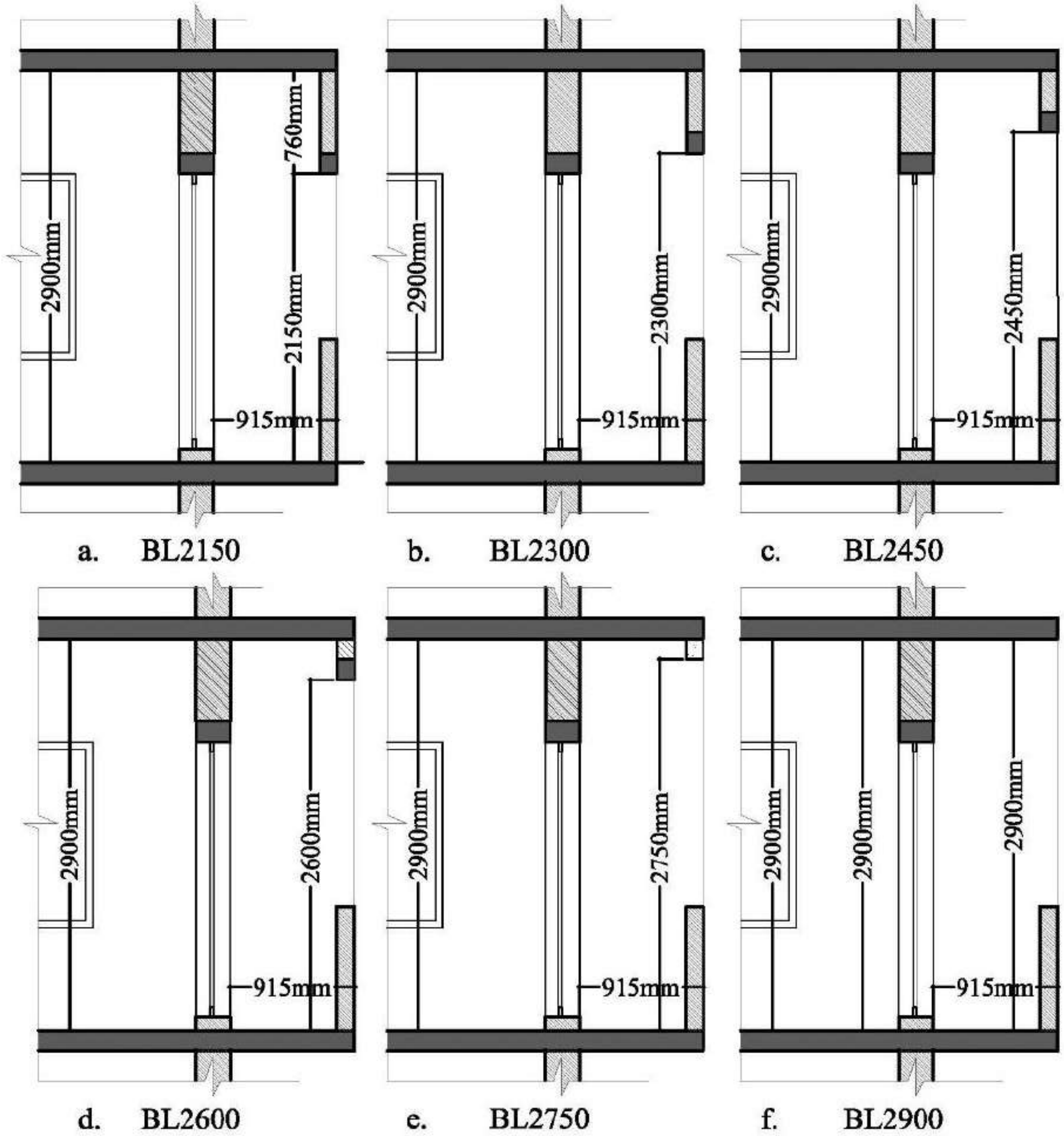
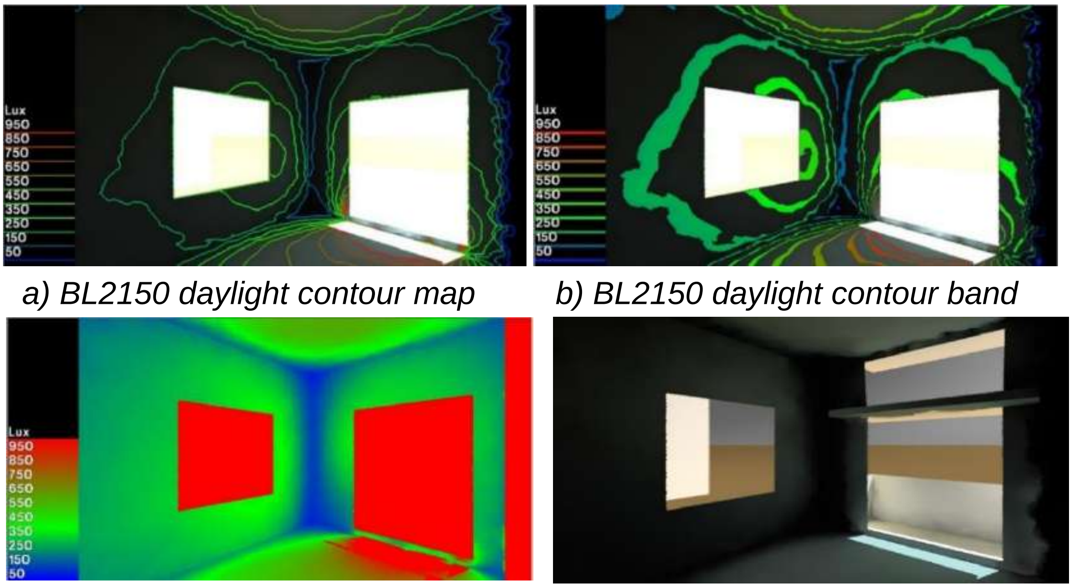


Figure 4. 4: Balcony drop levels for performance evaluation

Considering the performance evaluation process and ratings, the BL2150, where the balcony drops ended at 2150 mm from finished floor level is found as the most feasible based on lighting performance in the apartments' bedroom in the climatic context of Dhaka. Figure 4.5 shows daylight contour and false color maps, and Figure 4.6 shows the DA and $UDI_{100-2000}$ patterns at bedroom of BL2150.

Table 4. 2: Annual CBDM simulation outputs with rating points and ranking of different balcony drop levels

Balcony Drop bottom end Height (mm)	Value and Rating points (RP)	DA (%)	DA max (%)	UDI<100 (%)	UDI 100-2000 (%)	UDI>2000 (%)	Total RP	Ranks
BL2150	Value	**70.67**	**3.33**	**24**	**66**	**10**	**23**	**1**
	RP	**3**	**6**	**2**	**6**	**6**		
BL2300	Value	**72.33**	**5.67**	**23.67**	**61.67**	**14.67**	**22**	2
	RP	**4**	**5**	**3**	**5**	**5**		
BL2450	Value	**72.33**	**7**	**23.33**	**58.67**	**18**	**20**	**3**
	RP	**4**	**4**	**4**	**4**	**4**		
BL2600	Value	**73**	**8.33**	**23**	**55.33**	**21.67**	**19**	**4**
	RP	**5**	**3**	**5**	**3**	**3**		
BL2750	Value	**73.33**	**10**	**22.67**	**53.67**	**23.67**	**18**	**5**
	RP	**6**	**2**	**6**	**2**	**2**		
BL2900	Value	**73.33**	**11.33**	**22.67**	**51.67**	**25.67**	**15**	**6**
	RP	**6**	**1**	**6**	**1**	**1**		



a) BL2150 daylight contour map *b) BL2150 daylight contour band*

c) BL2150 daylight false color map *d) BL2150 human sensitivity*

Figure 4. 5: Daylight contour map, contour band, false colour map and human sensitivity map at bedroom for BL2150 type balcony

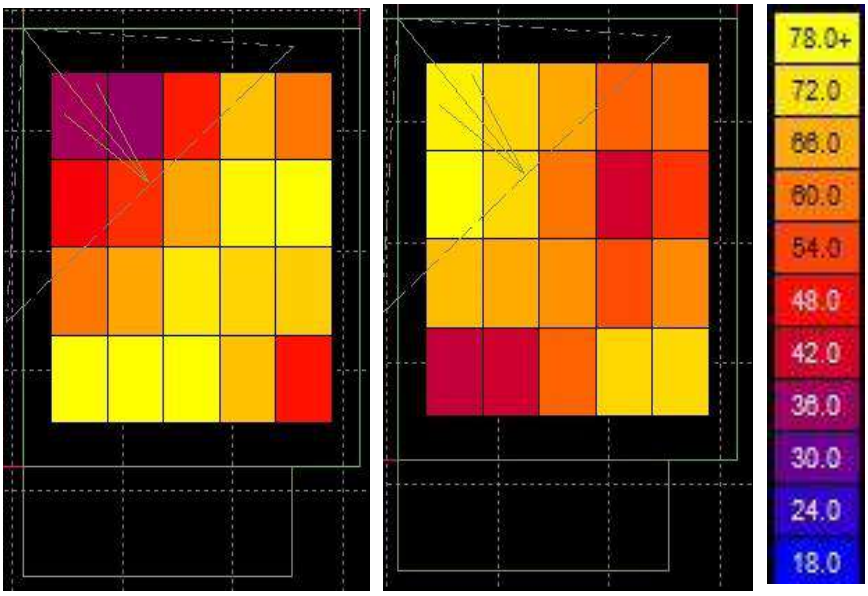


Figure 4. 6: DA (left) and UDI (right) patterns at bedroom for BL2150 type balcony

4.2.3 Adjacent Wall to Bedroom

In third phase, after finding the best option of balcony railing height and drop levels, two different adjacent wall configurations between bedroom and balcony are placed alternatively keeping the balcony railing height fixed to BR915, found in Section 4.2.1 and drop level fixed to BL2150, found as the best option in Section 4.2.2.

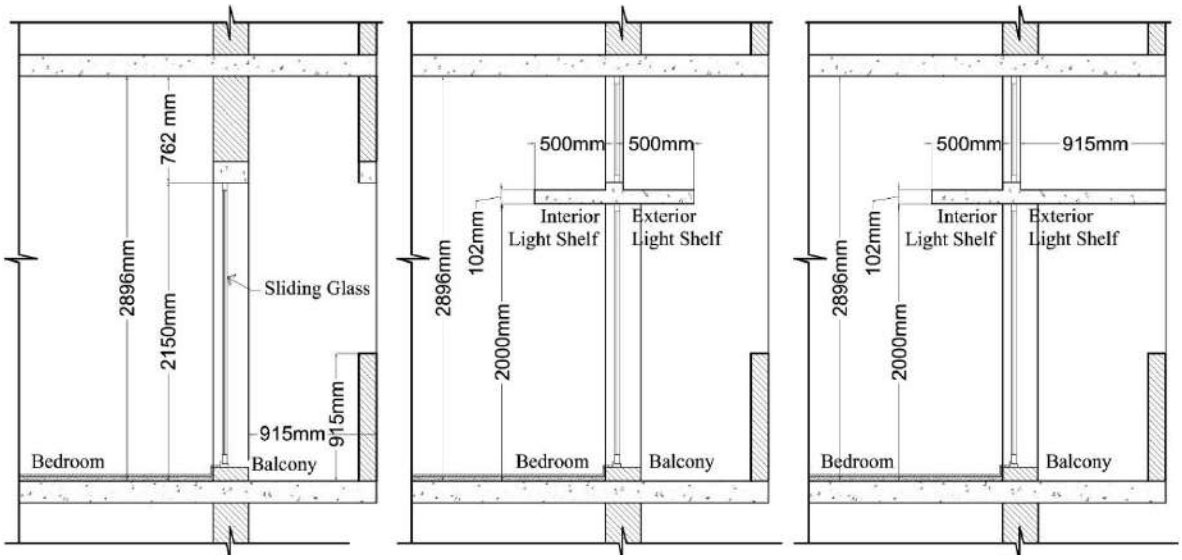
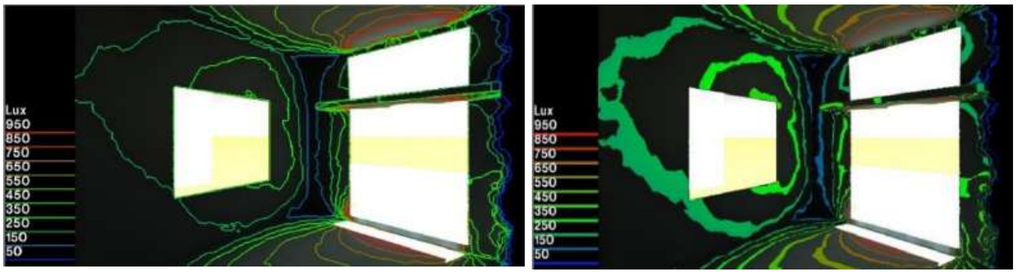


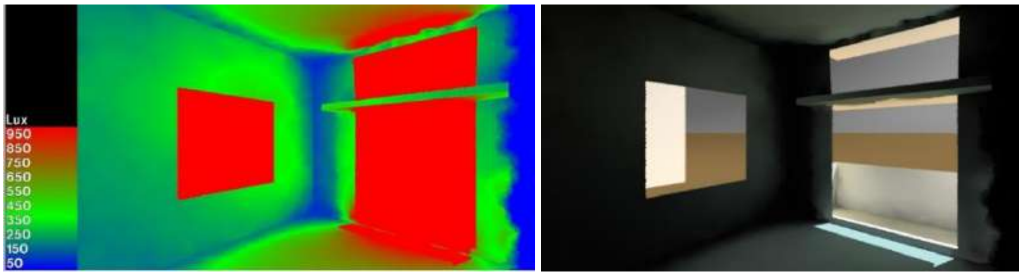
Figure 4. 7: Three balcony adjacent wall types for performance evaluation

Table 4. 3: Annual CBDM simulation outputs with rating points and ranking of three balcony to bedroom wall configurations

Balcony Wall	Value and Rating points (RP)	DA (%)	DA $_{max}$ (%)	$UDI_{<100}$ (%)	UDI $_{100-2000}$ (%)	$UDI_{>2000}$ (%)	Total RP	Ranks
SG	Value	**70.67**	**3.33**	**24**	**66**	**10**	**11**	**2**
	RP	**1**	**2**	**2**	**3**	**3**		
LS	Value	**72.67**	**6.67**	**23.33**	**59.67**	**16.67**	**11**	**2**
	RP	**3**	**1**	**3**	**2**	**2**		
FC	Value	**71.33**	**3**	**24**	**66**	**10**	**13**	**1**
	RP	**2**	**3**	**2**	**3**	**3**		



a) FC daylight contour map *b) FC daylight contour bands*



c) FC daylight false color map *d) FC human sensitivity*

Figure 4. 8: Daylight contour amp, contour band, false colour map and human sensitivity at bedroom for FC type balcony

Mainly three types of partition walls are investigated: sliding with glass (SG); 500 mm deep light shelf in both interior and exterior of the bedroom (LS); and 500 mm deep light shelf in interior and exterior lightshelf depth equal to balcony floor depth (FC). In LS 500mm interior depth and 500mm exterior depth of the light shelf are used which proves that fixing 500mm exterior and interior depth light shelf work best at a height above 2m from floor level for a window in the tropical country i.e. Bangladesh (Jorder, 2009). In FC, a 500mm interior depth light shelf is used but the exterior depth is changed and kept as the balcony depth of 915mm. Figure 4.7 shows three balcony adjacent wall configurations and Table 4.3 shows a summary of annual CBDM DAYSIM simulation results and ranking points.

Here perceived the highest point as 3 points to least 1 point as the configurations from 1st to 3rd place. LS has a good value of DA and $UDI_{<100}$ but Da_{max} value is high which is not good. SG has good value in $UDI_{100-2000}$ and $UDI_{>2000}$ but DA value is not good. In FC the value of $UDI_{100-2000}$, $UDI_{>2000}$ is the highest and DAmax value is the lowest. Considering the rating points, FC scores the better in the studied fields and ensures a uniform distribution of daylight, compared to other types of adjacent wall configurations between bedroom and balcony. It ranked 1st place according to the result of Table 4.3. Figure 4.8 shows the daylight contour, contour band, false color and human sensitivity maps and Figure 4.9 shows the DA and $UDI_{100-2000}$ patterns at bedroom of FC.

