Daylight and View Quality in Offices

Developing Multifactor Evolutionary Simulation Methods to Achieve Occupant Well-Being: A Case Study of Commercial Buildings in Cairo (Egypt) and Salford (England)

Mohamed Salah Mansour Abdelrahman

Ph.D. Thesis 2024

Daylight and View Quality in Offices

Developing Multifactor Evolutionary Simulation Methods to Achieve Occupant Well-Being: A Case Study of Commercial Buildings in Cairo (Egypt) and Salford (England)

The University of Salford

The School of Science, Engineering and Environment.

Mohamed Salah Mansour Abdelrahman

Submitted in partial fulfilment of the requirements of Doctor of Philosophy, Dec 2024

Table of Contents

Declaration

While registered as a candidate for the current PhD degree, I have not been registered for any other research award. The results and conclusions in this thesis are the work of the named candidate and have not been submitted for any other academic award.

The various parts of associated research work have been published in international journals, conference proceedings, and discussed amongst the wider research community through doctoral workshops and industrial talks where appropriate. The PhD candidate has taken the lead in the dissemination and integration of knowledge to attain the impact of this research.

Mohamed Abdelrahman

List of Tables

List of Figures

Acknowledgements

I would like to express my sincere gratitude to my supervisors, Dr. Paul Coates and Dr. Tanja Poppelreuter both from University of Salford, for their advice, support, enthusiasm and encouragement throughout my PhD study. It has been a very rewarding and illuminating experience for me and I am so grateful that my supervisors were always there to provide help and guidance. I feel lucky to have them as my supervisors.

The majority of the Virtual Reality experiment performed for this research occurred at Maxwell VR lab at University of Salford. I thank the staff at The School of Science, Engineering and Environment, University of Salford, for providing me with the access to VR lap and also for their guidance and provide me with the latest VR software.

I would like to thank my wife for her enthusiastic support during my PhD study. I credit my parents and brothers for keeping me grounded and cheerful during the last five years. The successful completion of my doctoral education is a testament to their unconditional support and love.

Abbreviations

2D	two-dimensional
3D	three-dimensional
ASE	annual sunlight exposure
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	computer-aided design
cDA	continuous daylight autonomy
CIBSE	Chartered Institution of Building Services Engineers
CS	circadian stimulus
CW_{map}	comfort and well-being map
DA	daylight autonomy
DF	daylight factor
DI	daylight illuminance
DLS	direct lines of sight
DLS_{blind}	direct line of sight to blind (i.e. shading)
$DLS_{context}$	direct line of sight to context
$DLS_{greenery}$	direct line of sight to greenery
DLS_{sky}	direct line of sight to sky
$DVS_{multifactor\ system}$	daylight, visible outside view and shading multifactor system
EA	evolutionary algorithm
ES	evolutionary strategy
EML	equivalent melanopic lux
FOV	field of view
GA	genetic algorithm
HDR	high dynamic range
IESNA	Illuminating Engineering Society of North America
LEED	Leadership in Energy and Environmental Design
LRT	likelihood ratio test
MEO	multi-evolutionary optimization
MOEA	multi-objective evolutionary algorithm
MOP	multi-objective optimisation problem
MN_{map}	mental network map
NSGA II	non-dominated sorting genetic algorithm I
P-O	pareto-optimal
sDA	spatial daylight autonomy
SC_{map}	spatial cognitive map
SPEA	strength pareto evolutionary algorithm
UDI	useful daylight illuminance

VPL	visual programming language
VOV	visible outside view
$VOV_{context}$	visible outside view to context
$VOV_{greenery}$	visible outside view to greenery
VOV_{sky}	visible outside view to sky
VR	virtual reality
VT	visible transmittance
WP	well-being potential
WWR	window-to-wall ratio

Abstract

Keywords; Daylight, View quality, Optimisation, Shading systems.

Viewing the natural environment from inside homes and workplaces has been recognised by a range of scholars as having an impact on improving health and well-being. Research has shown that a combination of outdoor elements – such as blue sky, sea view and greenery – is highly preferred as these elements are therapeutic for human wellbeing. However, installing shading systems is an important strategy for passive building cooling but it could affect our sense of connection to the outside environment. Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analyzing the geometry outside using 2D and 3D software which needs the outdoor environment to be fully built in the simulation accurately takes more time and may cause a system crash to run. This research presents a new multifactor system called (DVS) to quantify the visible outside view (VOV) by analyzing the outside view image by converting the view content into red, blue, and green (RGB) pixels using image processing technique. VOV measures the occupant's ray tracking percentage to the visible outside view content taking into consideration the blind factor of shading and daylight quality. An indicator starting from 0 % to 100 % is given to quantify the outside view content including shading systems which then the overall VOV is related to the visible outside view quality as a factor of well-being potential (WP). The DVS multifactor system was validated by conducting a virtual reality experiment to investigate the system results. The simulation outcomes were visualised on a comfort and well-being map showing the quantitative measurements for the new visible outside view (VOV) daylight metrics and daylight quality simulation. The study found that the shading strategy should not be the same at all levels and shading devices in primary design stages considering the view to the natural elements positively affects occupants' wellbeing potential. These findings suggest that the proposed algorithm needs to be implemented with building energy and daylight simulation to produce more holistic systems. This will be the only way to get efficient and sustainable buildings highly connected with the human dimension.

CHAPTER 1: Introduction

1-1 Introduction

Views and daylight quality can positively impact eye health (Amundadottir et al., 2017), occupant well-being (Matusiak & Klöckner, 2016) and visual comfort (Ko et al., 2021; Rizi et al., 2024; Yildirim et al., 2024). Workers in offices with poor daylight quality and poor views take more sick leave hours. In the workplace, the ability to see natural landscapes significantly impacts stress reduction and attention (Matusiak, 2020). The WELL building standard set a new regulation to enhance occupants' access to the outside view by evaluating workplace view quality to the space itself and not to the biophilia within the interior space (WELL addenda, 2024). The benefits of having a good view can reduce anxiety and stress and increase creativity. Viewing the natural environment from inside homes and workplaces has been recognised by several scholars as improving health and well-being (Elzeyadi, 2012; Amundadottir et al., 2017; Boubekri et al., 2020; Jamrozik et al., 2019; Sherif et al., 2015; Fathy et al., 2020; Yao et al., 2024) and has shown that a combination of outdoor elements – such as blue sky, sea view and greenery – is highly preferred in a coherent scene as these elements are therapeutic for human well-being. well-being is 'a special case of attitude' (Steemers, 2021) consisting of two key elements: feeling good and functioning well (Fletcher, 2016).
Although installing shading systems is an important strategy for passive building cooling, it can affect our sense of connection to the outside environment. This study focuses on daylight, view and well-being and seeks to improve our knowledge of the relationships between subjective aspects (e.g., visual comfort and well-being) and the physical stimuli of indoor daylight levels and the views to the outside environment through windows. To design healthier spaces, the quantitative simulations of daylight and view quality should align with users' perceptual experiences to improve their feelings and satisfaction with their seat location inside a space. It is critical to readdress how spaces evaluated by simulation tools currently are not designed for greater comfort and well-being potential (WP). New methods are needed to incorporate daylight and view quality with the shading design in the simulation process to predict subjective targets such as visual comfort and well-being.

The level of daylight inside office buildings and around work spaces influences physiological and psychological health and well-being. Daylight quality in the indoor environment directly impacts the health and well-being of building occupants (Fissore et al., 2023). Although light is predominantly perceived as a visual phenomenon, it also affects human physiology, behaviour and mood. These effects are described as non-visual ones (CIE, 2016). The visual effects of daylight refer to the photometric measurements used to analyse how much light is present in a given space for given tasks. In contrast, daylight non-visual effects are assessed subjectively whereby building occupants evaluate how the light is perceived (colour, intensity, distribution, uniformity, etc.) (Xiao et al., 2021).

Some building rating systems such as LEED (Leadership in Energy and Environmental Design), European standard EN 17037 and CIBSE (Chartered Institution of Building Services Engineers) put forward metrics to measure the view quality without referring to the impact of installing a shading device (LEED v4, 2019; CEN, 2021; CIBSE, 2005). However, CEN standard provides a metric to measure the view clarity of different shading systems based on the visible transmittance (VT) factor, but it does not show the acceptable levels of the visible outside view (VOV) content that will be affected by installing this shading system. Also, CIBSE recommends that good view content is important for improving occupant well-being, but the literature review undertaken in this study failed to find a metric to measure the visible view content percentage through any kind of shading.

Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analysing the geometry outside using two-dimensional (2D) (Matusiak et al., 2020; Ko et al., 2021; Lin et al., 2022; Li & Samuelson., 2020) and three-dimensional (3D) software (Domjan et al., 2023; Yao et al., 2024; Rizi et al., 2024). The software needs the outdoor environment to be fully built in the simulation, which takes more time and may cause a system crash. In related studies such as (Pilechiha, 2020; Hellinga & Hordijk, 2014; Turan et al., 2021; Lee & Matusiak, 2022; Jaeha et al., 2022) little attention has been given to elements obstructing outside views, such as shading devices. This may be explained by the difficulty of measuring the visible outside view (VOV) ratio using shading devices. Applications of the software that can evaluate daylight, view quality while installing shading devices outside academia are limited; some software can be used to measure the view quality but it is not connected to the actual VOV content (green, art, context, sky). This means that the blind factor of shading devices is only used to measure the view access ratio, not the visible view content ratio. To my knowledge, there is no tool, application or software yet to integrate daylight quality, outside view quality and shading devices in an optimisation process.

To address the challenge mentioned above, this study introduces a novel multifactor system to optimise shading parameters using virtual simulation and multi-objective evolutionary algorithm (MOEA) techniques to enhance occupant comfort and WP. This multifactor system (DVS system) is considered to be the first to integrate daylight quality, visible outside view quality and shading parameters in one optimisation process and predict occupant comfort and WP inside a building (via CW_{map}, a comfort and well-being potential map).

1-2 Importance of Shading Devices in Egypt and England

1-2-1 Climate in Egypt: Shading Devices as Mandatory Elements

According to the Köppen-Geiger 'world climate classification map', Egypt is considered to be in the 'hot–arid desert' climate with small parts (along the north coast of Egypt) in the 'hot–arid steppe' (Peel et al., 2007). The Housing and Building Research Centre in Egypt developed a climatic classification according to geographic regions, dividing Egypt into eight regions.

In 2021, 95% of business owners in 50 countries, including Egypt, were concerned about employee well-being (Daily News Egypt, 2021). In another study, employees in six large companies in Egypt were surveyed about their satisfaction with various aspects of the physical working environment (El-Zeiny, 2018). The highest satisfaction score was derived from lighting, with a mean value of 3.95, indicating that the six companies have adequate lighting for tasks. However, the satisfaction score for outside view had a mean value of 3.19, indicating workspace outside view is not enjoyable for most employees. Perhaps that is why most administration buildings are located in the downtown area, where the dominant outside view is a view of the street or square (Fig. 1-1).

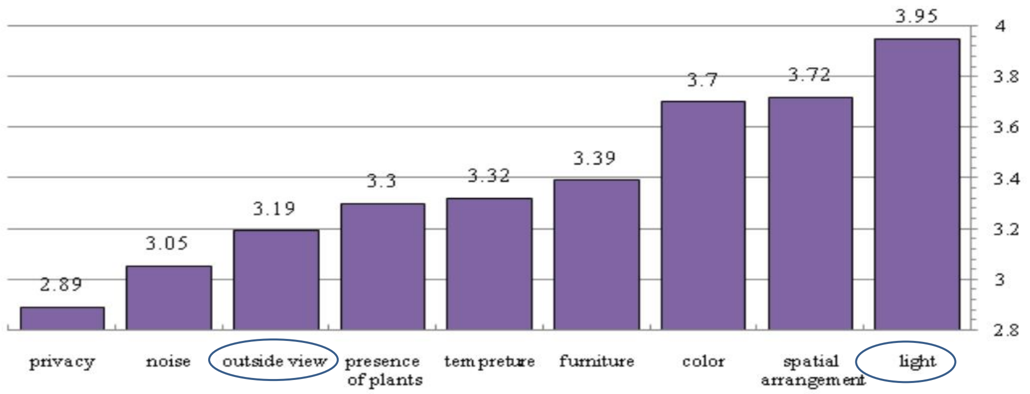


Figure 1-1: Employee satisfaction with daylight and outside view in Egypt. (Source: El-Zeiny, 2018).