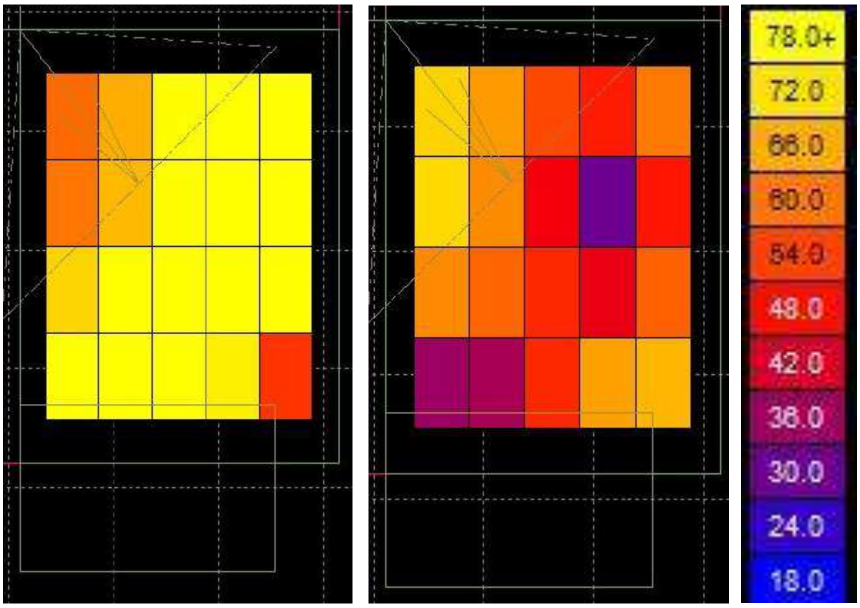


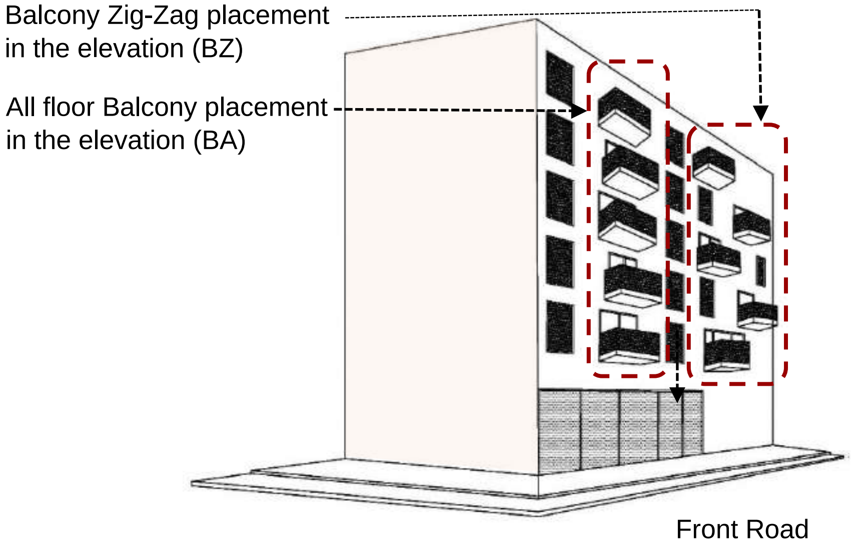
Figure 4. 9: DA (left) and $UDI_{100-2000}$ (right) patterns at bedroom for FC type balcony

4.2.4 Balcony Placement on Building Elevation

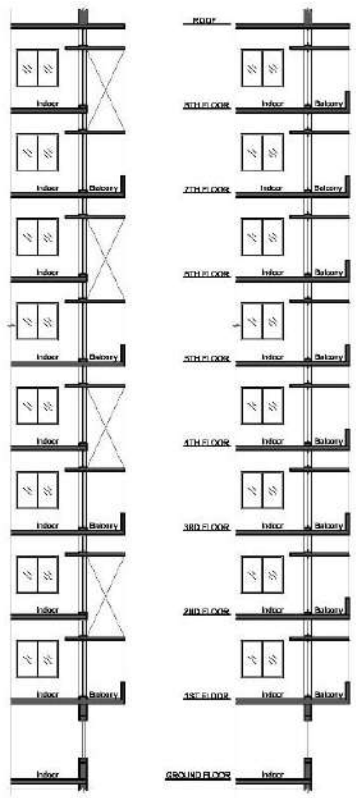
After finding the best results for balcony railing height, drop level and adjacent wall configurations between bedroom and balcony; in phase four, two different balcony positions are composed on elevation alternatively (Figure 4.10.a) keeping the balcony railing height fixed to BR915 found in Section 4.2.1; drop level fixed to BL2150 found as the best in Section 4.2.2 and adjacent wall configurations between bedroom and balcony with light shelf FC found as the best in Section 4.2.3. Figure 4.10 shows the balcony placement options and Table 4.4 shows a summary of annual CBDM simulation results and ranking points for recommended two types of balcony placement configurations. One is with a balcony in the same place for all floors coded as BA and the other is having a balcony in alternative floors in the same place with zig-zag in terms of elevation placement coded as BZ.

Considering DA, BZ performs better than the BA configuration type but the DA_{max} value range is also higher for BZ which may cause glare and heat in the case space. On the other hand, BA has a better value of $UDI_{100-2000}$ and $UDI_{>2000}$ which is good. Overall BA performs better.

Considering the fact, here perceived the highest point as 2 points to least 1 point as the configurations from 1st and 2nd places. The rating system is presented by monitoring the mean value of dynamic metrics of core sensor points for two balcony placement configurations. Considering the rating points BA scores, the highest and ensures a uniform distribution of daylight, compared to other studied type and ranked as the 1st according to result shown in Table 4.4.



a. Two types of balcony placement on same building elevation in perspective

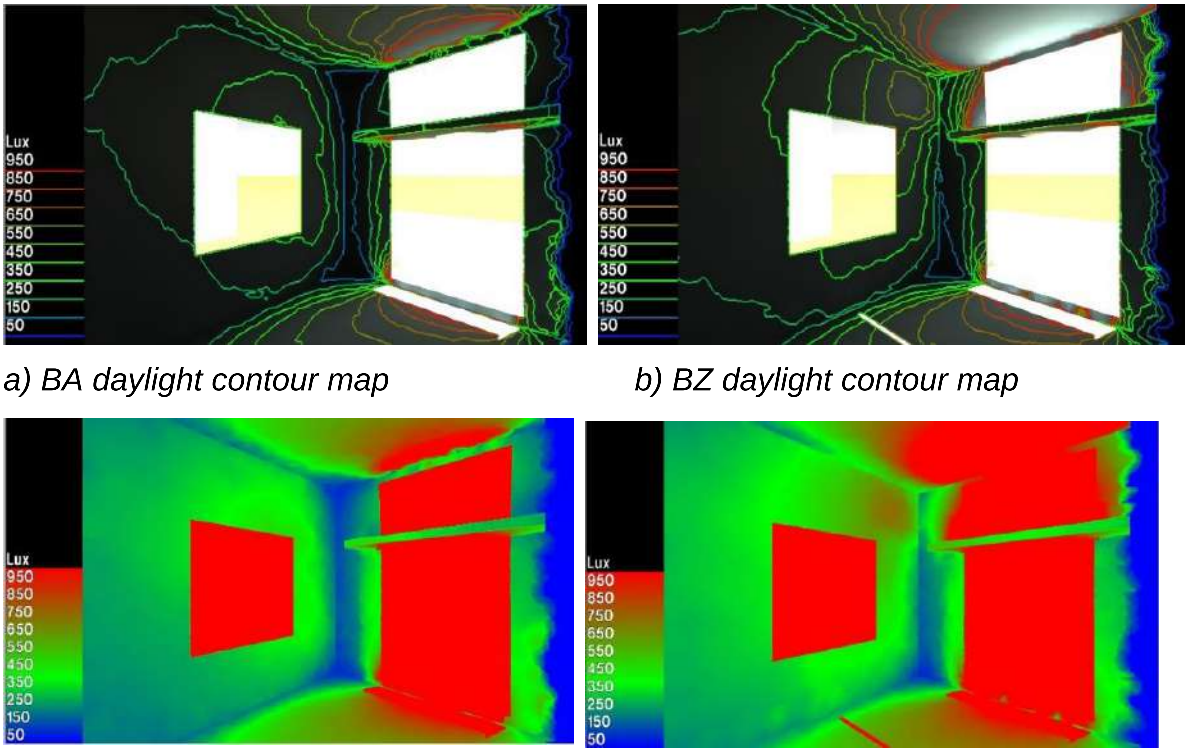


b. Section shows balcony placement of alternative floor in zig-zag pattern on building elevation (left) and all floor balcony placement (right) options

Figure 4. 10: Two types of balcony placement on building elevation for performance evaluation

Table 4. 4: Annual CBDM simulation outputs with rating points and ranking of balcony placements

Balcony Placement	Value and Rating points (RP)	DA (%)	DA max (%)	UDI<100 (%)	UDI 100-2000 (%)	UDI>2000 (%)	Total RP	Ranks
BA	Value	71.33	3	24	66	10	8	1
	RP	1	2	1	2	2		
BZ	Value	73.33	5	23.33	55	21.67	7	2
	RP	2	1	2	1	1		



a) BA daylight contour map *b) BZ daylight contour map*

c) BA daylight false color map *d) BZ daylight false color map*

Figure 4. 11: Daylight contour and false colour map at bedroom for BA and BZ type balconies

Figure 4.11 shows daylight contour and false color maps of two types of balcony placements, and Figure 4.12 shows the DA and $UDI_{100\text{-}2000}$ patterns at bedroom for BA balcony placement.

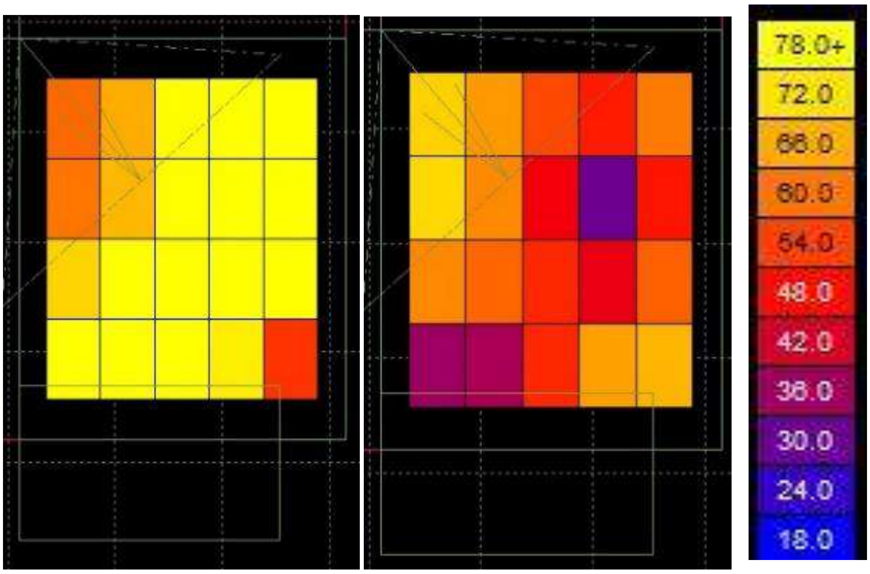


Figure 4. 12: DA (left) and $UDI_{100-200}$ (right) patterns at bedroom for BA type balcony

4.2.5 Balcony Floor Depth

In phase five, after finding the best results of balcony railing height, drop level, adjacent wall and balcony placement configurations between bedroom and balcony; five different balcony floor depths are analyzed alternatively keeping the balcony railing fixed to BR915 found in Section 4.2.1; drop level fixed to BL2150 found as the best in Section 4.2.2, adjacent wall configurations between bedroom and balcony with light shelf FC found as the best in Section 4.2.3 and all floor balcony scored the best in section 4.2.4. Figure 4.13 shows balcony floor depth options and Table 4.5 shows a summary of annual CBDM simulation results for recommended five types of balcony floor depth configurations and performance evaluation rating points with ranking.

Table 4. 5: Annual CBDM simulation outputs with rating points and ranking of balcony floor depths

Balcony Floor Depth (mm)	**Value and Rating points (RP)**	**DA (%)**	**DA $_{max}$ (%)**	**$UDI_{<100}$ (%)**	**$UDI_{100-2000}$ (%)**	**$UDI_{>2000}$ (%)**	**Total RP**	**Ranks**
BD915	Value	**71.33**	**3**	**24**	**66**	**10**	**10**	**5**
	RP	**2**	**3**	**3**	**1**	**1**		
BD1065	Value	**82.33**	**2.33**	**13.67**	**76.67**	**9.33**	**18**	**4**
	RP	**5**	**4**	**5**	**2**	**2**		
BD1220	Value	**80**	**1.67**	**14.33**	**79.33**	**6.67**	**20**	**2**
	RP	**3**	**5**	**4**	**4**	**4**		
BD1370	Value	**80**	**1.67**	**14.33**	**79.67**	**6**	**22**	**1**
	RP	**3**	**5**	**4**	**5**	**5**		
BD1525	Value	**80.33**	**1.67**	**14.33**	**77.67**	**8**	**19**	**3**
	RP	**4**	**5**	**4**	**3**	**3**		

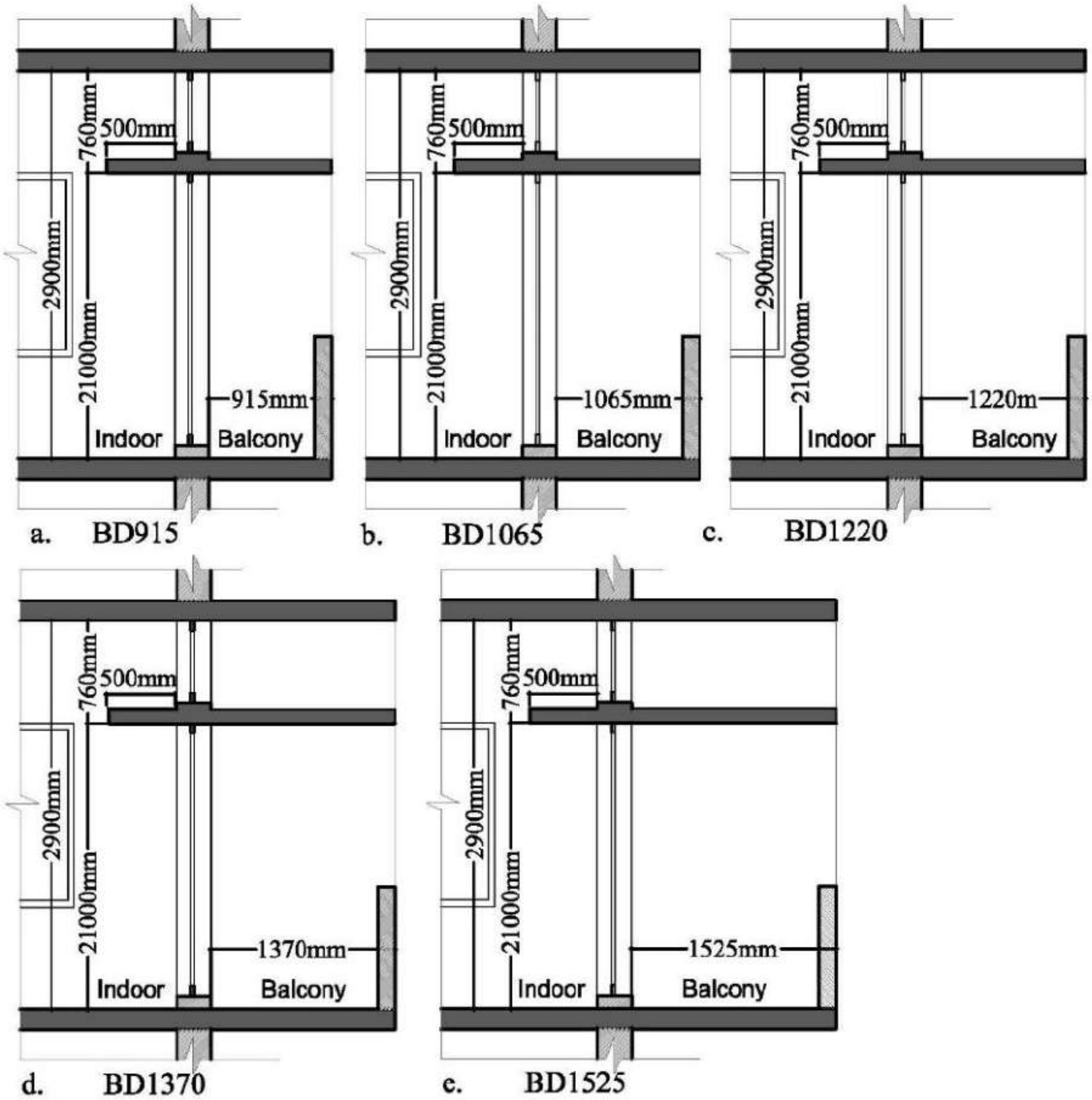
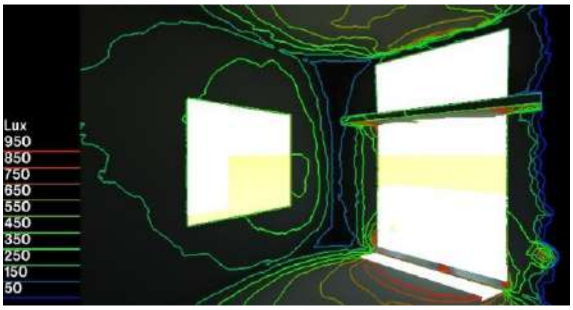
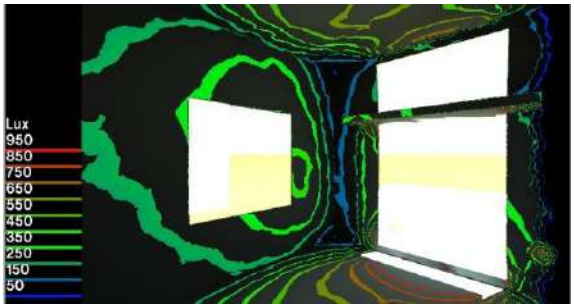


Figure 4. 13: Balcony floor depths for performance evaluation

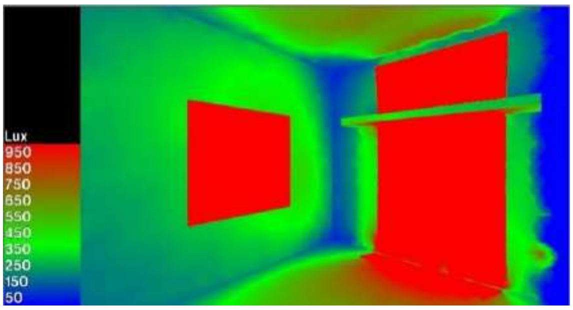
Considering DA, BD1065 performs the best to other configuration types but DA_{max} is high which may cause glare. Considering DA_{max}, $UDI_{100-2000}$ and $UDI_{>2000}$, BD1370 performs the best. Here perceived the highest point as 5 points to least 1 point as the configurations from 1st to 5th place. The rating system is presented by monitoring the mean value of dynamic metrics of core sensor points for five balcony depths. Considering the rating points BD1370 scores, the highest and ensures a uniform distribution of daylight, compared to other studied types and ranked as the 1st according to the result.