The Egyptian government announced the New Capital Cairo Project in 2018. The plans proposed the new city to be 40 kilometres south of Cairo, with 7 million inhabitants on 700 square kilometres making the new capital more significant than Washington D.C. The plans conceived a greenery scene based on creation of the Green River. An essential component of the new capital, the Green River is the most extensive green garden in the Middle East and was designed to serve as a green lung and natural outlet for all neighbourhoods and compounds of the new administrative capital. It is one of the essential features of the new administrative capital (Fig. 1-2).

Figure 1-2: Greenery view to replace the streets and square view in the downtown area.

Figure 1-3: Visible outside view through shading device to the outside environment.

Biophilic design can improve occupant comfort and well-being because interacting with good direct sunlight and having a view of the outside environment reduce stress and improve worker performance (Schweizer et al., 2007, Aamer, 2021). View quality could be measured based on some metrics related to view access, view content, and view clarity. Ko et al., (2021) indicate that view quality has three main factors: (i) view access, which is defined as the angle of sight seen to the outside (Wilson, 1984); (ii) view clarity, which refers to how an occupant can see the outside view content clearly (Wilson, 1984); and (iii) view content, which is related to layers found in the outside view such as sky, greenery and context (Farley & Veitch 2001).

Therefore, it is important when design an office building at this city to consider daylight quality and the connection to the outside view (Fig. 1-3). To avoid direct harm from sunlight, such as glare, and to improve the quality of daylight inside the working environment, a shading system based on multi-objectives is needed. These objectives will contribute to increasing the contact with outside view and preventing daylight issues such as glare.

1-2-2 View Quality and Overheating Issues in England

In the United Kingdom, building regulations for shading devices are primarily concerned with energy efficiency, thermal comfort, and overall building performance (Dudzińska, 2021). A shading device, such as an external blind, louvre, or overhang, reduces solar heat gain during summer months and maximises natural daylighting in buildings (Overheating Approved Document O, 2022). Glazed facades are widely used in modern buildings, which can increase solar heat gain. Therefore, shading devices are considered part of the overall strategy to improve a building's energy performance.

For view quality over the natural landscape, over half of the land area in the United Kingdom is farmland (fields, orchards, etc.). The built-up area including roads and buildings is around 6% and green urban space is around 2.5%. According to the National Landscape Association Survey (2023), over 66% of England's population lives within 30 min of a national landscape. In addition, approximately 15% of England's land area is covered by 34 national landscapes. According to Mayor of Salford Paul Dennett, Salford is currently 60% green space (Salford City Council, n.d.).

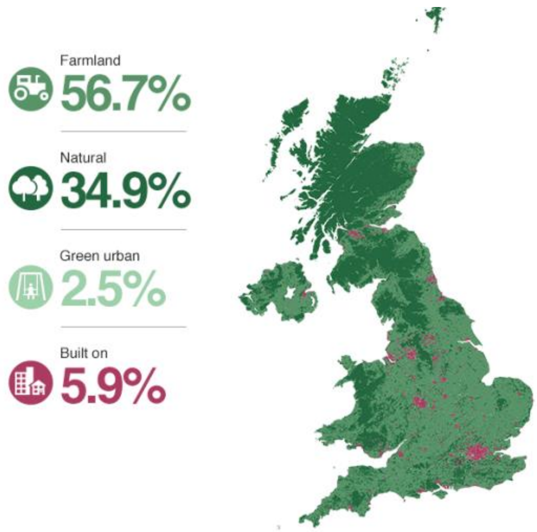


Figure 1-4: Land use in the UK (source: BBC)

This research selects Cairo and Salford as case study locations based on their distinct climatic and environmental conditions, which provide valuable insights for studying daylight's role in occupant well-being.

This research selects Cairo and Salford as case study locations based on their distinct climatic and environmental conditions, which provide valuable insights for studying daylight's role in occupant well-being. Cairo's high solar exposure and abundance of natural daylight make it a critical context for understanding how daylight can be managed effectively through shading systems. The city experiences intense, year-round sunlight, making it essential to study how shading devices can optimise daylight while preserving well-being potential. Cairo's conditions are ideal for testing the DVS system's ability to maintain a connection with natural elements (sky, greenery, etc.) under high-light conditions that are challenging for thermal comfort.

The selection of Salford, located in the UK with its relatively lower levels of sunlight and overcast conditions, provides a contrasting environment to test the DVS system under lower daylight conditions. Salford's weather variability makes it a unique setting to evaluate how well the DVS system adapts to moderate or low daylight while ensuring occupant well-being. By using Salford as a case, this study tests the flexibility and robustness of the DVS system in environments where managing limited daylight and maximizing outdoor views require a different shading strategy.

These two cities, with their contrasting climates and daylight availability, enable a comprehensive validation of the DVS system across diverse environmental contexts. This dual-site approach provides a balanced analysis of daylight's role in well-being, establishing the system's applicability across regions with varying solar and daylight characteristics. (Fig. 1-5).

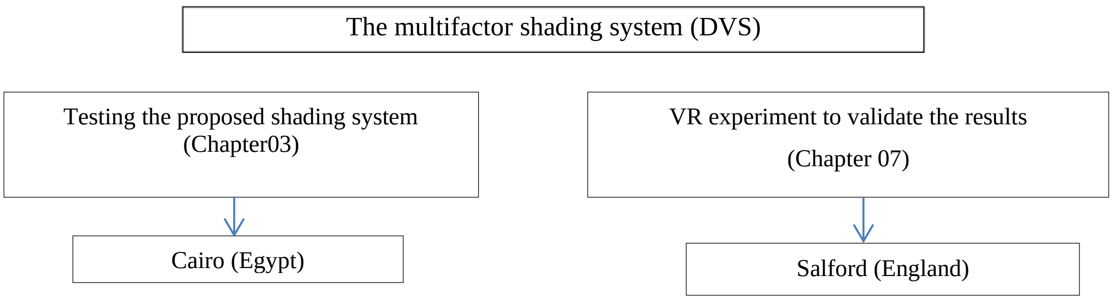


Figure 1-5: Greenery view to replace the streets and square view in the downtown area.

1-3 Transition from Office to Working Environment

1-3-1 Definition of an Office

The concept of the office has evolved through history, transforming into the concept of the working environment. The word 'office' comes from the Latin *officium*; this term has also been used as a synonym for a mobile bureau or an abstract idea of a formal position in judicial, administrative, and managerial tasks (Ng et al., 2022). Generally, an office is a place that undertakes and manages a range of processes and functions. According to Dale and Burrel (2007), three factors affect an office design:

(1) spatial environment (i.e. where humans perform work), (2) physical environment (i.e. physical objects and bodies) and (3) built environment (e.g. architecture, urban locale).

Since the Renaissance, the office became a common English expression for a place as a standalone building where government functions such as military services were conducted. The design of office buildings and the evolution of workspaces were the inevitable result of changes in the nature of office work (Danielsson & Bodin, 2008). The conventional office building is no longer the only suitable place for work, and work types and styles are moving towards more creative integration of spatial configuration in workspace design to make a working environment for effective human use. This transformation from office to working environment aims to achieve a healthy environment in which the surroundings contribute to occupant productivity, comfort and a sense of health and well-being (Ng et al., 2022). In recent years, there has been an increase in the use of casual or temporary workplaces as well as shared task-based settings (co-working spaces). A new term was added to the working environment to become a collaborative work environment that needs a specific change in office spatial design solutions. Due to the growing trend of remote work, flexibility in office settings and choice of places have become critical factors that contribute to occupant productivity, comfort and a sense of health and well-being (Ng et al., 2022).

1-3-2 Innovation of Curtain Walls

With the industrial revolution, office structures grew in many European countries. The indoor environmental quality for comfort and lighting was able to meet occupant needs due to developments in heating, ventilation and air conditioning systems and artificial lighting (Heiselberg, 2007). In addition, the industrial revolution in construction and material helped to create new architectural forms with fully glazed façades. This trend is called the ‘international style’ and office buildings in many countries, such as the United Kingdom, the United States and Egypt, have been affected by this trend (McMullin, & Price, 2016) (Figs. 1-6, 1-7, 1-8). The fully glazed façade (glass curtain wall) in Figures 1-3 to 1-5 allows entry of abundant natural light and makes it possible for more people to use a full office area with minimal need for artificial light. In addition, view quality needs to maximise the curtain-to-wall ratio to increase view clarity and access to the outside. Consequently, daylight levels and exposure will exceed the recommended levels internally.



Figure 1-6: Office buildings in the United Kingdom, Building: 30 St Mary Axe Tower, London. Figure 1-7: Office buildings in the United States, Building: 150 North Riverside, Chicago, Illinois. Figure 1-8: Office buildings in Egypt, Building: El ahly Bank of Egypt, Cairo.

1-3-3 Innovation of Deep-Plan Working Spaces

In the early twentieth century, office buildings in Europe were dominated by cellular offices, that is, multiple rows of closed offices around a central corridor, around an atrium or a central room (Hascher et al.,2002). These building structures were adopted because of the general building regulations on the depth of buildings to ensure daylight and natural ventilation. Marfella (2010) reviewed a sample of 16 tall office buildings in Melbourne CBD from the late 1960s to the 1990s. Marfella's research illustrates five parameters that could affect an office building design (Fig. 1-9): (1) floor plate efficiency, (2) leasing depth, (3) service core configuration, (4) modular coordination and (5) stacking strategy (Marfella, 2010).

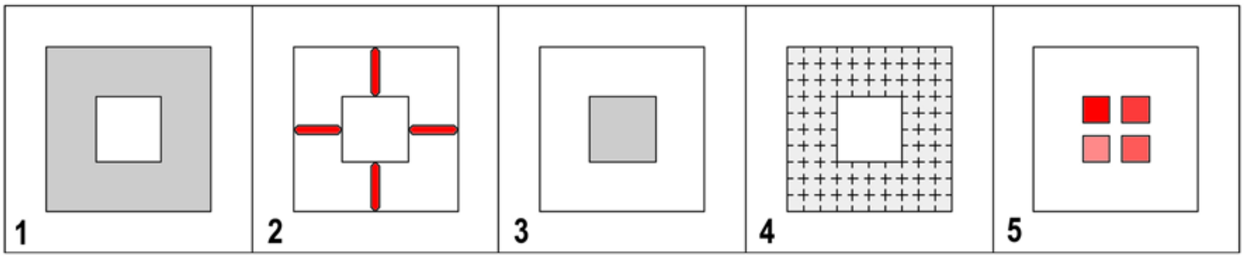


Figure 1-9: Five speculative parameters for office building design.

In architecture, a deep-plan building is considered a building with a leasing depth of more than 17 metres (Property Services Agency and Department of the Environment, 1976) (Fig. 1-10). In addition, regarding energy efficiency in buildings, a passive zone is considered as the area in a building that can be daylit and naturally ventilated (Baker et al, 1993). Deep-plan buildings are popular in commercial building designs for two main reasons: (1) their ability to maximise site coverage to maximise profit, and (2) the need to consider daylight quality in the zone that exceeds the 17-metre depth. Daylight devices installed in windows can only redirect daylight up to about 8–10 metres. Among contemporary open-plan office buildings, Osram GmbH Administration Building in Munich is very distinctive in its layout (Baker et al, 1993). The Osram building was the first spatial expression towards achieving organizational efficiency by enhancing information flow, interaction and transaction among colleagues (Laing, 2005) (Fig. 1-11).

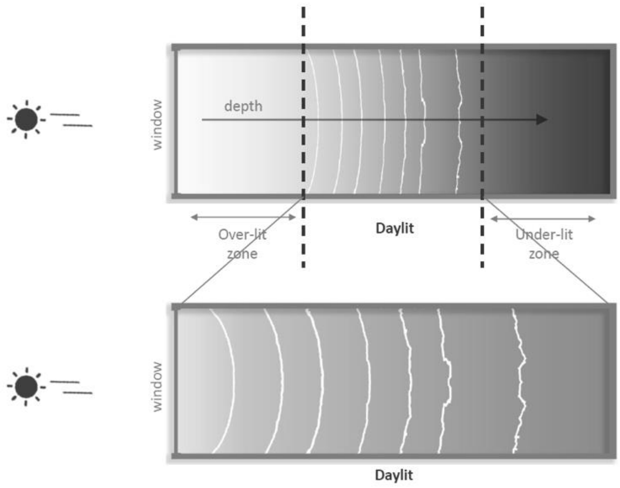


Figure 1-10: Deep-plan open office.(source: Author)

Figure 1-11: The *buerolandschaft*—a first open-plan office building, Quickborner team at Bertelsmann, Gütersloh (1950).(Source: Laing, 2005)