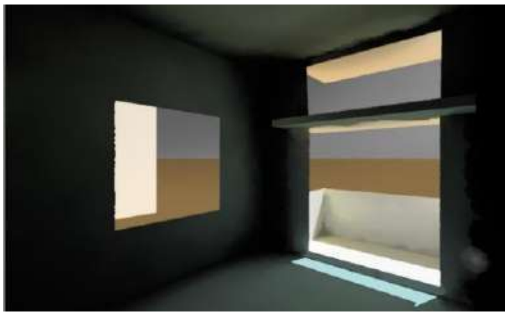
a) *BD1370 daylight contour map*



b) *BD1370 daylight contour bands*



c) *BD1370 daylight false color map*



d) *BD1370 human sensitivity*

Figure 4. 14: Daylight contour map, contour band, false colour map and human sensitivity at bedroom for BD1370 type balcony

Figure 4.14 shows daylight contour and false color maps of two types of balcony placements and Figure 4.15 shows the DA and $UDI_{100-2000}$ patterns at bedroom for BD1370 type balcony.

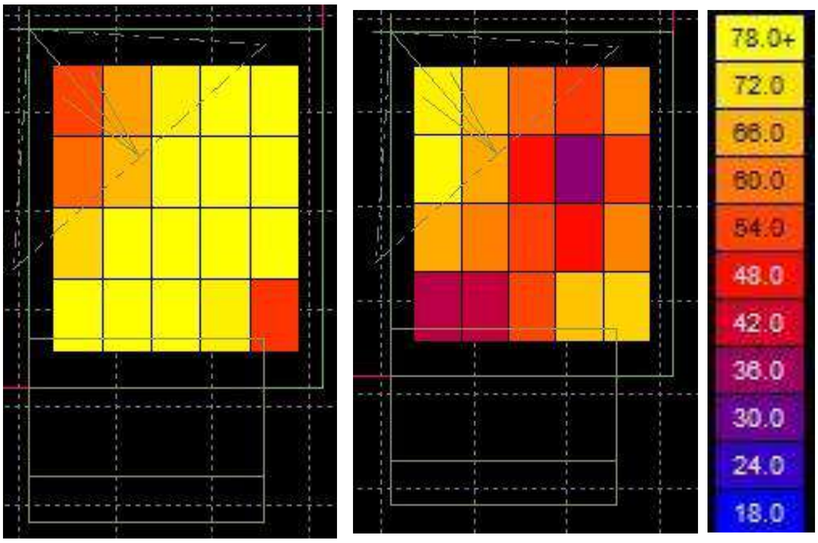


Figure 4. 15: DA (left) and $UDI_{100-2000}$ (right) patterns at bedroom for BD1370 type balcony

4.2.6 Balcony Floor Material

After finding the best results of balcony railing height, drop level, adjacent wall configuration, balcony placement and balcony floor depth configurations; in phase six, four different balcony floor materials (Figure 4.16) are alternatively used keeping the balcony railing fixed to BR915 found in Section 4.2.1; drop bottom end level fixed to BL2150 found as the best in Section 4.2.2 and adjacent wall configurations between bedroom and balcony with light shelf found as the best in Section 4.2.3, all floor balcony score best in section 4.2.4 and balcony floor depth BD1370 score highest at Section 4.2.5. In this section both the material and light reflective value (LRV) of materials are considered. LRV measures how much of the ambient light a surface reflects back and the value is expressed as a percentage. Zero (0) being a perfectly absorbent surface and 100 being a perfectly reflective surface (Figure 4.16).

Five types of materials with varying reflectance (ET, 2012) are considered for evaluation as floor materials, i.e., Mat tiles (MT; reflectance 20), Concrete or NCF flooring (CO; reflectance 40), Timber flooring (TF; reflectance 60), Epoxy flooring (EF; reflectance 80), and Silver glossy tiles (highly polished) flooring (GT; reflectance 90).

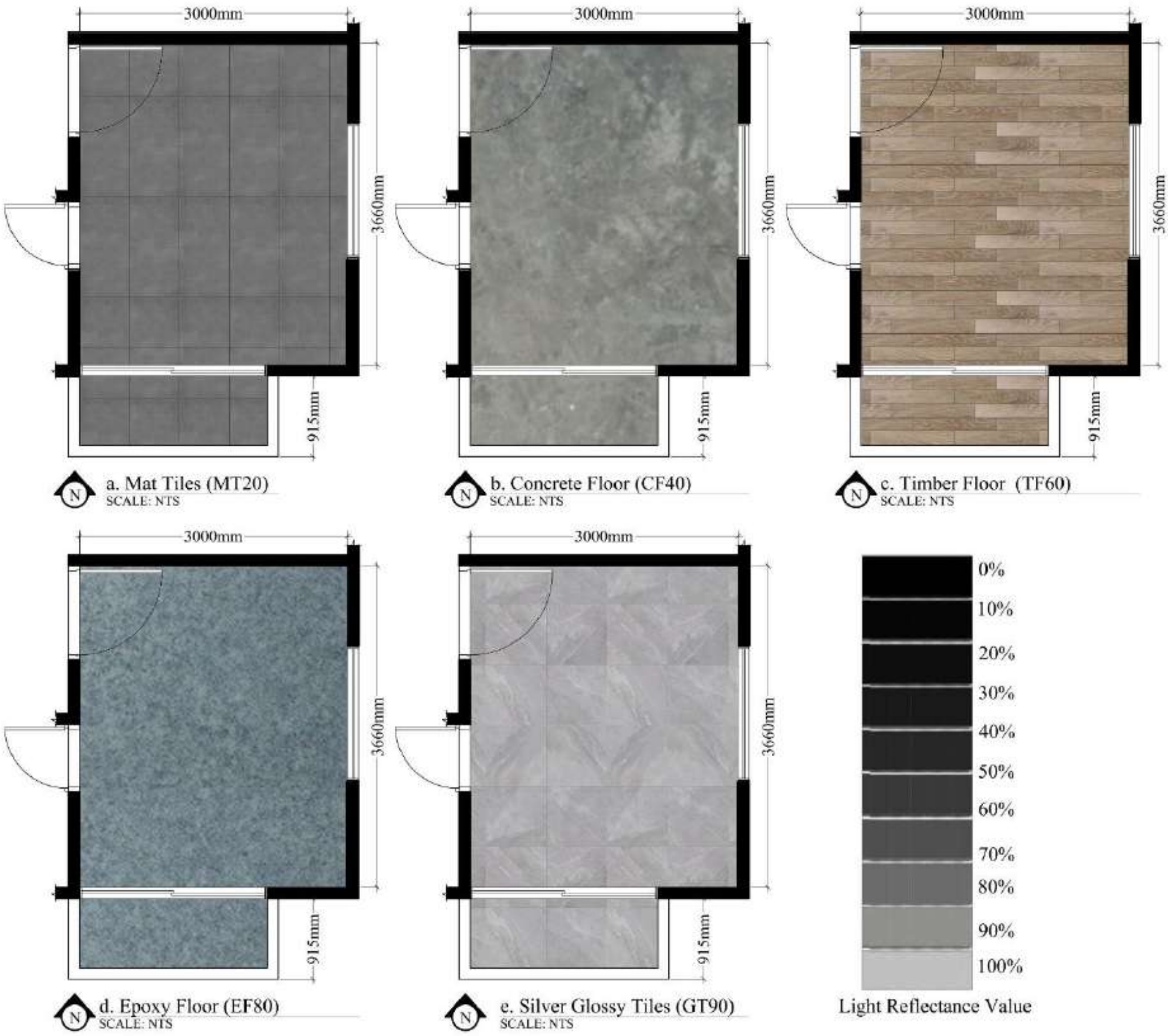
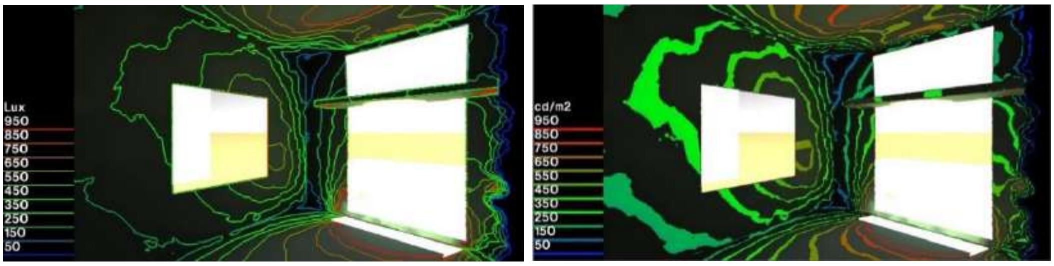


Figure 4. 16 Balcony floor materials for performance evaluation

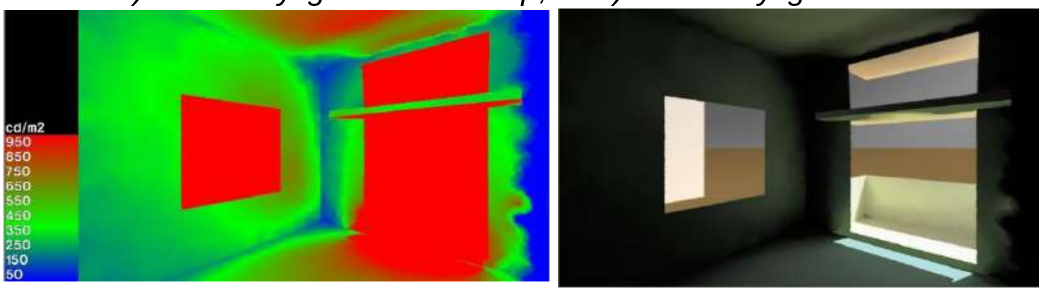
Table 4.6 shows a summary of annual CBDM simulation results for studied five types of balcony floor materials and performance evaluation rating points with ranking.

Table 4. 6 Annual CBDM simulation outputs with rating points and ranking of balcony floor materials

Floor Material	Value and Rating points (RP)	DA (%)	DA_{max} (%)	$UDI_{<100}$ (%)	$UDI_{100-2000}$ (%)	$UDI_{>2000}$ (%)	Total RP	Ranks
MT20	*Value*	**82.33**	**6.33**	**13.33**	**62.67**	**24**	**13**	**5**
	RP	**5**	**1**	**5**	**1**	**1**		
CF40	*Value*	**81.67**	**2.33**	**14**	**76**	**10**	**18**	**2**
	RP	**3**	**4**	**3**	**4**	**4**		
TF60	*Value*	**81.67**	**3.67**	**13.67**	**71.33**	**14.67**	**16**	**3**
	RP	**3**	**3**	**4**	**3**	**3**		
EF80	*Value*	**82**	**5.33**	**13.33**	**66.33**	**20.33**	**15**	**4**
	RP	**4**	**2**	**5**	**2**	**2**		
GT90	*Value*	**80.67**	**1.67**	**14**	**79**	**7**	**20**	**1**
	RP	**2**	**5**	**3**	**5**	**5**		



a) GT90 daylight contour map; *b) GT90 daylight contour bands*



c) GT90 daylight false color map; *d) GT90 human sensitivity*

Figure 4. 17: Daylight contour map, contour band, false colour map and human sensitivity at bedroom for GT 90 type balcony

MT20 and EF80 perform better to other types considering DA but the value range of DA_{max} is the highest for MT20. Considering $UDI_{100-2000}$ and $UDI_{>2000}$ MT20 and EF80 perform the worst but $UDI_{<100}$ rate is good in MT20 and EF80. CF40 and TF60 perform good considering DA but poor considering other values. GT90 performs the best in DA_{max} rating and done an average considering DA, $UDI_{<100}$, $UDI_{100-2000}$ and $UDI_{>2000}$. Here perceived the highest point as 5 points to least 1 point as the configurations from 1st to 5th place. The rating system is presented by monitoring the mean value of dynamic metrics of core sensor points for five balcony floor materials. Considering the rating points GT90 scores, the highest and ensures a uniform distribution of daylight, compared to other studied types and ranked as the 1st according to the result. Figure 4.17 shows daylight contour and false color maps of two types of balcony placements and Figure 4.18 shows the DA and $UDI_{100-2000}$ patterns at bedroom of balcony GT90 floor material which scores the best.

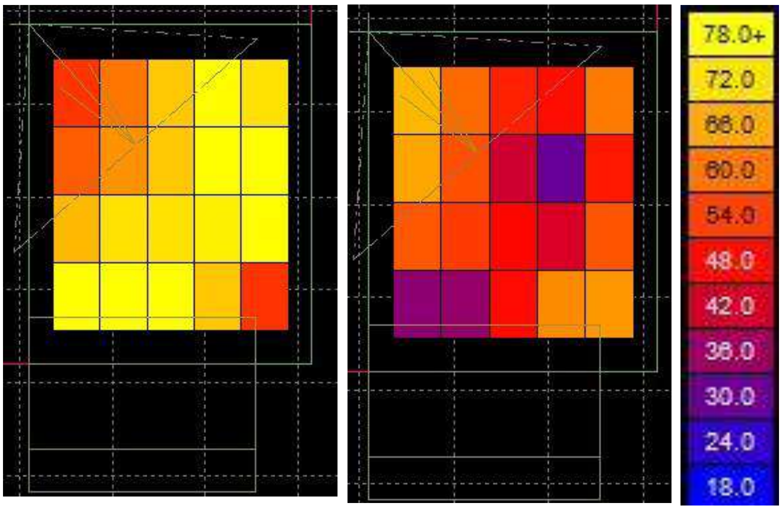


Figure 4. 18: DA (left) and UDI $_{100-2000}$ patterns at bedroom for GT90 type balcony

4.2.7 Balcony Wall Color

After finding the best results of balcony railing height, drop level, adjacent wall configuration, balcony placement, balcony floor depth, and floor material; in phase seven, six different balcony wall colors are alternatively used keeping the balcony railing height fixed to BR915 found in Section 4.2.1; drop level fixed to BL2150 found as the best in Section 4.2.2, adjacent wall configurations between bedroom and balcony with light shelf found as the best in Section 4.2.3, all floor balcony score best in section 4.2.4, balcony floor depth BD1370 scored highest at Section 4.2.5.and balcony with silver glossy tiles (highly polished) flooring means GT90 performed as the best in Section 4.2.6.

In Section 2.3, Table 2.1 shows the color reflectance values. Considering six different types of colors (primary color red, blue and yellow; secondary color green, and other colors white and black) with different reflectance values are selected to evaluate. White wall color (RW; reflectance 85), yellow wall color (RY; reflectance 68), green wall color (RG; reflectance 30), blue wall color (RB; reflectance 20), red wall color (RR; reflectance 18), and black wall color (RK; reflectance 07) are considered as an internal wall color and white is considered as the external wall color for the studied options. Figure 4.19 shows the wall colors and Table 4.7

shows a summary of annual CBDM simulation results for studied six types of balcony wall colors and performance evaluation rating points with ranking.

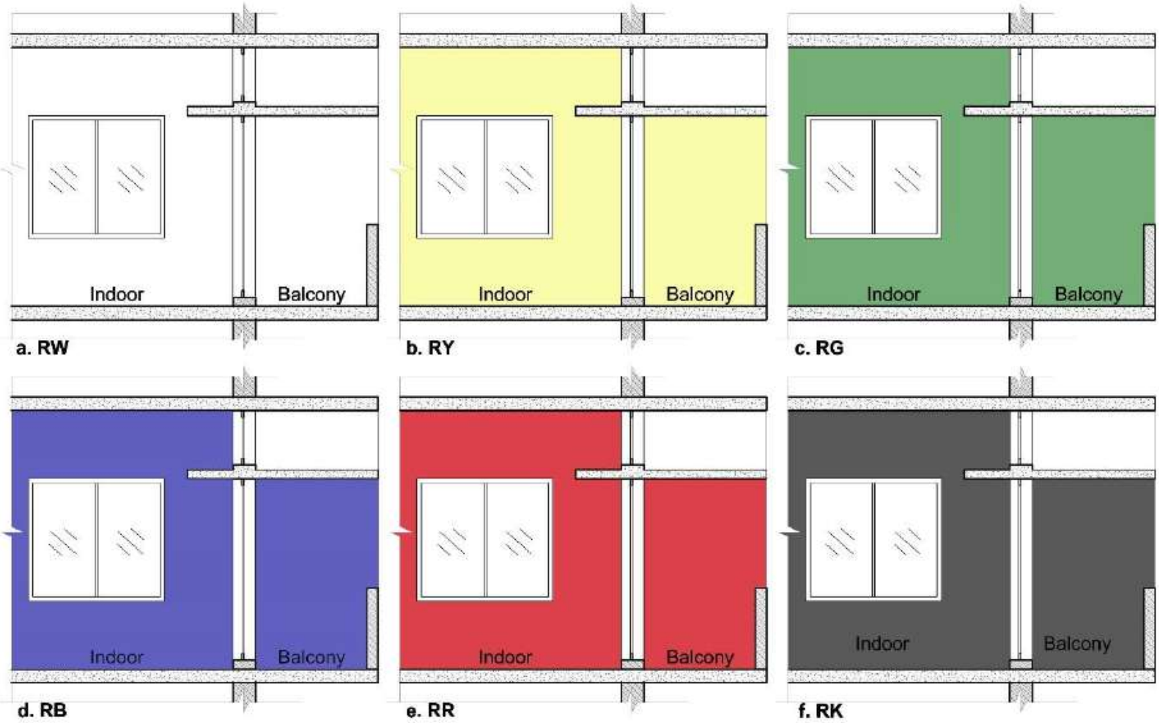
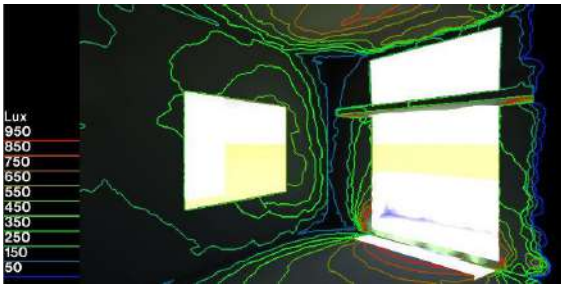


Figure 4. 19 Balcony and bedroom wall colors for performance evaluation

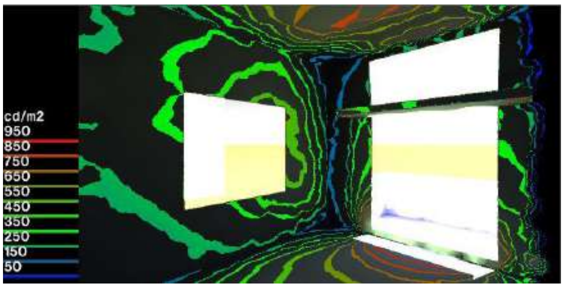
Table 4. 7: Annual CBDM simulation outputs with rating points and ranking of wall colors

Wall Color Reflectance	Value and Rating points (RP)	DA (%)	DA max (%)	UDI<100 (%)	UDI 100-2000 (%)	UDI>2000 (%)	Total RP	Ranks
RW	Value	83.67	8.33	12.67	56	31	20	4
	RP	6	3	6	3	2		
RY	Value	82	4.67	13.33	69.33	17.33	22	3
	RP	5	4	5	4	4		
RG	Value	80	2.33	14.33	77.33	8.67	22	3
	RP	3	5	4	5	5		
RB	Value	80.33	2	14.33	77.67	8.33	26	1
	RP	4	6	4	6	6		
RR	Value	80	2	14.33	77.67	8.33	25	2
	RP	3	6	4	6	6		
RK	Value	83.67	8.33	12.67	55.33	32	20	4
	RP	6	3	6	2	3		

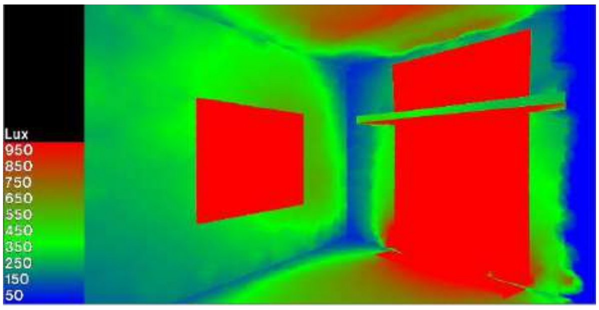
Considering DA, RW and RB perform the best to other types and the value of $UDI_{<100}$ is also the lowest which is good but the range of DA_{max} is highest which is avoidable. Considering DA_{max}, $UDI_{100-2000}$ and $UDI_{>2000}$, RB performs the best and the DA range is also an average here.