1-4 Defining the Area of Focus

1-4-1 Approach

It is now widely recognised that daylight quality throughout an internal space directly impacts building occupant health and well-being. Data from several field studies have linked daylight to productivity, mood, well-being, seasonal affective disorder and eye strain (Elzeyadi, 2012; Amundadottir et al., 2017; Boubekri et al., 2020; Jamrozik et al., 2019; Sherif et al., 2015; Yao et al., 2024). Another important psychological aspect of daylight is meeting the need for contact with the outside environment through a window. The façade is a central element to compromise between comfort requirements of an indoor space and the dynamic external environment parameters. Some working spaces stimulate occupant well-being and feelings of happiness, visual interest and excitement. In addition, installing a shading system to the façade could lead to better daylight quality. The advantages of shading are limited not only to protecting a building façade from being directly exposed to sunlight

(Ticleanu, 2021; Couvelas et al., 2018) but also to controlling the amount of daylight in a space. Shading systems are one of the most preferred methods to enhance the performance of building façades (Kirimtat et al., 2016). In contrast, other façades stimulate disturbance, gloom and discomfort depending on the daylighting conditions, which could be optimised using shading systems. Klein (2013) presents a classification of façade systems based on recent and future functions, but there is no reference to a façade system to improving occupant comfort and well-being (Fig. 1-13). This research adopts the approach of Klein (2013) which reveals that façade functions can be defined as a separator and filtration between nature and interior spaces that aim to improve visual contact with the outside view and visual comfort to daylight quality (Fig. 1-12).

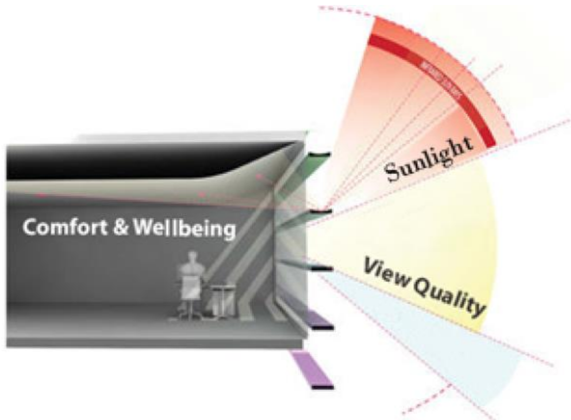


Figure 1-12: Shading device functions to improve occupant comfort and well-being potential (Source: Author).

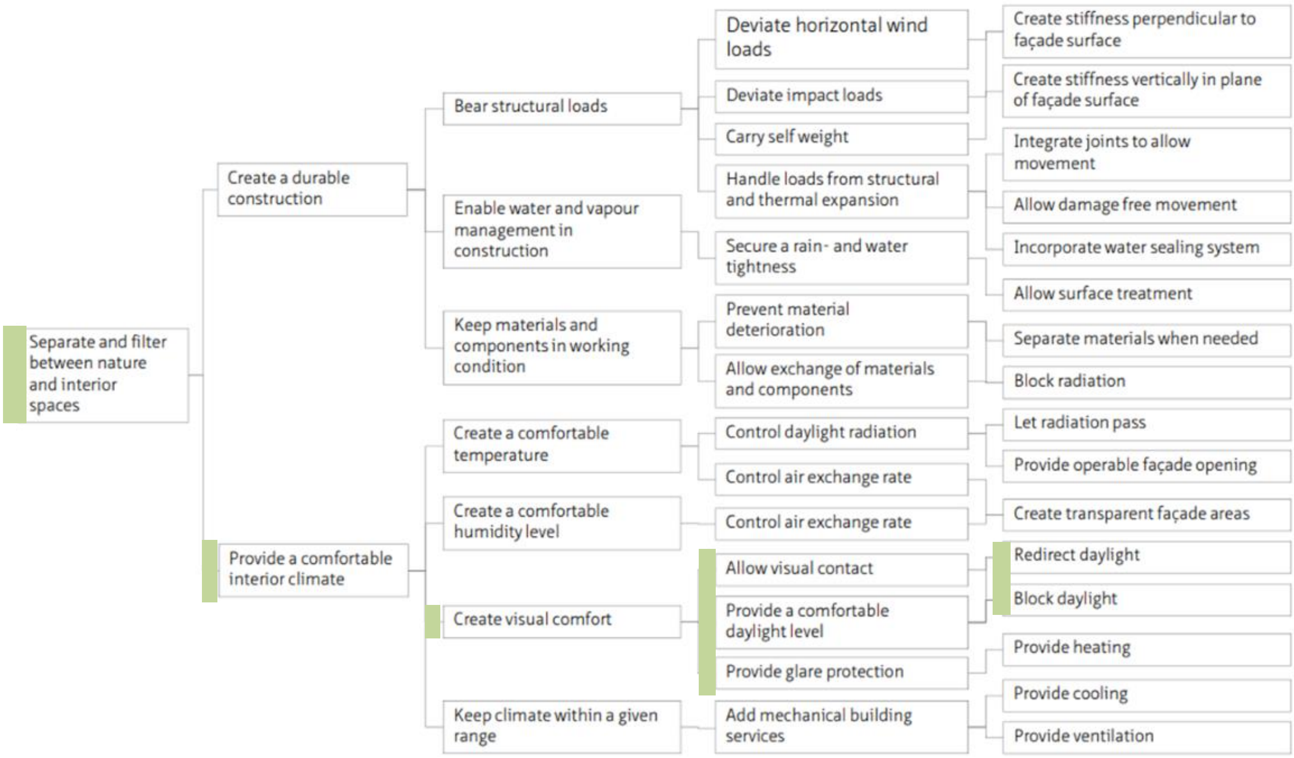


Figure 1-13: Façade functions (Source: Klein, 2013).

1-5 Aims and Objectives

1-5-1 Aim

This research aims to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms as a means to enhance occupant comfort and WP related to daylight quality and view quality recommendation values and standards.

1-5-2 Objectives

1. To determine the current understanding of daylight standards and rating system recommendations to improve occupant well-being.
2. To determine the significant terms used by occupants that affect their feelings and satisfaction with daylight and outside view in relation to their seat location inside the working environment.
3. To provide a method to quantify VOV content as an indicator for quantifying occupant well-being.
4. To define a new multifactor system to test different shading alternatives using simulation and genetic algorithms to optimise both daylight quality and view quality.
5. To validate the new multifactor system (DVS system).