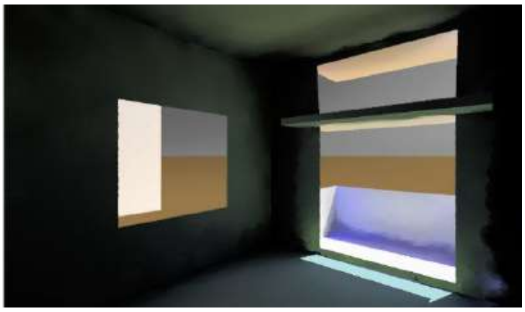
a) RB daylight contour map



b) RB daylight contour bands



c) *RB daylight false color map*



d) *RB human sensitivity*

Figure 4. 20: Daylight contour map, contour band, false colour map and human sensitivity at bedroom for RB type balcony

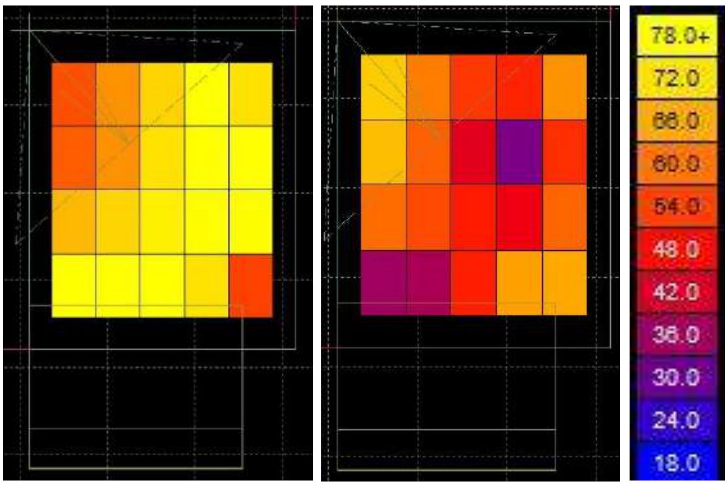


Figure 4. 21: DA (left) and UDI $_{100-2000}$ patterns at bedroom for RB type balcony

Here perceived the highest point as 6 points to least 1 point as the types from 1st to 6th place. The rating system is presented by monitoring the mean value of dynamic metrics of core sensor points for six balcony wall colors. Considering the rating points RB scores, the highest and ensures a uniform distribution of daylight, compared to other studied types and ranked as the 1st according to the result.

Figure 4.20 shows daylight contour and false color maps of two types of balcony placement and Figure 4.21 shows the DA and $UDI_{100-2000}$ patterns at bedroom for RB type balcony which score the best.

4.2.8 Balcony Types

After finding the best results of balcony railing height, drop level, adjacent wall configuration, balcony placement, balcony floor depth, floor material and wall color; in phase eight, three local balcony patterns are alternatively analyzed keeping the balcony railing height fixed to BR915 found in Section 4.2.1; drop level fixed to BL2150 found as the best in Section 4.2.2, adjacent wall configurations between bedroom and balcony with light shelf found as the best in Section 4.2.3, all floor balcony scored as the best in Section 4.2.4, balcony floor depth BD1370 score the highest at Section 4.2.5, balcony with glossy tiles floor means GT90 perform best in Section 4.2.6 and balcony wall with blue color means RB performed as the best in Section 4.2.7.

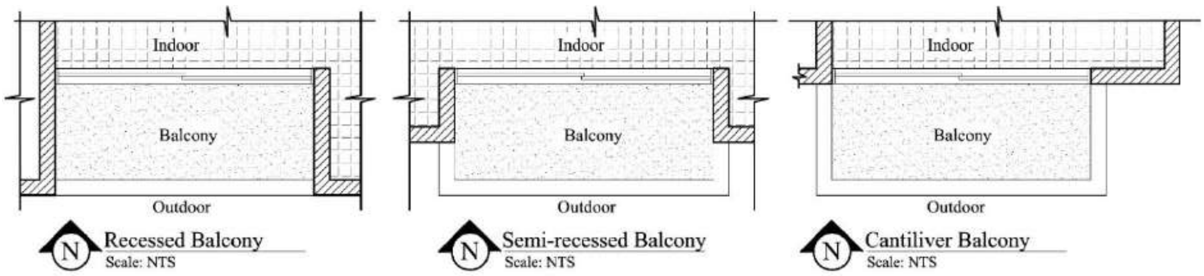


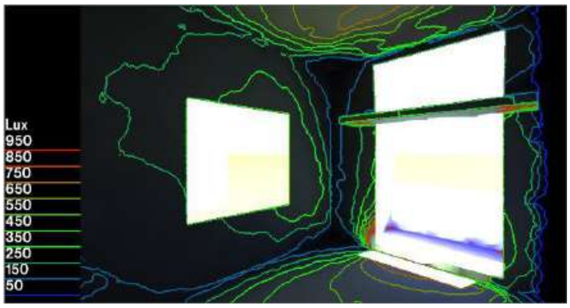
Figure 4. 22: Local balcony types for performance evaluation

Three local types of balconies are found common in tropical countries identified from literature review (Section 2.6.2). Recessed (R), semi-recessed (SR) and cantilever (C) type of balconies are considered to evaluate. Figure 4.22 shows plan of the studied local balcony types and Table 4.8 shows a summary of annual CBDM simulation results for recommended three types of balcony configurations and performance evaluation rating points with ranking.

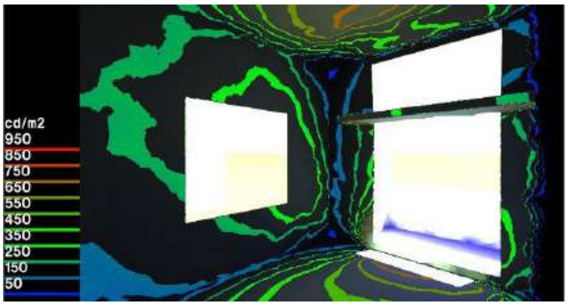
Considering DA, type C performs the best to other configuration types but the value of DA_{max} is the highest which may cause glare. Considering DA_{max}, $UDI_{100-200}$ and $UDI_{>2000}$, type R performs the best and DA range is also an average. Considering $UDI_{<100}$, type SR value the highest. Here perceived highest point as 3 points to least 1 point for the configurations from 1st to 3rd place.

Table 4. 8 Annual CBDM simulation outputs with rating points and ranking of balcony types

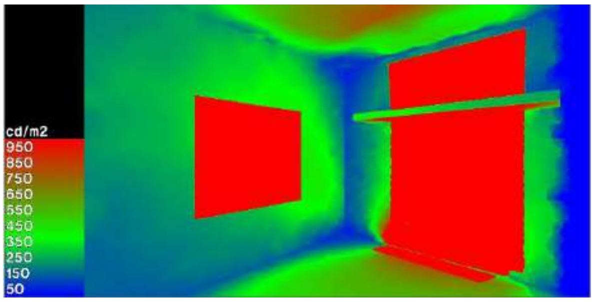
Balcony Type	**Value and Rating points (RP)**	**DA (%)**	***DA*** *max (%)*	***UDI***$_{<100}$ *(%)*	***UDI*** $_{100-2000}$ *(%)*	***UDI***$_{>2000}$ *(%)*	**Total RP**	**Ranks**
R	*Value*	**75.67**	**0**	**14.67**	**82.67**	**2.67**	**12**	**1**
	RP	**1**	**3**	**2**	**3**	**3**		
SR	*Value*	**78.33**	**0**	**14.67**	**79.67**	**6.33**	**11**	**2**
	RP	**2**	**3**	**2**	**2**	**2**		
C	*Value*	**80.33**	**2**	**14.33**	**77.67**	**8.33**	**10**	**3**
	RP	**3**	**2**	**3**	**1**	**1**		



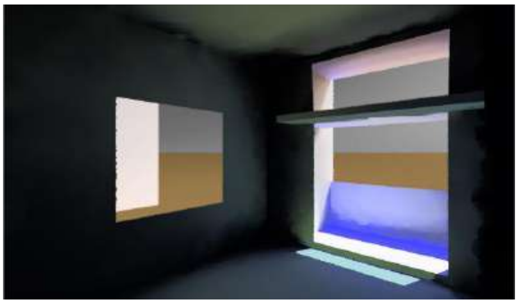
a) Type R daylight contour map



b) Type R daylight contour band



c) Type R daylight false color map



d) Type R human sensitivity

Figure 4. 23: Daylight contour map, contour band, false color map and human sensitivity at bedroom for R type balcony

Considering the rating points type R scores the highest and ensures a uniform distribution of daylight, compared to other studied types. Figure 4.23 shows daylight contour maps, the false color of two types of balcony placements and Figure 4.24 shows the DA and UDI100-2000 patterns at bedroom for R type balcony. Figure 4.25 shows $UDI_{100-2000}$ of R, SR, C accordingly.

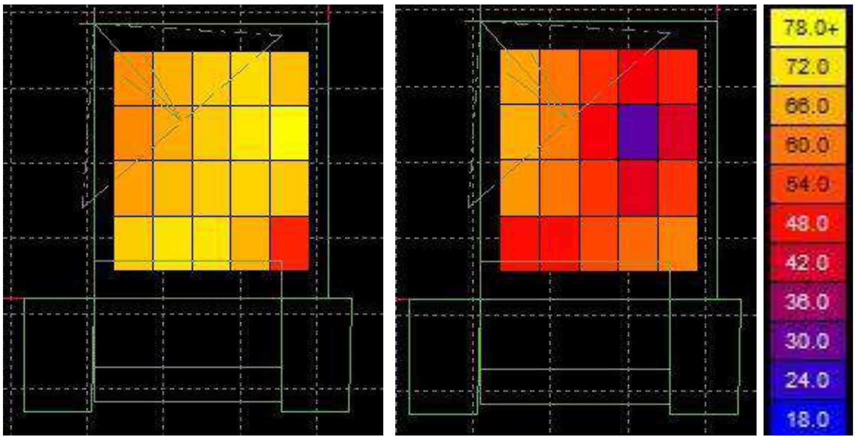


Figure 4. 24:DA (left) and UDI$_{100\text{-}2000}$ patterns at bedroom for R type balcony

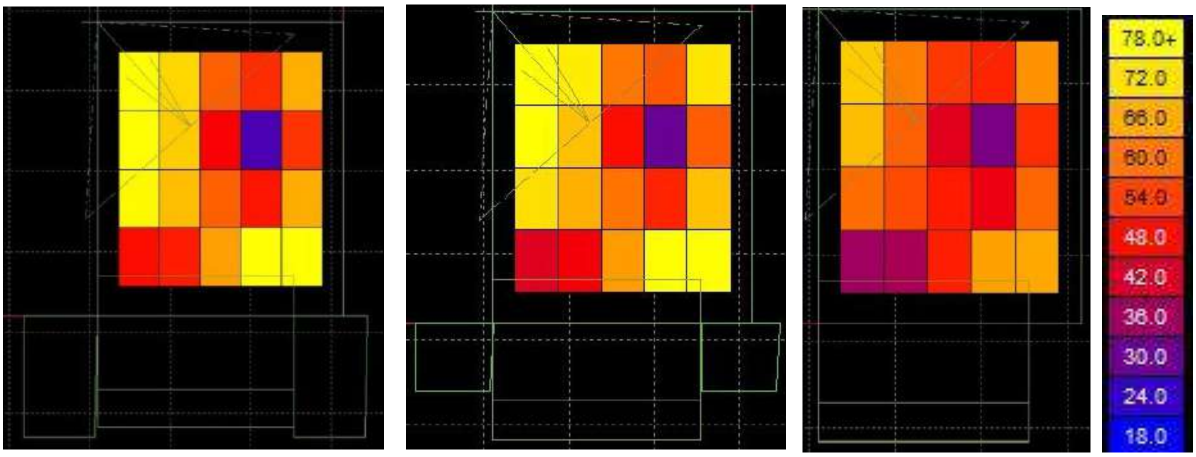


Figure 4. 25: UDI $_{100\text{-}2000}$ patterns at bedroom for R, SR and C type balconies

4.3 Summary of the Chapter Findings

This chapter ends with some decisions of combined findings of the parametric simulation study. According to the performance, each point is equally important and make a huge change when changing the parameters in every section. Fixing the best performance next section is proceeded. Table 4.9 shows the summary of the findings with the best outputs among the studied balcony parameters.

Table 4. 9 Best outputs among the studied balcony parameters

No.	Type of Analysis	Best Output
1	Balcony railing height	915mm
2	Balcony drop end level	2150mm
3	Balcony adjacent wall	Sliding glass opening with light shelf (indoor 500mm depth and outdoor as balcony depth)
4	Balcony placement	Zig-zag placement in terms of elevation
5	Balcony floor depth	1370 mm
6	Balcony floor material	Silver glossy floor tiles, LRV90
7	Balcony wall color	Blue color, reflectance 20
8	Balcony type	Recessed balcony

4.4 Validation of Test Results

A single way one-way Analysis of Variance (ANOVA) calculation is done to validate the test results. ANOVA checks whether any statistically significant differences existed among the generated values. Table 4.10 presents summary of ANOVA for validation of the results. Appendix E presents details of ANOVA calculation results for individual balcony parameters with their co-relation graphs.

Table 4.10 : Summary of ANOVA for validation of the results

No.	Type of Analysis	P-value	F value	F critical value
1	Balcony railing height	1	0.000201	2.445259
2	Balcony drop end level	0.999997	0.00384	2.620654
3	Balcony adjacent wall	0.998339	0.001663	3.885294
4	Balcony placement	0.967246	0.001795	5.317655
5	Balcony floor depth	0.999991	0.001995	2.866081
6	Balcony floor material	0.999997963	0.000963029	2.866081402
7	Balcony wall color	0.993935	0.085013	2.620654
8	Balcony type	0.998464	0.001537	3.885294

Here in the studied cases F value is lower than F critical value. Therefore, the null hypothesis is not rejected (Tabassum, 2021). P-value is greater than 0.05 in each case. Thus, there is not much strong evidence against this specific null hypothesis (Tabassum, 2021) either, and it can be concluded that the calculations are significant and can be used for further studies. Results of ANOVA testing conclude that the calculation results of balcony features are valid and recommendation is considerable for further research.

4.5 Summary

This chapter has shown the simulation analysis results to achieve the second objective of the research in two steps. The first step has been conducted by establishing a balcony railing height and drop level as possible options to improve the daylight penetration of bedroom beside the balcony in the context of urban apartments in Dhaka. The balcony with 915mm railing height with a drop ended at 2150mm from finished floor level is found as the most practicable configuration for daylight penetration among the studied configurations in the climatic context of Dhaka. By using this railing and drop level effective daylight penetration could be ensured for the apartments throughout the year. The effective adjacent wall configurations between bedroom and balcony is found. Based on the observations made by simulation studies, it can be stated that sliding glass openings with light shelf performs better than brick wall with only sliding glass window openings. The performance of different balcony placements for the case building shows that all floor balcony is the feasible balcony position that produces useful daylight inside bedrooms beside balconies. The second stage has been conducted by establishing a balcony floor depth, floor material, facade material and the best local balcony pattern as possible options.1370 mm floor depth with indoor light shelf of 500mm and outdoor light shelf equal to balcony floor depth performs better. Silver glossy tiles (LRV 90) as floor material and blue color interior wall are found as the most feasible options. The recessed type of balcony scored better among the studied balcony configurations in the climatic context of Dhaka. An ANOVA test also give validation of the results. This chapter margins to the presentation of the achievement of the research objectives. In next Chapter 5 concludes the thesis with some indicative recommendations and suggestions for further work.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Preamble

This thesis is covered in five chapters. Chapter one introduces the research. Chapter two presents information based on theory, history, national and international rules and guidelines. The third chapter elaborates on detailed steps of the methodology applied in this research. In the fourth chapter, the detailed dynamic performance analysis and rating of simulated results are evaluated and discussed simultaneously. The final results of the dynamic simulation studies are done to identify the most capable balcony configurations and placement of the balcony beside bedrooms of the apartment buildings in an urban residential area in the context of Dhaka. This last chapter concludes the research with the achievement of the two objectives which is mentioned in the first chapter and provides some recommendations for further research and studies.

5.2 Achievements of the Objectives

The achievements of the two objectives of the research, developed in Chapter 1 (Section 1.3), are discussed in this section as follows.

5.2.1 Effectiveness of Different Balcony Types as Screening and Shading Elements

The first objective is to determine the effectiveness of different balcony types as screening and shading elements to enhance indoor daylighting for an apartment building in Dhaka City. Literature review and field investigations are done to attain this purpose. Figure 5.1 shows the balcony types that were identified after a review of the literature. Studies of the literature have revealed that there are primarily three types of balconies: the Open balcony, glazed balcony and eliminated balcony. One of the forms of balconies that fall under the category of an enclosed balcony is a courtyard. Because they are common in tropical and sub-continental areas, local forms of balconies might be grouped under open balconies. Recessed, semi-recessed, and cantilever are the three local varieties of balconies identified during field survey. These three types have well environment quality, appropriate ventilation, high visual comfort and good acoustic quality with use of appropriate materials. Cantilever balconies get excessive sunlight than the other two types of balconies which is a concern for thermal comfort. For safety issues appropriate railing height with a balcony door lock system have to be ensured for all three types of balconies.

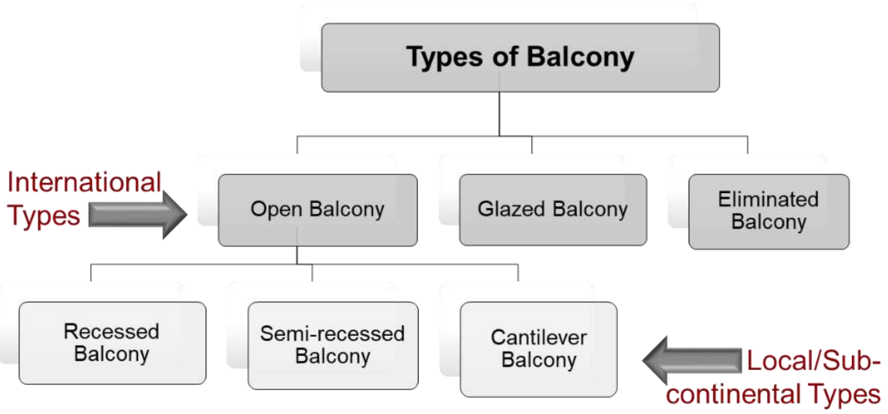


Figure 5. 1 Balcony type

5.2.2 Various Balcony Treatments to Enhance the Daylight Performance

The second objective is to investigate the role of various design parameters e.g. railing height, drop level, depth, material, color, placement and types of balconies to enhance the daylight performance in adjacent bedrooms. To achieve this objective, in the beginning, a field survey was conducted on the apartment buildings after selecting a target group (middle income).

Among several buildings, four buildings were selected with common types of balconies. Of these four surveyed buildings the most suitable one was selected as case building considering indoor lighting penetration and amply better in correspondence to the selection criteria of Section 3.2.2.e.

Dynamic daylight simulation is conducted with five different heights of the balcony railings. Figure 5.2 shows perspective view of recessed balcony with the best features included. With the best result found, 915 mm railing height, dynamic daylight simulation is conducted with six different drop heights and the drop ended at 2150 mm from finished floor level is found as the most feasible configuration among the studied configurations in the climatic context of Dhaka. By using this railing and drop level an effective daylight penetration could be ensured for the adjacent bedrooms throughout the year.

Dynamic daylight simulation is conducted with three different partition wall configurations. Based on the observations made by simulation studies, it can be stated that sliding glass openings towards the balcony with a light shelf outer depth same as balcony depth and an internal depth of 500 mm perform better than the punched door and windows in the adjacent wall to balcony. The bedroom receives effective illumination at the task plane in the indoor spaces by using light shelf.

By evaluating the performance of different balcony placements in the selected building, all floor balcony is found as most feasible balcony placement which produces useful daylight in balcony adjacent indoor spaces. Dynamic daylight simulation is also done with five different depths of balconies and 1370mm depth performs the best with light shelf.

To evaluate the floor and facade materials, five different floor materials and six different wall colors with various reflectance were investigated alternatively. The floor with silver glossy tiles and wall with blue color work best for daylighting penetration in indoor through balcony.

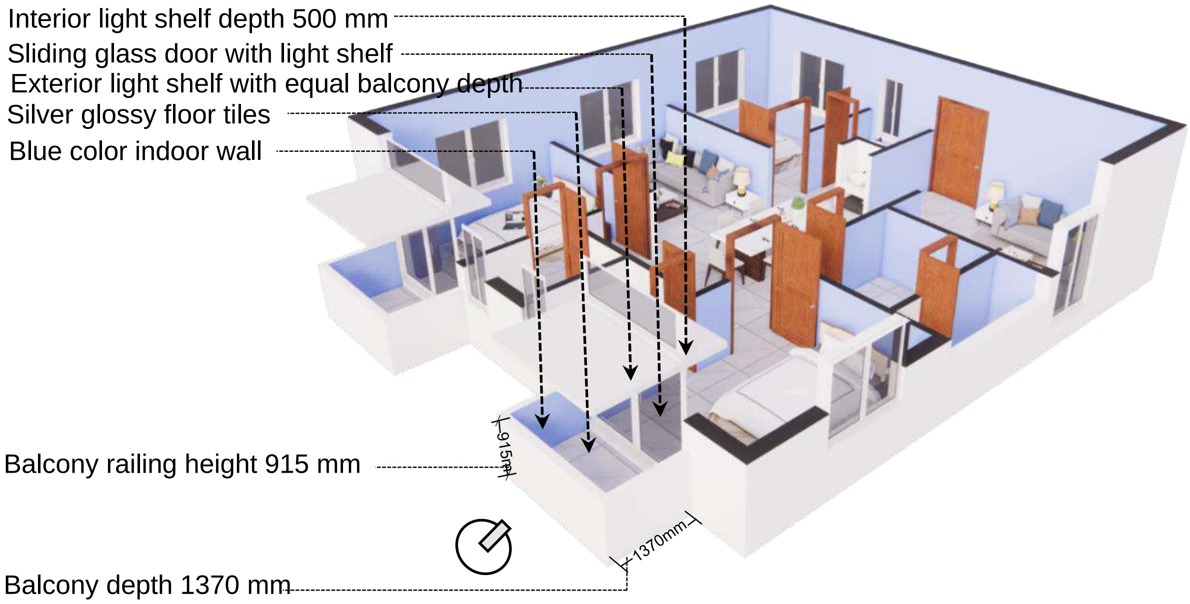


Figure 5. 2: Prespective view of recessed balcony with the best features included

Finally, three local types of the balconies were evaluated with the best-performed materials and recessed balcony performs better against the other two balcony types for a preferable daylighting for bedroom through the balcony in the context of tropical cities i.e Dhaka.

5.3 Recommendations

Some familiar endorsement is drawn attention from this research for apartments to enhance the glare-free daylighting condition of the balcony adjacent indoor spaces are the following.

a. The depth of the balconies should be kept at 1370 mm.
b. Balcony with 915 mm railing height provides effective daylighting on the task plane at the adjacent bedroom.
c. The balcony with a drop ended at 2150mm from finished floor level is the most feasible among the studied configurations in the climatic context of Dhaka.
d. Sliding glass with a light shelf performs better than punched doors and/or windows in the adjacent wall to the balcony.
e. Balcony on all floors as a regular pattern ensures glare-free daylight in adjacent indoor spaces.
f. Silver glossy tiles as floor material (reflectance 90) and blue wall color (reflectance 20) perform best than other studied materials.
g. Recessed balcony type with the above features works effectively for daylighting penetration in the context of Dhaka.

5.4 Areas for Further Research

Some points that need to be addressed in further studies with the appropriate reference to daylighting in apartments through balconies are the following.

- As this study focuses only on the daylighting of the apartment balconies, a thermal comfort study could be done in the future.
- Only a south-facing apartment was modeled. The impression of the daylighting in different orientations of the apartment building's balconies could be identified.
- The impact of rules, regulations and planning on daylight formation in urban apartments is needed to be find out in future.
- The consequences of daylighting through balconies on overall energy consumption for apartments can be studied.
- Investigation can be executed on users' physical and mental well-beings to find out influence of daylight formation through balcony.
- Any inter-zonal thermal exchange is ignored in this research. The internal influence of the bathroom and kitchen are also avoided. This could be included in future.
- Rather than an integrated design combining the effects of different strategies combinedly, in this research each strategy was calculated linearly to achieve a glare free daylighting. Further optimization studies could be done to consider the combined effect of different strategies at a time in future.

5.5 Concluding Remarks

To create a comfortable visual experience and assure sustainability, daylight is crucial in interior designs. In the context of Dhaka, an appropriate shading depth for a full façade sliding glass aperture (usually used as a door to the balcony) for south orientation is huge. A balcony, attached to the bedroom with a glass sliding door can be treated as a shading device to ensure glare-free daylighting inside bedroom. The balcony with recommended parameters in this research will re-direct and transmit daylight in interior space and will provide uniform illumination distribution in bedrooms. It is anticipated that this research can be used as a basis for further research to execute other aspects as mentioned above for daylighting in apartments through balconies to get glare-free indoor daylighting.

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APPENDICS

Appendix A

This presents summary of the Key findings of the research in relation to the objectives, methodologies and concerned chapter

Appendix B
This presents the Key terms and concepts related to this thesis

Appendix C
This presents the specification of tools and simulation software

Appendix D
This presents the detail daylight simulation result

Appendix E
Single way one-way Analysis of Variance (ANOVA) calculation

Appendix A: Summary of the Key Findings

Summary of the key findings of the research in relation to the objectives, methodologies and concerned chapters

Objective	Methods	Chapter	Key findings
Objective 1: To determine the effectiveness of different balcony types as screening and shading elements to enhance indoor daylighting for apartment buildings in Dhaka.	Literature review	Chapter 2	Balconies are mainly three types: open balcony, glazed balcony and eliminited balcony. Courtyard is also one of the types of balconies categorized under an enclosed balcony. The local types of balconies could be categorized under open balconies because of their availability in the sub continent and tropical countries. Recessed, semi-recessed and cantilever are three types common in the sub-continent. These three types have well environment quality, appropriate ventilation, high visual comfort and good acoustic quality with use of appropriate materials. Cantilever balconies get excessive sunlight than the other two types of balconies which is a concern for thermal comfort. For safety issues appropriate railing height with a balcony door lock system have to be ensured for all three types of balconies.
Objective 2: To investigate the role of various design parameters e.g. railing height, drop level, depth, material, color, placement and types of balconies to enhance the daylight performance in adjacent bedrooms.	Dynamic daylight simulation analysis	Chapter 4	The balcony with 915mm railing height with a drop ended at 2150mm from finished floor level is found to be the most practicable configuration for daylight penetration among the studied configurations. Based on the findings of simulation studies sliding glass openings with a light shelf outer depth equal to balcony depth and an internal depth of 500mm performs better compared to only punched or sliding door on the adjacent wall to the balcony. It is also discovered that when balconies are placed one above another in each floor outperforms the type when balconies are placed in zig-zag pattern on building elevation. After finding the best balcony depth1370mm, the floor and facade materials were discovered to be silver glossy tiles flooring (reflectance 90) and blue color (reflectance 20) indoor walls. Finally, when these are taken into account, the recessed balcony outperforms over cantilever and semi-recessed balcony types.

Appendix B: Lighting Terminology

DA (Daylight Autonomy): is the percentage of the occupied times of the year when the minimum illuminance requirement at the sensor is met by daylight alone. a percentage of annual daytime hours that a given point in space is above a specified illumination level. For this research, the DA threshold is assumed as 300 lux. The activities are based on daylight, if starts at 6:00 AM and ends at 6:00 PM, it means 12 hours of a day x 365 days=4380 luminous hours round the whole year.

Useful daylight Index (UDI%): is hourly time values based upon three illumination ranges, 0-100 lux, 100-2000 lux, and over 2000 lux (Nabil and Mardaljevic, 2006). Below 100 lux is not considered working light. It provides full credit only to values between 100 lux and 2,000 lux. This range is regarded as a useful daylight illumination range. Horizontal illumination values outside the 2,000 lux range are not useful. 2000 lux is the upper threshold, above which daylight is not wanted due to potential glare or overheating.

Maximum Daylight Autonomy (DA_{max} %): is the percentage of the occupied hours when the daylight level is 10 times higher than design illumination; represents the likely appearance of glare. It is an illuminance-based glare analysis metric. The idea is to calculate DA max using an illuminance threshold that is 10 times the design illuminance. For example, if 300 lux is the threshold then over 300 x 10= 3000 lux will be counted as the DA max value. DA max must not exceed 1%, for more than 5% of a critical working plane area (Iqbal, 2015)

DAcon (Continuous Daylight Autonomy): is the percentage of the minimum illuminance requirement met by daylight alone at the sensor during the full occupied times of the year. The metric acknowledges that even a partial contribution of daylight to illuminate a space is still beneficial. e.g., if the design illuminance is 300 lux on the core work plane sensor, and 180 lux are provided by daylight alone at one sensor point during the whole office hours of the year; a partial credit of 180lux/300lux=0.6 (60%) is given to that sensor point.

Diffuse radiation: is the total amount of radiation falling on a horizontal surface from all parts of the sky apart from the direct sun.

Direct radiation: is the radiation arriving at the earth's surface with the sun's beam.

Global radiation: is the total of direct solar radiation and diffuse sky radiation received by a horizontal surface of a unit area.

Illuminance: is the quantitative expression for the luminous flux incident on the unit area of a surface. A more familiar term would be ―lighting level‖. Illuminance is expressed in lux (lx). One lux equals one lumen per square meter (lm/m^2). In Imperial units, the unit is the foot-candle which equals lumen per square foot (lm/ft^2). Other units are – meter candle, phot, nox.

UDI (Useful daylight illuminance): try to find out when daylight levels are useful for the user and when they are not. Based on occupants' preferences in daylit RMGs, UDI results in three metrics, i.e., the percentages of the occupied times of the year when daylight is useful (100- 2000lux), too dark (<100 lux), or too bright (> 2000 lux).

LIGHTING METHODS

Ambient accuracy (aa): value is approximately equal the error from indirect illuminance interpolation. A value of zero implies no interpolation.

Ambient bounces (ab): is the maximum number of diffuse bounces computed by the indirect calculation. A value of zero implies no indirect calculation.

Ambient division (ad): The error in the Monte Carlo calculation of indirect illuminance will be inversely proportional to the square root of the number of ambient divisions. A value of zero implies no indirect illumination.

Ambient resolution (ar): determine the maximum density of ambient values used in interpolation. Error will start to increase on surfaces spaced closer than the scene size divided by the ambient resolution. The maximum ambient value density is the scene size times the ambient accuracy divided by the ambient resolution.

Ambient sampling (as): are applied only to the ambient divisions which show a significant change.

Backward raytracing: simulates individual rays from the points of interest to light source or other objects backwardly with respect to a given viewpoint. It is possible to simulate different basic surfaces (e.g., 100% specular surfaces, lambertian surfaces, transparent surfaces and translucent surfaces) and a random mixture of these basic surfaces under raytracing.

DAYSIM simulation: calculates the performance metrics considering the impact of local climate and generates a time series indoor annual illuminance profile at points of 137 interests in a building. DAYSIM requires two steps to calculate the annual amount of daylight in a building. Daylight coefficients are calculated first considering the available daylight surrounding the building. After that, the daylight coefficients are combined with the specified climate data of building site. Based on generated illumination profile, DAYSIM derives several dynamic, climate-based daylight performance matrices, such as Daylight Autonomy (DA), Useful Daylight Index (UDI), Continuous Daylight Autonomy (DAcon) and Maximum Daylight Autonomy (DAmax). More details on the simulation algorithm used by DAYSIM can be found under Reinhart (2006).

DAYSIM uses **Perez all weather sky luminance model**. Perez sky model was developed in early nineties by Richard Perez et al. (1990; 1993). To investigate the performance of a building under all possible sky conditions that may occur in a year, DAYSIM first imports hourly direct and diffuse irradiances from a climate file and if 138 required, a stochastic autocorrelation model is used to convert the time series down to five-minute time series of direct and diffuse irradiances from one hour. Then, these irradiances are converted into illuminance and a series of sky luminous distributions of the celestial hemisphere. The sky luminous distribution for a given sky condition varies with date, time, site and direct and diffuse irradiance values, and influence the relative intensity of light back-scattered from the earth surface, the width of the circumsolar region, the relative intensity of the circumsolar region, the luminance gradient near the horizon, and darkening or brightening of the horizon.