1-6 Methodology

Choosing the appropriate research method is crucial to achieving the research goal. Research methodologies determine how data will be collected, whether quantitatively or qualitatively (Saunders et al., 2015). This study is subjective because I, as the sole researcher, have selected and interpreted the results regarding occupant experiences of daylight impact on comfort and well-being. I have made key decisions throughout the study, from choosing specific parameters to defining the criteria for assessing the effects of daylight. These choices are inherently influenced by my individual perspective, knowledge, and understanding of the subject matter. For example, I did not include gender or education level in the questionnaire also, I decide to work according to LEED standard as they are most widely used in middle east.

The study needs to be objective to be more scientific; therefore, there is a need for both qualitative and quantitative data (Collis et al., 2014). Qualitative techniques cannot be used for objective data collection, which is an advantage of quantitative techniques. Accordingly, this study uses a mixed method approach of qualitative research supported by quantitative methods of data collection, such as questionnaires.

This mixed method will help to explain the relationship between qualitative and quantitative results. The mixed method's characteristics will help develop the rationale for integrating objective quantitative and subjective qualitative data (Creswell, 2009). Combining these data types and analysis is mandatory to answer the research question: 'Is it possible to improve and predict occupants' comfort and well-being by using a multifactor shading system?'

In this study, a sequential mixed exploratory research method is used as follows: (1) qualitative, (2) quantitative, (3) qualitative, and (4) interpreting the connected results. The research starts with a thematic analysis of the literature review to define the research gaps followed by the administration of an online questionnaire to define the variables and determine their relationship with each other and also to determine the terms used by occupants that affect their feelings and satisfaction with daylight and outside view quality inside their working environment.

In the second step, based on the literature review and the questionnaire findings, a quantitative analysis driven by the simulation and optimisation process was undertaken using Rhino and Grasshopper as parametric platforms. In the third step, a quantitative experiment was conducted to examine occupant experiences with daylight and view quality and shading devices in a virtual environment using a VR technique. This VR experiment was conducted by using Unreal software to validate and test occupant feelings and satisfaction in a workspace built virtually to achieve the assessment criteria used in the multi-objective optimisation process. These assessment criteria focus on achieving daylight quality and view quality extracted from the literature review stage. Finally, the research interprets in what ways and to what extent the multifactor system (DVS system) affects occupant comfort and well-being in workspaces. The four stages, adapted from Creswell & Plano Clark (2011), are summarised below:

- *First stage*: Qualitative analysis for comfort and well-being in terms of daylight (online questionnaire)
- *Second stage*: Quantitative assessment of VOV quality as a new metric to measure WP
- *Third stage*: Quantitative assessment of daylight, VOV and shading (multifactor DVS system)
- *Fourth stage*: Qualitative assessment of the multifactor system (DVS system) to validate the simulation results by using a VR experiment (semi-structured interview)

To achieve the first research objective, a systematic literature review was conducted to define recommendations and guidelines for daylight comfort and well-being in the working environment.

The review starts with a chronological overview and presents daylight metrics as well as their underlying methodologies to define the gap in using these metrics to assess daylight non-visual effects and the need to use building rating system guidelines and recommendations to enhance this assessment. Then, a thematic analysis was conducted to extract the relative recommendations and metrics on how these building rating systems can contribute to comfort and well-being in terms of daylight. These recommendations and metrics are used later as standard parameters in the quantitative stage during the simulation process.

To achieve the second research objective, a qualitative study was initially conducted through an online questionnaire to determine variables that occupants use in the daylit zone to describe their feelings and satisfaction with daylight (visual and non-visual effects) and outside view quality in their working environment.

To achieve the third research objective, a quantitative approach was taken by defining a new facilitation tool using parametric analysis of the outside view to quantify VOV content based on the recommendation metrics and variables for comfort and well-being while using automated shading systems.

To achieve the fourth research objective, a quantitative approach was taken by defining a new multifactor system (DVS system) using multi-objective evolutionary algorithms (MOEAs) technique to integrate daylight quality, VOV content and shading systems in one optimisation process to improve occupant comfort and WP. A comfort and well-being map (CW_{map}) was produced to interpret the comfort and well-being percentage based on the daylight and view quality received.

Finally, *to achieve the fifth research objective*, a qualitative approach was implemented using semi-structured interviews with participants by conducting a VR experiment to validate the DVS system occupant experiences in assessing their best seat location, feelings and satisfaction while using a shading system produced from the simulation. The results of this experiment were compared with CW_{map} to investigate the relationship between participant response in the VR experiment and the simulation output and to validate the DVS system.

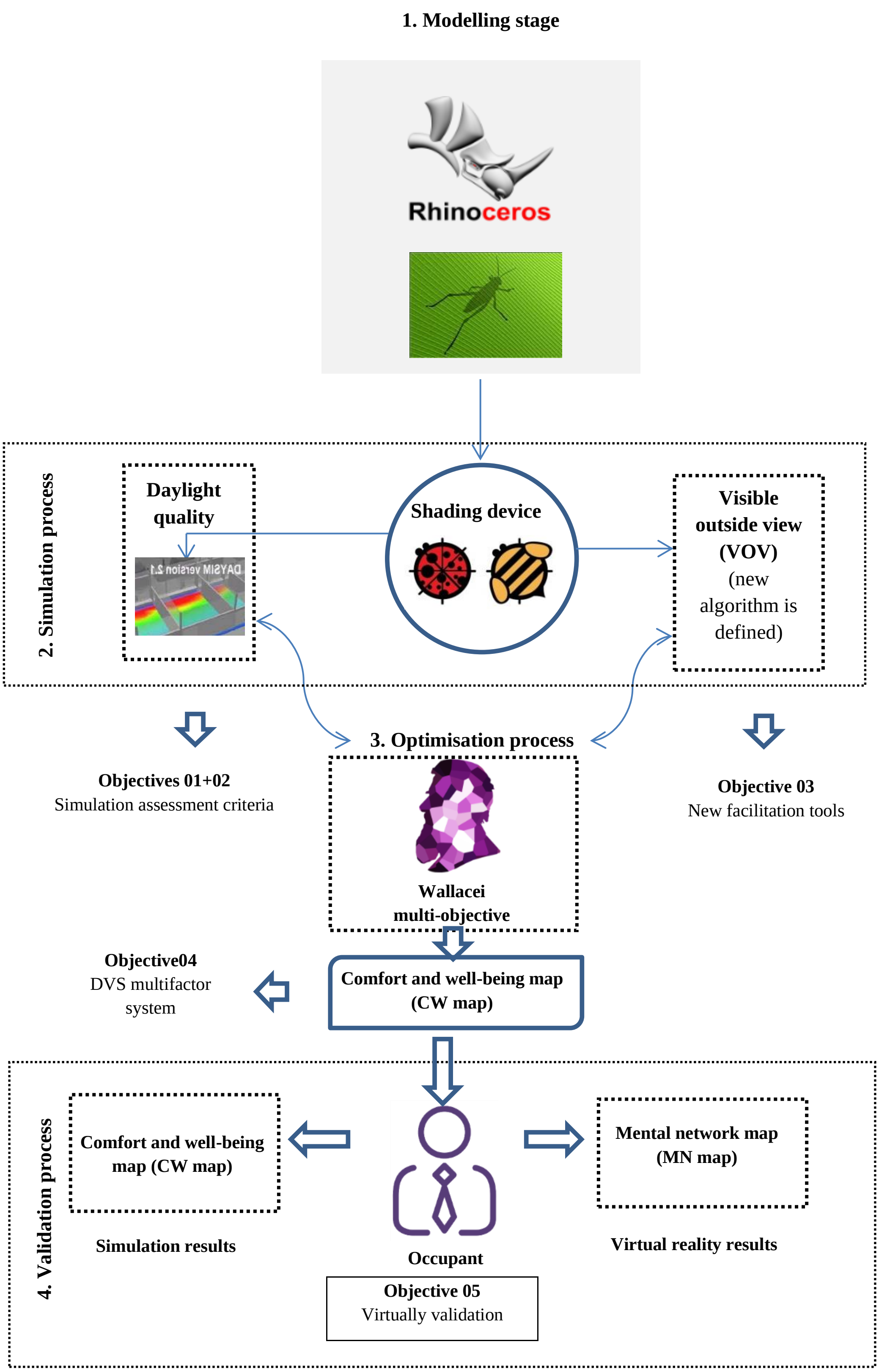


Figure 1-12: Research methods.

1-7 Work Scope and Limitations

This research represents a study of three significant areas: daylight quality, view quality and shading systems. This research contains a large number of factors that could affect the research results at each stage. To keep the research within a manageable state, this study concentrated on a specific factor from the three primary areas mentioned earlier.

- View quality was limited to the composition of the outside environment (greenery, sky, context). View access had fixed parameters as the window-to-wall ratio will be 90% and, for view clarity, the glazing had a visual transmittance 0.7 VT as recommended by LEED and WELL Building Standard in their view quality credit.
- Daylight quality was limited to glare, spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) as objective visual comfort. (Justification provided in Chapter 2.)
- The shading systems in this research aimed to explore different shading configurations, such as horizontal shading, vertical shading and panelling prototype.
- The proposed multifactor system was only used for Venetian blinds, mullions, overhangs or fins shading, but did not work for roller shades since the openness (holes) is very small and hard to model in Rhino. However, it provided views of the outdoors but it minimised the view clarity. This study applied LEED assessment criteria, which state that view glazing should provide a clear image of the outside environment. Therefore, the study was limited to using only clear glass and not working with the transparent blinds and small meshes that take more time and may cause a system crash to run the iteration.
- Regarding the material provided in this study during the simulation process, internal walls were finished in white plaster, the floor was covered with grey tiles, and the ceilings were white. It is assumed that the reflectance of the interior wall is 50%, the ceiling 80% and the floor 50%, and glazing has visual transmittance of 0.7 VT as recommended by LEED and WELL Building Standard in their view quality credit.
- Regarding the daylight performance simulation, it was assumed that the sky is clear, with the sun at a minimum of 500 lux on the work plane at a height of 0.75 m from the floor. A grid of sensors 0.6×0.6 m^2, as recommended by LEED, and artificial light were used during the simulation process.

The multi-objective optimisation process was performed and managed using a digital platform consisting of many digital applications, such as Revit®, Rhinoceros®, Grasshopper®, Honeybee®, Energyplus®, Ladybug® and Wallacei®.

1-8 Structure of Thesis

This thesis is structured into eight chapters, systematically exploring the interrelationship between daylight, outside views, and shading systems in enhancing occupant well-being. Chapter 1 introduces the research by outlining its purpose, significance, and scope. Chapter 2 provides a comprehensive literature review, examining previous studies on daylighting, the quality of outside views, and shading systems, to identify gaps in current knowledge. Chapter 3 explains the research methodology, detailing the approaches and tools used.

Chapter 4 presents the first stage of the research, where a qualitative analysis is conducted through an online questionnaire to evaluate comfort and well-being in relation to daylight. This is followed by Chapter 5, which introduces a quantitative assessment of outside view quality as a novel indicator for measuring well-being potential, forming the second stage. Chapter 6 extends this analysis by developing a multifactor system (DVS) to quantitatively assess daylight, visible outside views, and shading systems in the third stage.

In Chapter 7, the DVS system is validated through simulations and empirical testing, ensuring its accuracy and applicability. Finally, Chapter 8 summarises the research findings, offering conclusions and practical recommendations for improving occupant well-being through better daylighting and shading strategies in architectural design. This chapter also reflects on the limitations and potential directions for future research

Chapter 1: Introduction
Chapter 2: Literature review of daylight, outside view and shading systems
Chapter 3: Methodology.
Chapter 4: Qualitative analysis for comfort and well-being in terms of daylight (online questionnaire) (Stage 01)
Chapter 5: Quantitative assessment of visible outside view quality as a new indicator to measure well-being potential. (Stage 02)

Chapter 6: Quantitative assessment of daylight, visible outside view and shading (DVS multifactor system) (Stage 03)

Chapter 7: DVS system validation

Chapter 8: Conclusions and recommendation

CHAPTER 2: Literature Review

2.1 Introduction [1]

Daylighting quality throughout an internal space directly affects the health and well-being of building occupants. Various physiological and psychological benefits have been attributed to the presence of daylight in buildings. To enhance the performance of building façades, shading systems are one of the most preferred methods. The advantages of shading are limited to protecting a building façade from direct sunlight and controlling the amount of natural light in a space. Recommended practices in daylight design primarily focus on improving the energy efficiency of buildings and the comfort of building occupants rather than on optimising its role in enhancing occupants' health and well-being (Elkadi & Al-Maiyah, 2021). Although some of the biological influences associated with the amount of daylight received by building occupants and its impact on their stress, level of productivity, and sleep quality are well documented, there is a general ambiguity in the literature about measuring occupant well-being related to daylighting design. Many studies assess daylight exposure as an indicator to directly measure health and well-being of individuals. Other studies measure visual comfort from having enough contrast in daylighting illuminance to quantify well-being. The main aim of this chapter is to define themes of well-being related to daylight design founded in studies referring to the role of shading systems to improve daylight inside the working environment.