Daylight coefficients: calculate indoor lighting levels due to outdoor natural light levels under arbitrary sky conditions. Tregenza (1983) first proposed the concept of daylight coefficients. In this concept, the celestial hemisphere is theoretically divided into disjoint sky patches at the beginning. Then, total illuminance at a point in a building is calculated by summing the contribution of each sky patch individually. After, calculating a complete set of daylight coefficients on a sensor point for a building geometry, it is possible to couple the daylight coefficient with an arbitrary sky luminance distribution and calculate the total illuminance on the specified point by a simple linear superposition. So, using this simple algebraic equation, DAYSIM calculates daylight levels annually considering the short-time-step variances of the outdoor available natural light simultaneously with a time variation of minutes to hours. Reinhart and Herkel (2000) compared six different RADIANCE-based (backward raytracer) dynamic daylighting simulation concepts and found that daylight coefficient approaches is the most reliable and fastest methods to define the short-time step illuminance change in a building.

Appendix C: Specifications

C1: About ECOTECT software

ECOTECT v5.20

The ECOTECT software is developed by Dr. Andrew Marsh as part of his PhD thesis in the University of Western Australia. It is a very useful tool for architects to test the environmental impact on their design scheme even at an early design stage. Autodesk ECOTECT is very user-friendly software that could potentially integrate with the architectural design process. The 3D models are first generated in the ECOTECT, to study the distribution and uniformity of daylight within the interior space using the split-flux method

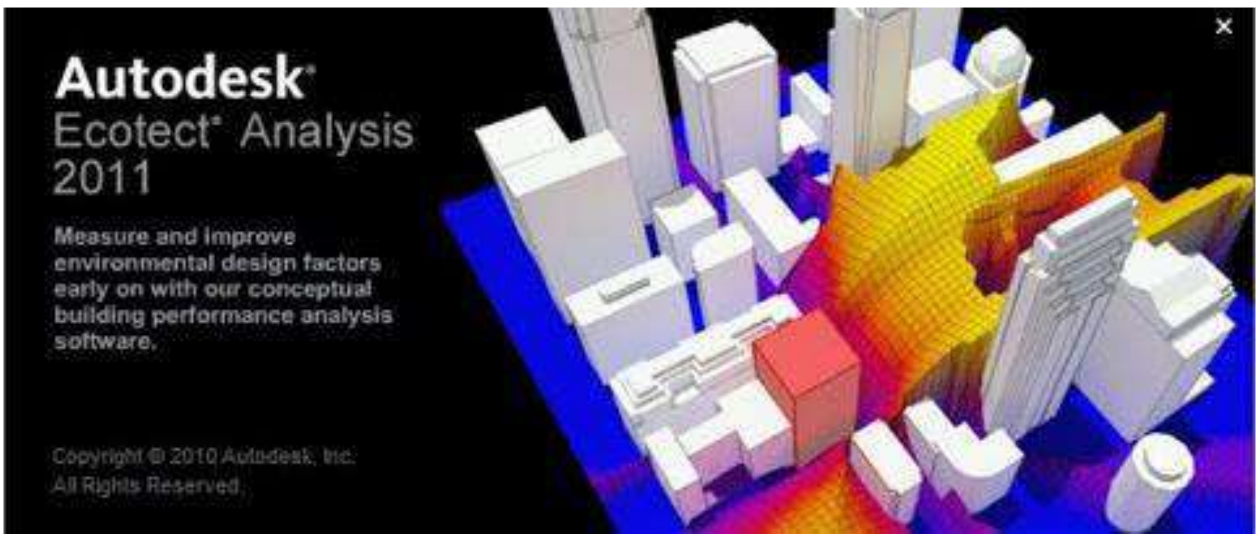

Figure A1: Detail Interface of ECOTECT simulation software

Thermal performance analysis in Autodesk ECOTECT is based on the Chartered Institution of Building Services Engineers (CIBSE) admittance method and thus inherits its limitations. Hence, the need to use more detailed thermal simulation tools during the final stage of a building design or research project. For daylighting performance analysis, ECOTECT software is used to obtain illuminance levels and daylight factor (DF) for glazing. It is an environmental assessment tool that allows simulating a model in terms of thermal, acoustic and lighting, having several detailed analysis functions with a visual and interactive display that presents test results directly within the context of the model of the building.

ECOTECT 5.6 tool offers a range of lighting analysis options. The main focus is on daylighting analysis. It implements the Building Research Establishments (BRE) split flux method for determining the natural light levels at points within a model. This is based on the Daylight Factor concept which is a ratio of the illuminance at a particular point within an enclosure to the simultaneous unobstructed outdoor illuminance. Figure presents the main screen of ECOTECT for daylighting calculation.

Currently, the new version of ECOTECT software is “Autodesk ECOTECT Analysis”. It is now sustainable design analysis software with a comprehensive concept-to-detail sustainable building design tool. ECOTECT Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. This new version also allows simulation types shown in older versions (thermal performance, solar radiation and daylighting) whole building energy analysis; water usage and cost evaluation; shadows and reflections. For correct assessment of the values in daylighting simulations is required to produce the climate file from "epw" file (EnergyPlus) to “. wea” file in ECOTECT 5.6. According to the latitude of the location the outside illuminance is calculated. Although the exterior illuminance obtained by software ECOTECT present differences of the real situation, it is known that such values depend on the latitude of the location and do not affect the daylight factor obtained by computational simulation.

C2: About DAYSIM software

DAYSIM v2.1

At the most fundamental level DAYSIM offers an efficient way to calculate the annual amount of daylight available in and around buildings. To do so DAYSIM combines a daylight coefficient approach with the Perez all weather sky model and the RADIANCE backward ray-tracer. The resulting time series of illuminance, radiances or irradiances at user defined sensors points can be used for a number of purposes:

To derive climate-based daylighting metrics

To calculate annual electric lighting use for different lighting controls based on available daylight

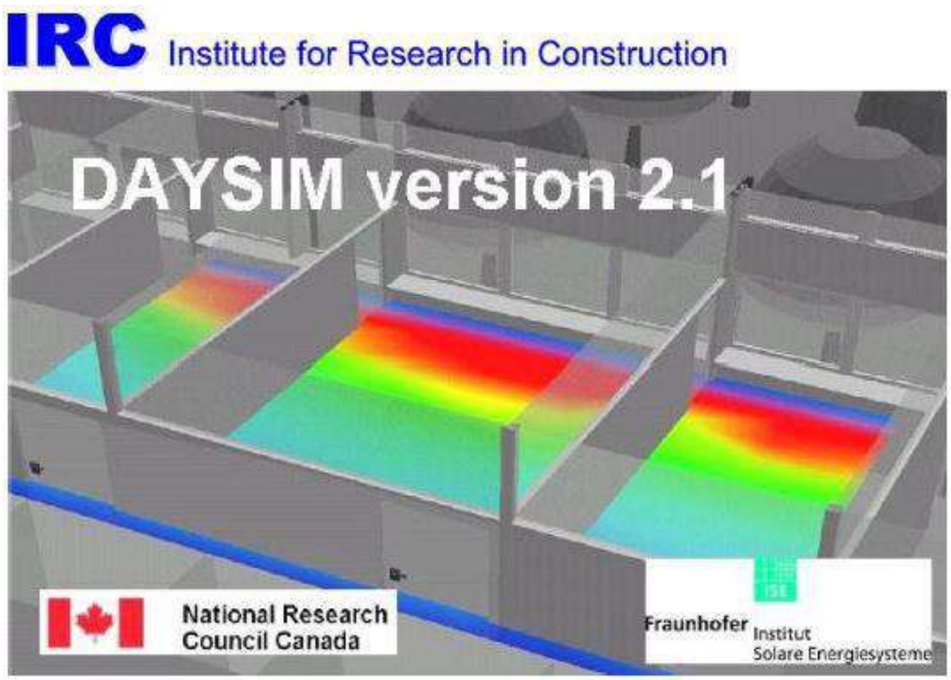

Figure A2: Detail Interface of DAYSIM simulation software.

Climate-based Daylighting Metrics: Over the past decade a new family of daylighting metrics to describe and evaluate daylight in spaces has been developed. These metrics summarize the daylight availability over the year and throughout a space. Two prominent daylighting metrics which are calculated by DAYSIM are Daylight Autonomy and Useful Daylight Illuminance. Daylight Autonomy is now being a recommend metrics by the Illuminating Engineering Society of North America (IESNA).

Electric Lighting Use: DAYSIM uses an occupant behavior model called Lighswitch to model called Light switch to predict based on annual illuminance profiles and occupancy schedules how occupants in a space are going to manually operate electric lighting controls and shading systems (see below). The model thus predicts overall electric lighting energy use in a space. DAYSIM also outputs an Internal Gains schedule as can be used by energy simulation programs such as EnergyPlusTM and eQuest to conduct an integrated thermal lighting analysis of a space.

Dynamic Shading: DAYSIM can also model spaces with multiple dynamic shading systems such as venetian blinds, roller shades and electro chromic glazing. In spaces with dynamic shading systems DAYSIM automatically generates multiple annual illuminance profiles each with the shading system(s) in a static position throughout the year. In a post-processing step it then uses the Light witch model to predict in which state the shading systems is going to be.

Glare Analysis: DAYSIM uses the daylight glare probability metric to predict discomfort glare from daylight for different viewpoint in a scene through the year. Similarly, as for the annual illuminance profiles DAYSIM generates annual daylight glare probability profiles for different shading device settings that in a post-process are then used to predict the setting of a dynamic shading system throughout the year.

Appendix D: Dynamic Daylight Simulation Results

Appendix D1:
Dynamic simulation result for balcony railing height BR915 with drop bottom end height 2150

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	4.4	75	77	15	22	49	28	50	10839098
3.862	2.566	0.800	9.0	76	78	46	21	22	57	0	22853620
4.370	2.566	0.800	9.9	76	78	54	21	16	64	0	24780740
4.878	2.566	0.800	8.1	76	78	36	21	22	57	0	19709176
5.386	2.566	0.800	2.2	68	74	7	25	65	10	80	5827757
5.894	2.566	0.800	0.7	54	67	0	31	68	0	68	1654904
3.354	3.297	0.800	2.7	71	75	1	24	64	12	99	4774846
3.862	3.297	0.800	3.7	73	76	7	23	54	23	88	6374079
4.370	3.297	0.800	3.9	73	76	4	23	56	21	100	6216140
4.878	3.297	0.800	3.4	72	76	4	23	59	18	90	6123571
5.386	3.297	0.800	1.6	67	72	0	26	73	2	98	3380643
5.894	3.297	0.800	2.1	68	74	1	25	65	10	99	4359587
3.354	4.029	0.800	1.7	66	73	0	25	75	0	98	3121973
3.862	4.029	0.800	1.4	62	71	0	26	74	0	97	2541522
4.370	4.029	0.800	2.4	71	75	0	24	75	1	99	4098978
4.878	4.029	0.800	3.1	73	76	6	24	61	15	85	6104217
5.386	4.029	0.800	4.1	74	76	14	23	47	31	53	9842206
5.894	4.029	0.800	9.2	76	78	45	21	24	56	0	21648260
3.354	4.761	0.800	1.3	62	71	1	26	72	2	93	2670076
3.862	4.761	0.800	1.4	63	72	1	25	72	2	94	2899761
4.370	4.761	0.800	1.6	65	73	2	25	71	4	93	3430398
4.878	4.761	0.800	2.4	70	75	8	24	65	10	75	5404387
5.386	4.761	0.800	4.2	74	77	14	23	54	23	48	11012698
5.894	4.761	0.800	7.5	75	78	34	21	30	49	8	18987920
3.354	5.492	0.800	1.2	59	71	1	26	72	2	96	2421471
3.862	5.492	0.800	1.0	57	69	0	27	72	1	94	2190922
4.370	5.492	0.800	0.8	54	66	3	28	67	5	77	2346199
4.878	5.492	0.800	2.2	69	74	8	25	66	10	76	5168846
5.386	5.492	0.800	2.7	70	75	8	24	65	11	67	6936429
5.894	5.492	0.800	0.9	53	67	2	29	69	3	68	2574671

Appendix D2:

Dynamic simulation result for balcony adjacent wall BW_BL2 with all floor balcony

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	4.3	74	77	14	22	48	29	51	10818314
3.862	2.566	0.800	8.6	76	78	45	21	21	58	0	22545408
4.370	2.566	0.800	9.1	76	78	51	21	17	63	0	23883808
4.878	2.566	0.800	7.7	75	78	36	21	21	58	1	19506226
5.386	2.566	0.800	2.6	70	75	8	25	64	11	80	6527439
5.894	2.566	0.800	1.1	64	71	0	27	73	0	93	2152853
3.354	3.297	0.800	3.1	73	76	2	23	60	16	98	5528478
3.862	3.297	0.800	3.7	74	76	7	23	52	25	87	6719102
4.370	3.297	0.800	4.1	74	77	6	23	53	24	100	6668539
4.878	3.297	0.800	3.6	73	76	5	23	57	20	90	6550412
5.386	3.297	0.800	2.8	71	75	1	24	62	14	99	5296108
5.894	3.297	0.800	2.6	70	75	1	25	60	15	99	5259426
3.354	4.029	0.800	2.1	69	74	0	25	75	0	99	3887956
3.862	4.029	0.800	2.5	71	75	0	24	74	2	99	4467279
4.370	4.029	0.800	2.8	72	76	0	24	69	7	99	4900771
4.878	4.029	0.800	3.3	73	76	6	23	53	24	84	6623958
5.386	4.029	0.800	5.3	75	77	21	22	32	46	51	11856506
5.894	4.029	0.800	9.4	76	78	46	21	23	56	0	22000840
3.354	4.761	0.800	2.0	70	74	2	25	72	3	96	4007116
3.862	4.761	0.800	2.2	70	75	2	25	72	3	96	4254421
4.370	4.761	0.800	2.7	72	75	3	24	69	7	93	5119292
4.878	4.761	0.800	3.3	73	76	9	23	58	19	75	7202234
5.386	4.761	0.800	5.0	75	77	16	22	38	40	48	12471553
5.894	4.761	0.800	7.8	76	78	37	21	28	51	5	19469476
3.354	5.492	0.800	1.9	69	74	1	25	73	2	99	3673986
3.862	5.492	0.800	2.2	70	75	1	25	73	2	99	4093072
4.370	5.492	0.800	2.6	72	75	5	24	67	9	85	5276515
4.878	5.492	0.800	3.1	73	76	8	23	62	15	75	6688616
5.386	5.492	0.800	3.3	73	76	9	23	61	15	66	8079713
5.894	5.492	0.800	2.1	68	74	3	25	72	3	83	4441934

Appendix D3:

Dynamic simulation result for balcony depth BD1370

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	4.3	74	77	15	22	47	30	51	10886992
3.862	2.566	0.800	8.7	76	78	46	21	21	58	0	22789530
4.370	2.566	0.800	9.2	76	78	52	21	16	63	0	24135496
4.878	2.566	0.800	7.7	75	78	36	21	21	58	0	19544546
5.386	2.566	0.800	2.5	70	75	6	25	66	9	80	6269313
5.894	2.566	0.800	1.1	64	71	0	27	73	0	94	2201704
3.354	3.297	0.800	3.0	73	76	2	24	60	16	98	5488789
3.862	3.297	0.800	3.7	74	76	7	23	52	25	87	6747462
4.370	3.297	0.800	4.0	74	76	4	23	54	23	100	6501406
4.878	3.297	0.800	3.6	73	76	4	23	56	20	90	6545477
5.386	3.297	0.800	2.8	71	75	1	24	62	13	99	5212049
5.894	3.297	0.800	2.5	70	75	1	25	61	14	99	5134177
3.354	4.029	0.800	2.1	69	75	0	25	75	0	99	3933831
3.862	4.029	0.800	2.4	71	75	0	24	75	0	99	4252579
4.370	4.029	0.800	2.7	72	75	0	24	70	6	99	4806738
4.878	4.029	0.800	3.3	73	76	6	23	52	25	84	6737048
5.386	4.029	0.800	5.3	75	77	21	22	33	46	50	11900820
5.894	4.029	0.800	9.4	76	78	46	21	24	56	0	21960070
3.354	4.761	0.800	1.9	69	74	2	25	73	3	95	3834524
3.862	4.761	0.800	2.2	70	75	2	25	72	3	95	4341729
4.370	4.761	0.800	2.6	72	75	3	24	69	7	93	4982412
4.878	4.761	0.800	3.3	73	76	9	23	59	18	75	7071605
5.386	4.761	0.800	5.1	75	77	16	22	37	41	47	12601485
5.894	4.761	0.800	7.9	76	78	38	21	29	51	3	19609318
3.354	5.492	0.800	1.7	67	74	1	25	73	2	98	3388954
3.862	5.492	0.800	2.0	70	74	1	25	73	2	99	3841236
4.370	5.492	0.800	2.4	71	75	5	24	68	8	85	5062024
4.878	5.492	0.800	2.9	73	76	8	24	63	13	75	6458689
5.386	5.492	0.800	3.2	73	76	9	23	62	15	66	7978410
5.894	5.492	0.800	2.0	67	74	3	25	72	3	83	4246343

Appendix D4:
Dynamic simulation result for balcony floor material GT100

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	4.1	84	87	13	12	63	24	52	10386875
3.862	2.566	0.800	8.7	86	88	48	11	25	64	0	22641496
4.370	2.566	0.800	9.0	86	88	51	11	22	68	0	23720494
4.878	2.566	0.800	7.4	85	88	35	11	32	57	8	18902244
5.386	2.566	0.800	2.3	78	84	8	15	75	10	80	5864249
5.894	2.566	0.800	0.9	64	77	0	19	81	0	89	1797252
3.354	3.297	0.800	2.8	82	86	1	14	76	10	98	4999527
3.862	3.297	0.800	3.4	83	86	4	13	68	19	89	6184476
4.370	3.297	0.800	3.7	83	86	1	13	66	21	100	6079921
4.878	3.297	0.800	3.5	82	86	5	13	67	19	91	6253473
5.386	3.297	0.800	2.7	80	85	1	14	72	14	99	4955849
5.894	3.297	0.800	2.4	79	84	1	15	72	14	99	4811820
3.354	4.029	0.800	1.9	77	84	0	15	85	0	98	3419706
3.862	4.029	0.800	2.3	80	85	0	14	85	0	99	3996912
4.370	4.029	0.800	2.5	81	85	0	14	86	0	99	4375926
4.878	4.029	0.800	3.3	83	86	4	13	67	20	84	6536525
5.386	4.029	0.800	5.1	85	87	16	12	44	44	52	11445118
5.894	4.029	0.800	9.3	86	88	46	11	28	61	0	21753536
3.354	4.761	0.800	1.6	75	83	1	15	84	1	95	3308856
3.862	4.761	0.800	2.0	79	84	1	15	84	2	96	3840169
4.370	4.761	0.800	2.4	81	85	2	14	83	3	93	4626064
4.878	4.761	0.800	3.2	83	86	7	13	73	13	75	6792968
5.386	4.761	0.800	5.0	85	87	15	12	50	38	48	12244591
5.894	4.761	0.800	7.8	86	88	34	11	38	52	6	19315398
3.354	5.492	0.800	1.6	76	83	0	15	84	1	98	3129976
3.862	5.492	0.800	1.8	78	84	0	15	84	1	98	3487326
4.370	5.492	0.800	2.3	80	85	4	14	81	5	85	4693602
4.878	5.492	0.800	3.0	83	86	6	13	74	12	75	6464163
5.386	5.492	0.800	3.3	83	86	10	13	73	14	66	7875849
5.894	5.492	0.800	1.8	74	83	2	15	82	3	83	3815837

Appendix D5:

Dynamic simulation result for balcony wall color reflectance RL

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	4.0	84	87	13	12	62	26	52	10422968
3.862	2.566	0.800	8.7	86	88	48	11	26	63	0	22730388
4.370	2.566	0.800	9.2	86	88	52	11	22	67	0	23989132
4.878	2.566	0.800	7.5	85	88	38	11	32	57	2	19240794
5.386	2.566	0.800	2.2	76	83	7	15	75	10	80	5834193
5.894	2.566	0.800	0.9	59	75	0	20	80	0	80	1705425
3.354	3.297	0.800	2.7	81	85	0	14	75	11	99	4914040
3.862	3.297	0.800	3.5	83	86	5	13	64	23	88	6383907
4.370	3.297	0.800	3.9	83	86	4	13	63	24	100	6332062
4.878	3.297	0.800	3.4	82	86	5	13	66	21	91	6197177
5.386	3.297	0.800	2.8	80	85	1	14	71	15	99	5171388
5.894	3.297	0.800	2.4	77	84	1	15	72	13	99	4735216
3.354	4.029	0.800	1.8	75	83	0	15	85	0	98	3391809
3.862	4.029	0.800	2.3	79	85	0	15	85	0	99	4125506
4.370	4.029	0.800	2.6	81	85	0	14	83	3	99	4555616
4.878	4.029	0.800	3.1	82	86	4	14	66	20	85	6359121
5.386	4.029	0.800	5.0	85	87	16	12	45	43	52	11376788
5.894	4.029	0.800	9.3	86	88	45	11	30	60	0	21689630
3.354	4.761	0.800	1.8	76	83	1	15	84	1	95	3597594
3.862	4.761	0.800	2.0	79	84	1	15	84	2	95	3997535
4.370	4.761	0.800	2.4	80	85	2	14	83	3	93	4686526
4.878	4.761	0.800	3.1	83	86	7	13	72	15	75	6832806
5.386	4.761	0.800	5.1	85	87	16	12	49	39	47	12568991
5.894	4.761	0.800	7.8	86	88	34	11	37	52	5	19428696
3.354	5.492	0.800	1.5	74	82	0	15	84	1	98	3089440
3.862	5.492	0.800	1.8	77	84	0	15	84	1	98	3533244
4.370	5.492	0.800	2.3	80	85	4	14	79	7	85	4937317
4.878	5.492	0.800	3.0	83	86	6	14	73	14	75	6598398
5.386	5.492	0.800	3.2	82	86	10	13	73	14	66	7846205
5.894	5.492	0.800	1.7	72	82	2	15	82	3	83	3774151

Appendix D6:

Dynamic simulation result for balcony types Recessed balcony type R

x	y	z	DF [%]	DA [%]	DA_{con} [%]	DA_{max} [%]	$UDI_{<100}$ [%]	$UDI_{100-2000}$ [%]	$UDI_{>2000}$ [%]	DSP [%]	annual light exposure [luxh]
3.354	2.566	0.800	3.0	80	85	7	14	73	13	66	7977589
3.862	2.566	0.800	5.2	85	87	18	12	55	33	43	13868614
4.370	2.566	0.800	5.4	85	87	17	12	53	35	42	14067357
4.878	2.566	0.800	5.1	84	87	15	12	57	31	45	13607101
5.386	2.566	0.800	1.4	68	79	5	16	77	6	77	4184138
5.894	2.566	0.800	0.5	27	56	0	33	67	0	40	1028745
3.354	3.297	0.800	2.1	75	83	0	15	84	1	99	3541417
3.862	3.297	0.800	2.6	79	85	0	14	79	7	99	4268631
4.370	3.297	0.800	2.7	80	85	0	14	77	9	99	4416142
4.878	3.297	0.800	2.7	80	85	0	14	76	9	99	4512774
5.386	3.297	0.800	2.1	75	83	0	15	80	6	99	3723581
5.894	3.297	0.800	1.8	72	82	0	15	81	4	98	3494045
3.354	4.029	0.800	1.5	70	81	0	16	84	0	97	2651450
3.862	4.029	0.800	1.8	75	83	0	15	85	0	98	3264633
4.370	4.029	0.800	2.1	77	84	0	15	85	0	99	3594646
4.878	4.029	0.800	2.9	82	86	4	14	74	12	85	5810062
5.386	4.029	0.800	4.6	84	87	14	12	52	35	53	10439622
5.894	4.029	0.800	8.8	86	88	41	11	34	55	0	20863956
3.354	4.761	0.800	1.4	71	81	1	16	83	1	94	2919976
3.862	4.761	0.800	1.6	73	82	1	15	84	1	95	3243914
4.370	4.761	0.800	2.1	78	84	1	15	83	2	94	4118576
4.878	4.761	0.800	2.9	81	86	6	14	73	13	75	6345181
5.386	4.761	0.800	4.7	84	87	15	12	57	31	48	11744262
5.894	4.761	0.800	7.2	85	88	28	11	42	47	11	18381650
3.354	5.492	0.800	1.4	71	81	0	16	84	1	97	2763510
3.862	5.492	0.800	1.7	76	83	0	15	84	1	98	3355858
4.370	5.492	0.800	2.1	79	84	4	15	81	5	86	4376324
4.878	5.492	0.800	2.6	80	85	6	14	75	11	75	5846908
5.386	5.492	0.800	2.8	80	85	10	14	74	12	67	7249961
5.894	5.492	0.800	1.4	65	79	2	16	81	3	82	3286668

Appendix E: Single Way One-Way Analysis of Variance (ANOVA) Calculation

Appendix E1:

ANOVA calculation results of seven balcony railing heights and co-relation among them

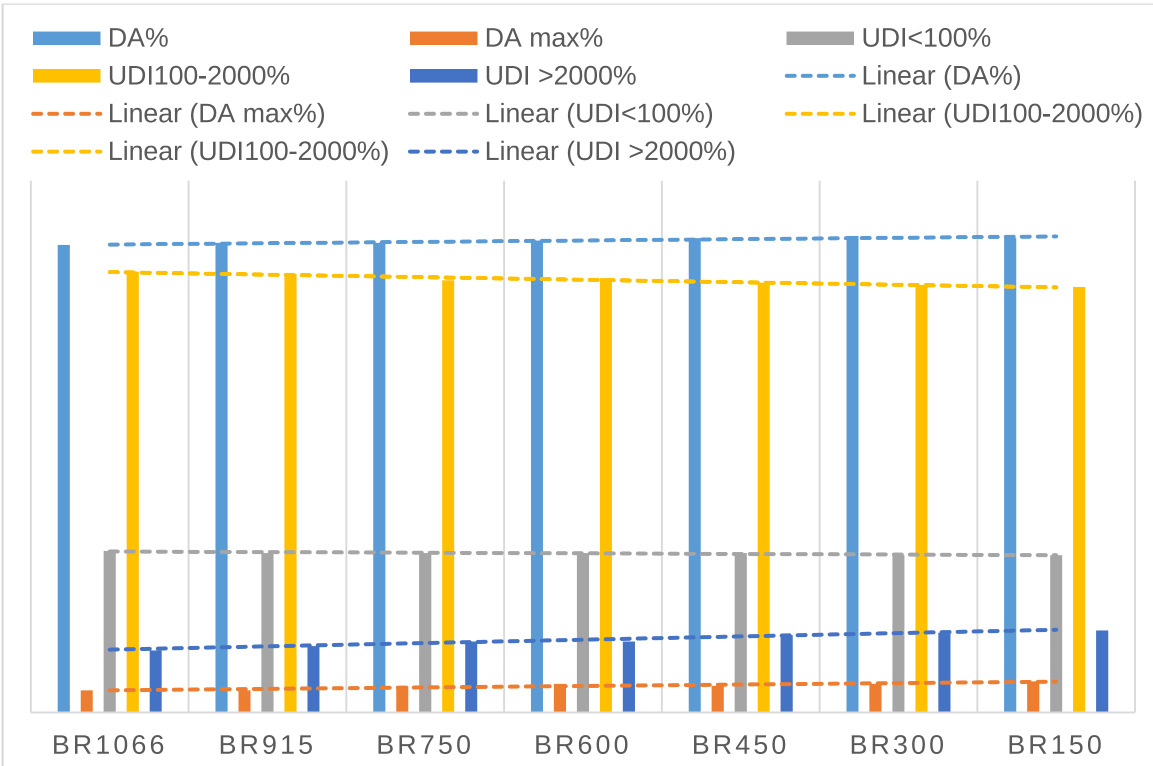

Figure E.1: Co-relation among the values of balcony railing heights

Table E.1: ANOVA for validation of the results of balcony railing heights

Groups	*Count*	*Sum*	*Average*	*Variance*
BR1066	5	173.65	34.73	1001.3
BR915	5	174	34.8	995.5345
BR750	5	174.34	34.868	961.5527
BR600	5	175.33	35.066	967.3712
BR450	5	175.67	35.134	956.5942
BR300	5	176	35.2	950.6889
BR150	5	176	35.2	930.7189

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.163177	6	0.193863	0.000201	1	2.445259
Within Groups	27055.04	28	966.2515			
Total	27056.2	34				

Appendix E2:
ANOVA calculation results of six balcony drop levels and co-relation among them.

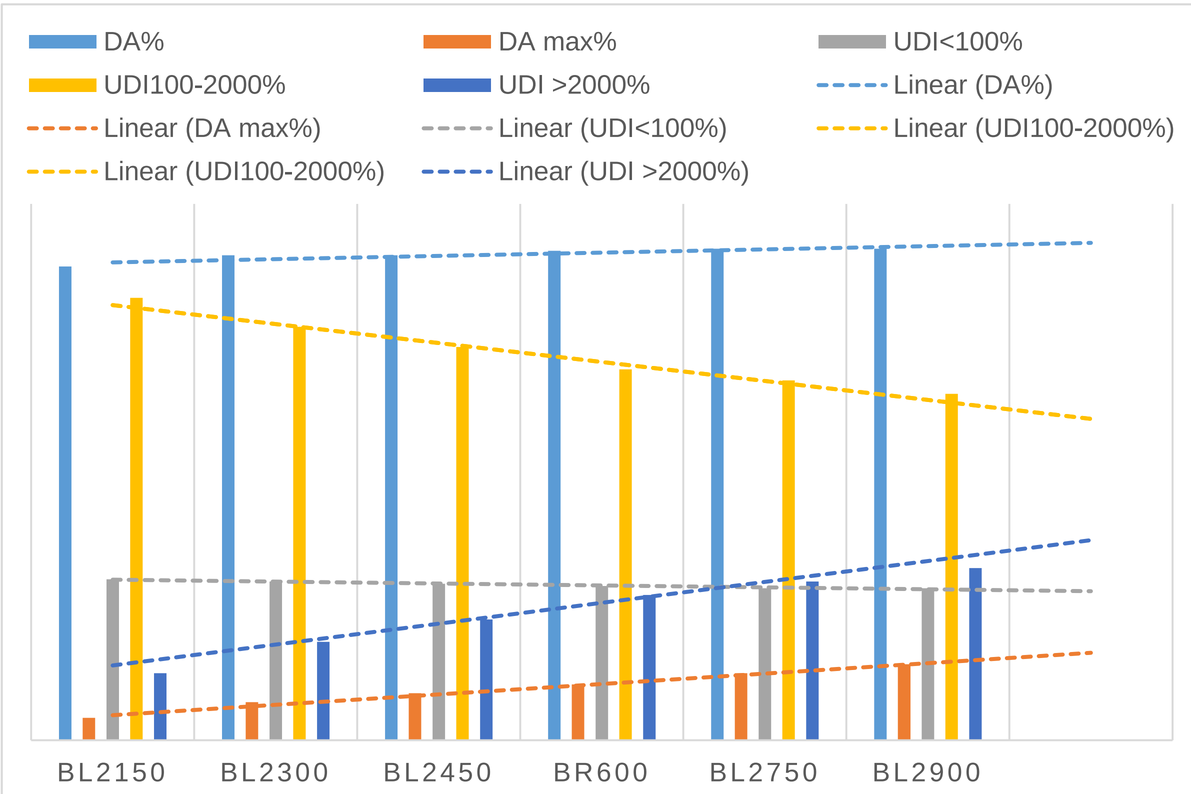

Figure E.2: Co-relation among the values of drop levels

Table E.2: ANOVA for validation of the results of balcony drop levels

Groups	*Count*	*Sum*	*Average*	*Variance*
BL2150	5	174	34.8	995.5345
BL2300	5	178.01	35.602	876.2331
BL2450	5	179.33	35.866	789.8092
BL2600	5	181.33	36.266	720.5682
BL2750	5	183.34	36.668	677.3111
BL2900	5	184.67	36.934	631.9307

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.01307	5	3.002613	0.00384	0.999997	2.620654
Within Groups	18765.55	24	781.8978			
Total	18780.56	29				

Appendix E3:
ANOVA calculation results of balcony adjacent wall configurations and co-relation among them.

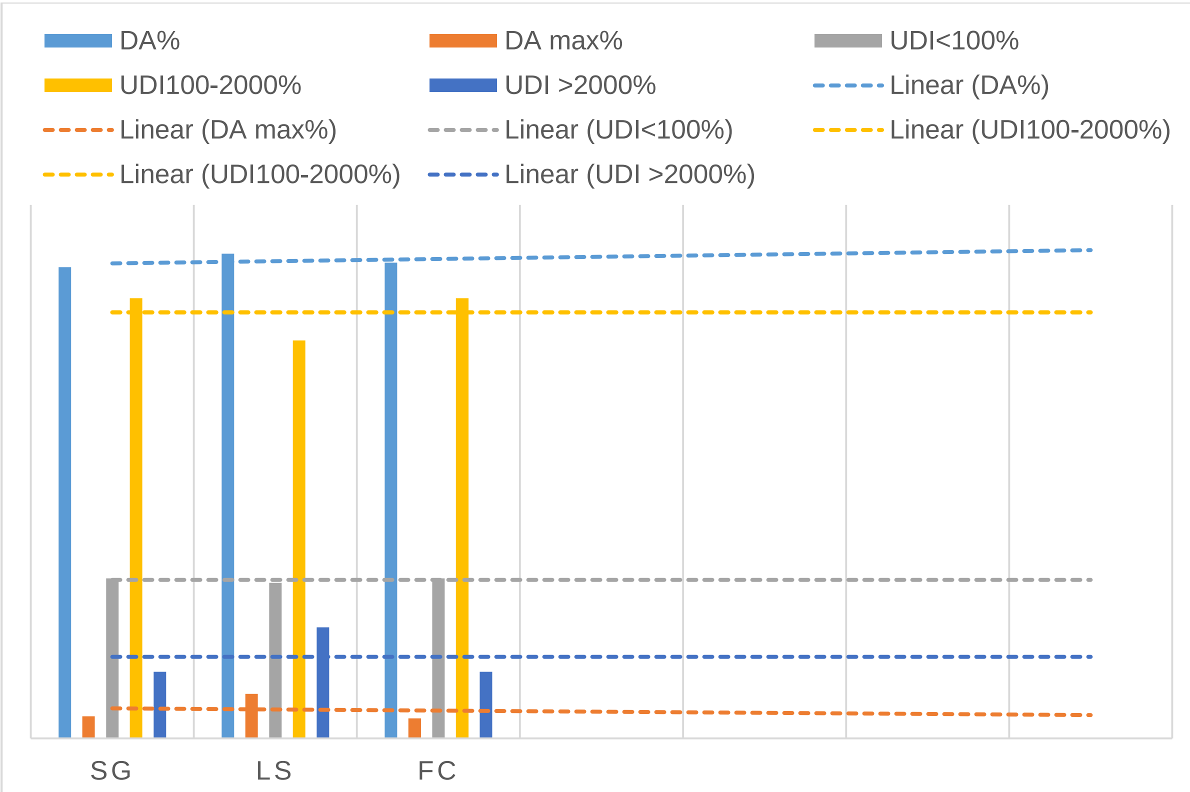

Figure E.3: Co-relation among the values of balcony wall to bedroom configuration

Table E.3: ANOVA for validation of the results of balcony to bedroom wall configurations

Groups	*Count*	*Sum*	*Average*	*Variance*
SG	5	174	34.8	995.5345
LS	5	179.01	35.802	824.7971
FC	5	174.33	34.866	1012.695

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.14076	2	1.57038	0.001663	0.998339	3.885294
Within Groups	11332.11	12	944.3421			
Total	11335.25	14				

Appendix E4:
ANOVA calculation results of balcony placements and co-relation among them.

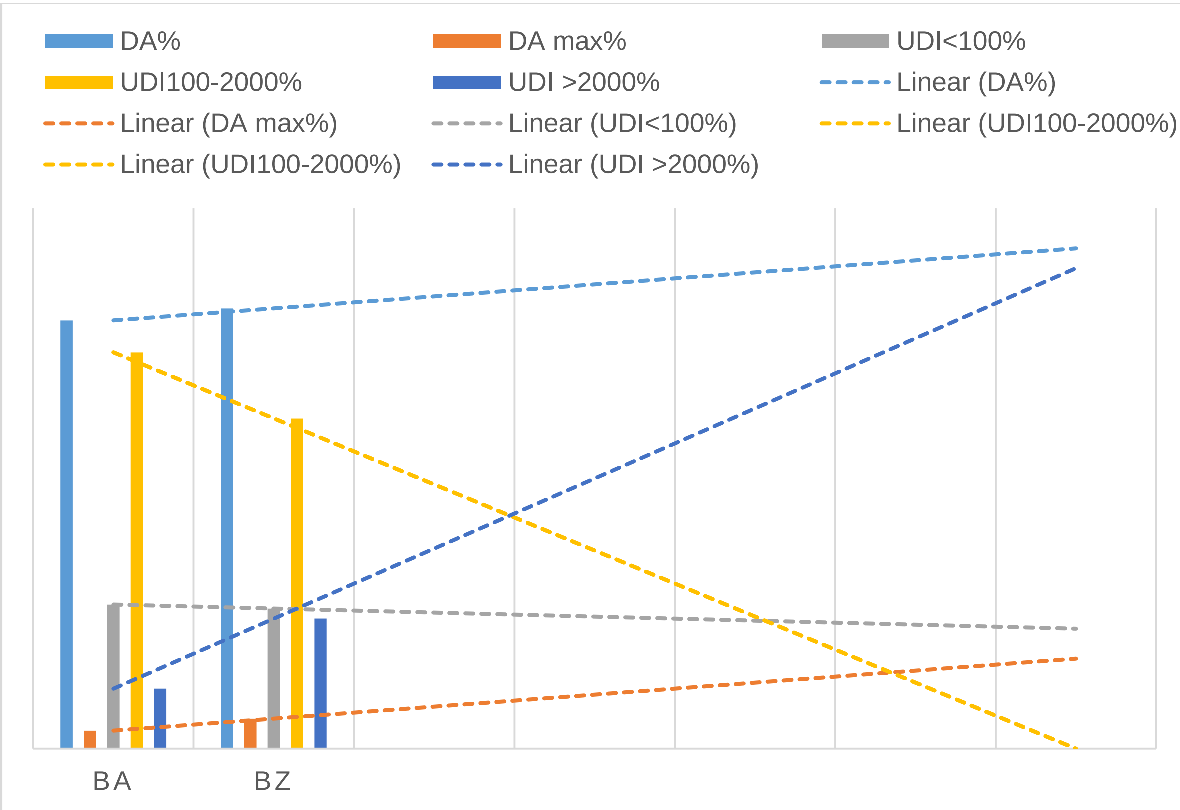

Figure E.4: Co-relation between the values of balcony placement

Table E.4: ANOVA for validation of the results of balcony placements

Groups	*Count*	*Sum*	*Average*	*Variance*
BA	5	174.33	34.866	1012.695
BZ	5	178.33	35.666	770.2122

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.6	1	1.6	0.001795	0.967246	5.317655
Within Groups	7131.628	8	891.4535			
Total	7133.228	9				

Appendix E5:
ANOVA calculation results of balcony floor depths and co-relation among them.

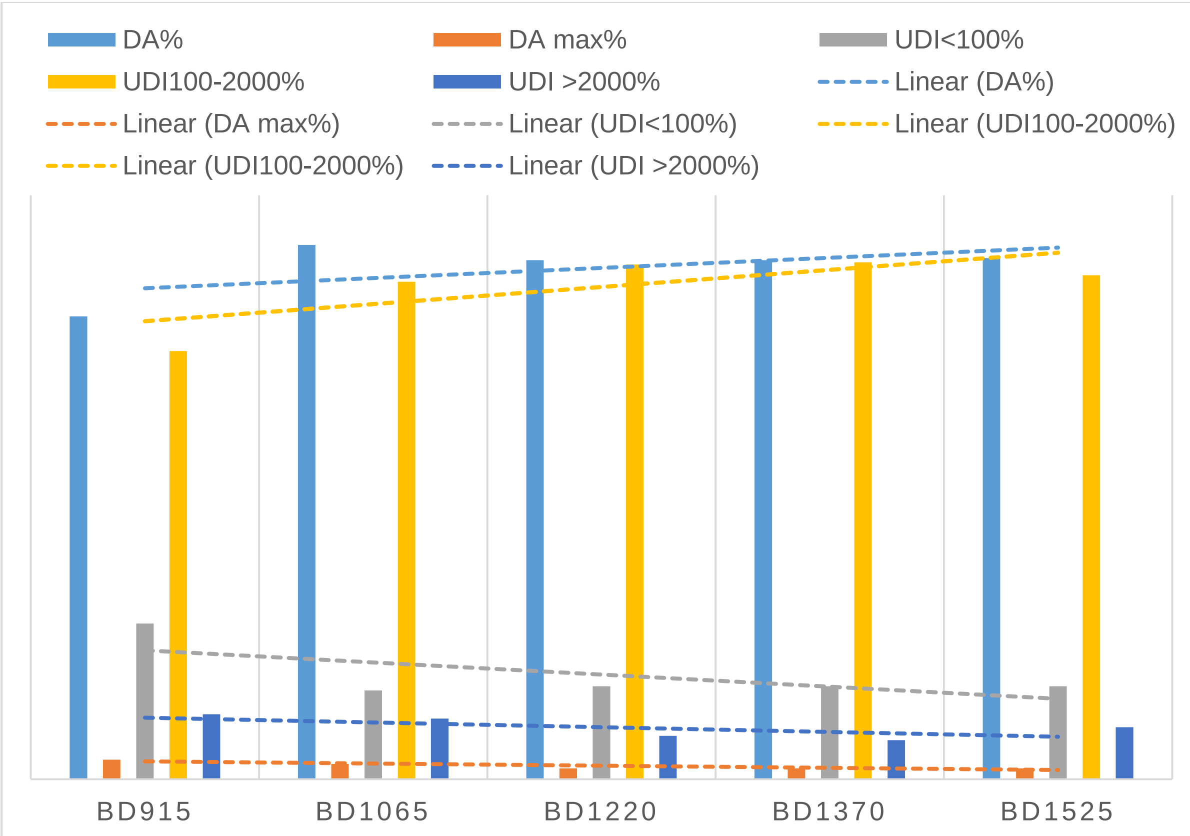

Figure E.5: Co-relation among the values of balcony floor depths

Table E.5: ANOVA for validation of the results of balcony floor depths

Groups	*Count*	*Sum*	*Average*	*Variance*
BD915	5	174.33	34.866	1012.695
BD1065	5	184.33	36.866	1535.089
BD1220	5	182	36.4	1580.269
BD1370	5	181.67	36.334	1597.662
BD1525	5	182	36.4	1533.219

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.58738	4	2.896846	0.001995	0.999991	2.866081

Within Groups	29035.73	20	1451.787
Total	29047.32	24	

Appendix E6:

ANOVA calculation results of balcony floor materials and co-relation among them.

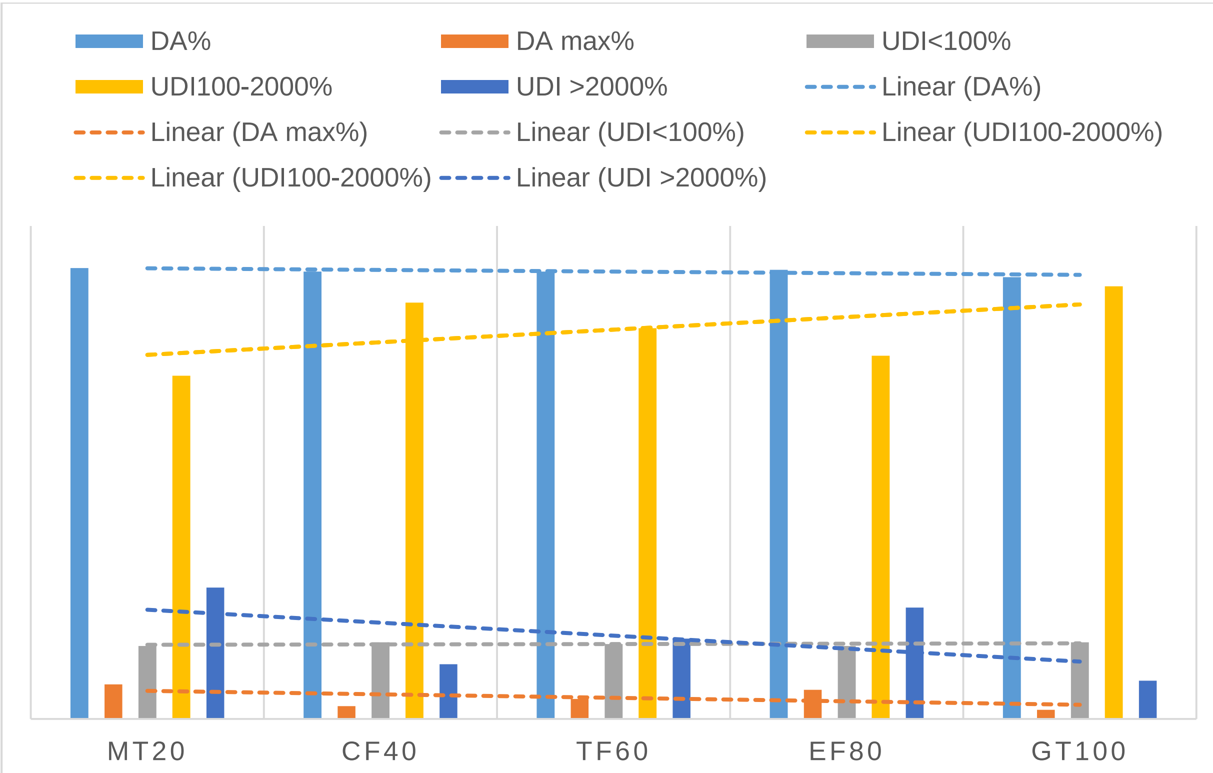

Figure E.6: Co-relation among the values of balcony floor materials

Table E.6: ANOVA for validation of the results of balcony floor materials

Groups	*Count*	*Sum*	*Average*	*Variance*
MT20	5	188.66	37.732	1095.24912
CF40	5	184	36.8	1494.05445
TF60	5	185.01	37.002	1331.94112
EF80	5	187.32	37.464	1181.32978
GT100	5	182.34	36.468	1586.71567

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.153584	4	1.288396	0.000963029	0.999997963	2.866081402

Within Groups	26757.16056	20	1337.858028
Total	26762.31414	24	

Appendix E7:

ANOVA calculation results of balcony wall colors and co-relation among them.

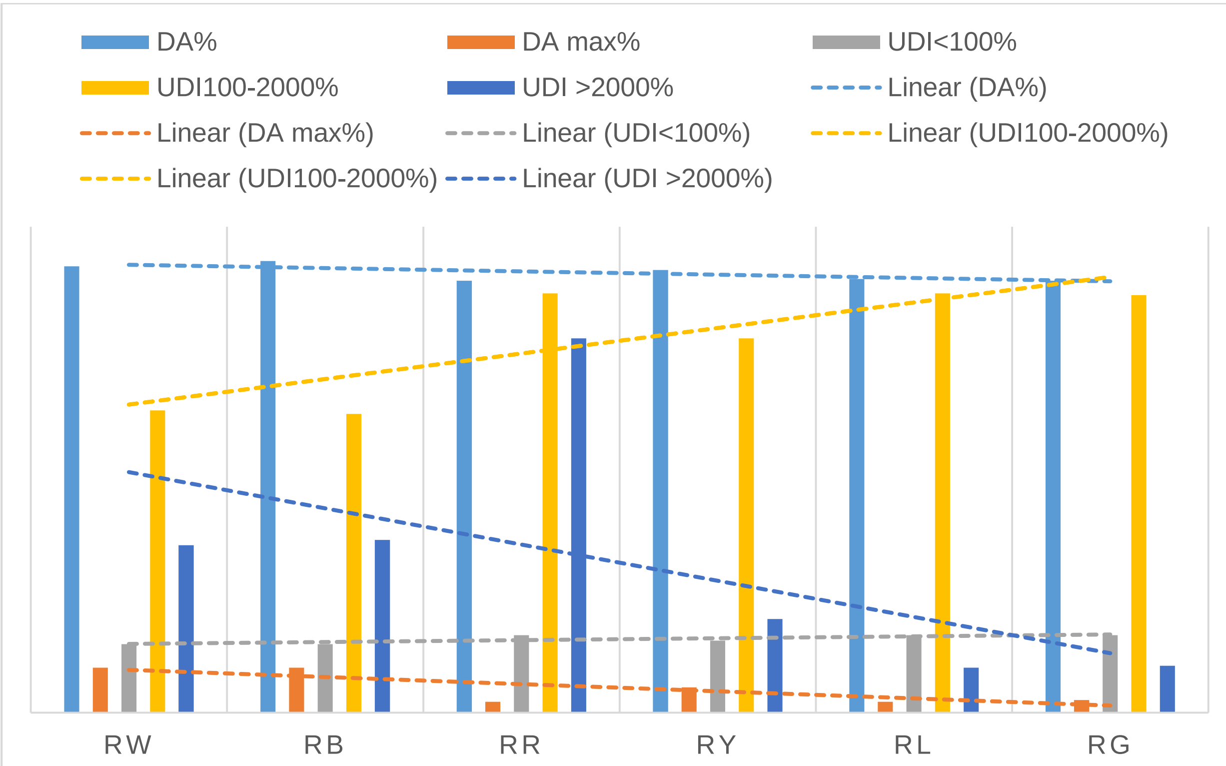

Figure E.7: Co-relation among the values of wall colors

Table E.7: ANOVA for validation of the results of wall colors

Groups	*Count*	*Sum*	*Average*	*Variance*
RW	5	191.67	38.334	995.0272
RB	5	192	38.4	985.7989
RR	5	243.33	48.666	1401.682
RY	5	186.66	37.332	1265.521
RL	5	182.66	36.532	1522.835
RG	5	182.66	36.532	1498.235

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	543.3089	5	108.6618	0.085013	0.993935	2.620654
Within Groups	30676.4	24	1278.183			
Total	31219.71	29				

Appendix E8:

ANOVA calculation results of balcony types and co-relation among them.

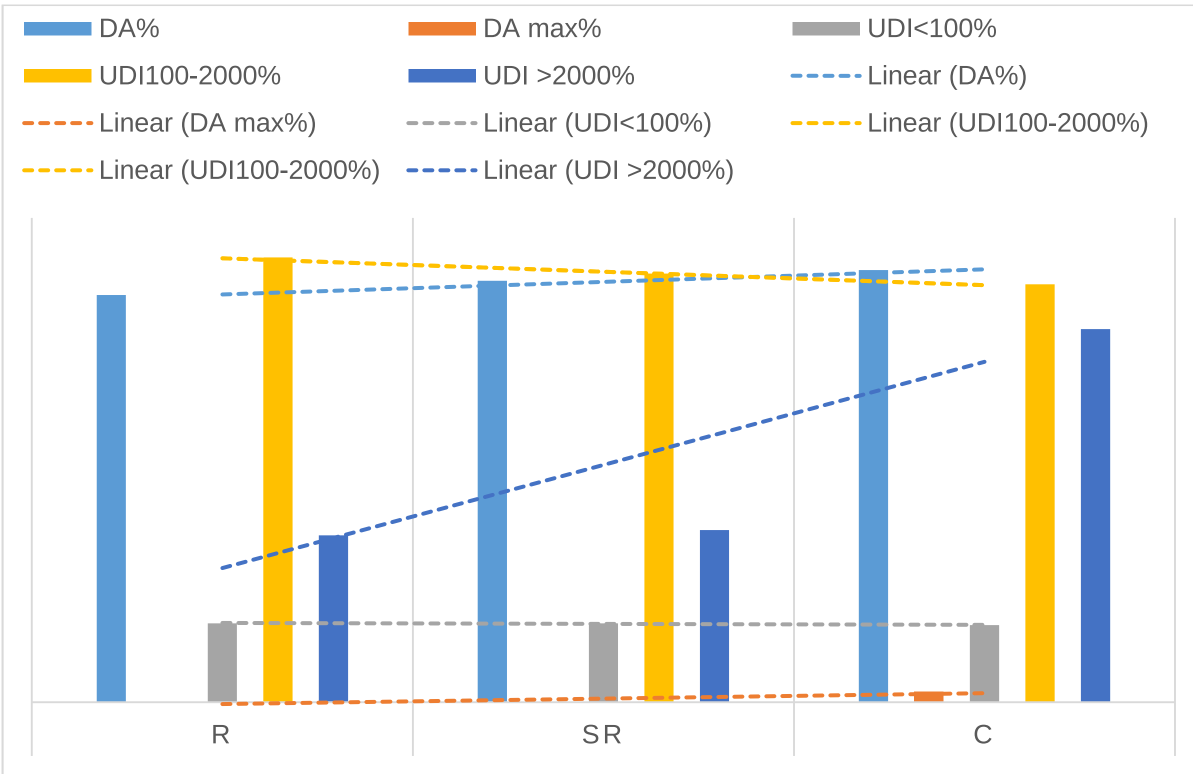

Figure E.8: Co-relation among the values of balcony types

Table E.8: ANOVA for validation of the results of balcony types

Groups	Count	Sum	Average	Variance
R	5	175.68	35.136	1652.481
SR	5	179	35.8	1582.494
C	5	182.66	36.532	1522.835

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	4.875893	2	2.437947	0.001537	0.998464	3.885294
Within Groups	19031.24	12	1585.937			
Total	19036.12	14				