In the building design field, improving occupant comfort and well-being has long been recognised as a potential problem in spatial design and many researchers try to achieve this goal by improving daylight quality and view quality but it is important to not neglect the important role of the shading systems that can optimise and control both daylight and view quality. Therefore, there is a need to know in more depth what daylight quality and view quality mean and how they could affect occupant comfort and well-being potential in the working environment. In addition, it is important to look at methods used to optimise shading systems designs and the other conflicting targets related to daylight quality and view quality. To provide an overview of the current state of research in this topic, a literature review of specialist academic journal articles published during the last decade was conducted

---

[1] The work presented in this chapter was originally published as:

Abdelrahman, M., & Coates, P. (2022a). *Themes of wellbeing associated with daylighting practice and shading systems in working environment.* Conference: Resilience in Research and Practice. University of Salford, Uk.

Abdelrahman, M., & Coates, P. (2022b). *Wellbeing in Daylighting Studies*. PLEA 2022—36th Conference on Will cities survive?, Santiago, Chile.

and limitations of the methods used to assess daylighting, non-visual effects, and well-being as well as the practical implications of this knowledge were examined.

The literature review will be divided into three sections. The first section reviews definitions and theories related to comfort and well-being and illustrates the relationship between comfort and satisfaction with daylight quality on the one hand, and well-being and satisfaction with view quality on the other hand. The second section reviews daylight and view recommendations in building rating systems, such as LEED, BREEAM (Building Research Establishment Environmental Assessment Method), WELL Building Standard and CIBSE, European standard, and IESNA (Illuminating Engineering Society of North America) standard, to understand the different assessment criteria for evaluating daylight and view quality. This better understanding of how to measure daylight and view quality will help in defining the assessment criteria of the new multifactor system to integrate daylight and view quality and shading design in one system. The third section extensively reviews the related studies focusing on daylight view quality, comfort, well-being and shading systems. The methodological process for conducting the review consisted of three steps: (1) identifying themes associated with the concept of comfort and well-being, (2) determining methods used for measuring daylight and view quality and (3) optimising systems used. An analytical summary of the literature is provided, followed by the findings from the analysis. Finally, the gaps in current knowledge and understanding have been identified and organized into three categories reflecting the identified research gaps (Fig. 2-1).

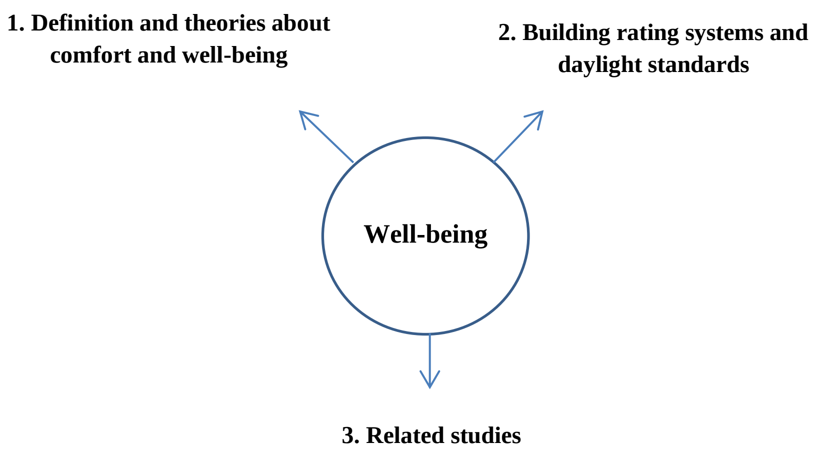


Figure 2-1: Literature review data sources.

To understand the effect of daylight on occupant comfort and well-being in literature and to define the research gap, three approaches were taken:

1. *Review of theories*: a theoretical review about theories, definitions and concepts of comfort and well-being.
2. *Review of daylight and view quality in building rating systems and standards*: a review of building rating systems and metrics used to assess well-being and comfort to justify the selected assessment criteria for evaluating daylight and view quality.
3. *Review of journals, books, and recent publications*: a review of the most recently international publications discussing daylight and view quality, comfort, well-being and shading systems.

2-2 Review of Theories: A Theoretical Review about Theories, Definitions and Concepts of Comfort and Well-Being

Philosophers have a massive debate about the meaning of well-being. Well-being's substantive theories tell us what makes something good or bad for a person and, more broadly, what makes a life well or not for the person. There are three main theories: hedonism, desire fulfilment theories and objective list theories. Hedonists define well-being as a feeling of pleasure and pain. Desire fulfilment theorists define well-being as a desire to be happy or sad. Objective list theorists claim well-being has various goals depending on what is appropriate to a person. Further, according to perfectionists, well-being depends on the development and exercise of an individual's natural capabilities.

The concept of well-being refers to what is intrinsically valuable to an individual. It consists of two dimensions on a personal and a social level that explain how individuals feel and function (Crisp, 2020). The well-being of a person is ultimately good for that person and is in that person's self-interest (Andrews & McKennell, 1982). In another definition, well-being is 'a special case of attitude' (Steemers, 2021) consisting of two key elements: feeling good and functioning well (Fletcher, 2016). Theories of well-being aim to clarify the features responsible for a person's well-being. Hedonistic theories equate well-being with the balance of pleasure and pain. Desire fulfilment theories state that well-being consists of desire satisfaction: the higher the number of satisfied desires, the higher the well-being. Objective list theories state that a person's well-being depends on a list of factors that may include both subjective and objective elements (Rea et al., 2005).

2-2-1 Daylight and Well-Being

To explain the relationship between daylight and well-being, a philosophical shift occurred to define the new knowledge related to architectural practice (Veitch, 2004). One of the prior clarifications concluded by Veitch, who illustrated a model based on the objective list theory of well-being, states that a person's well-being depends on a list of factors such as mood and comfort. Furthermore, according to architecture practice, Veitch identifies four factors to integrate with lighting quality: (i) form, (ii) composition, (iii) style and codes, and (iv) standards regulation (Fig. 2-2).

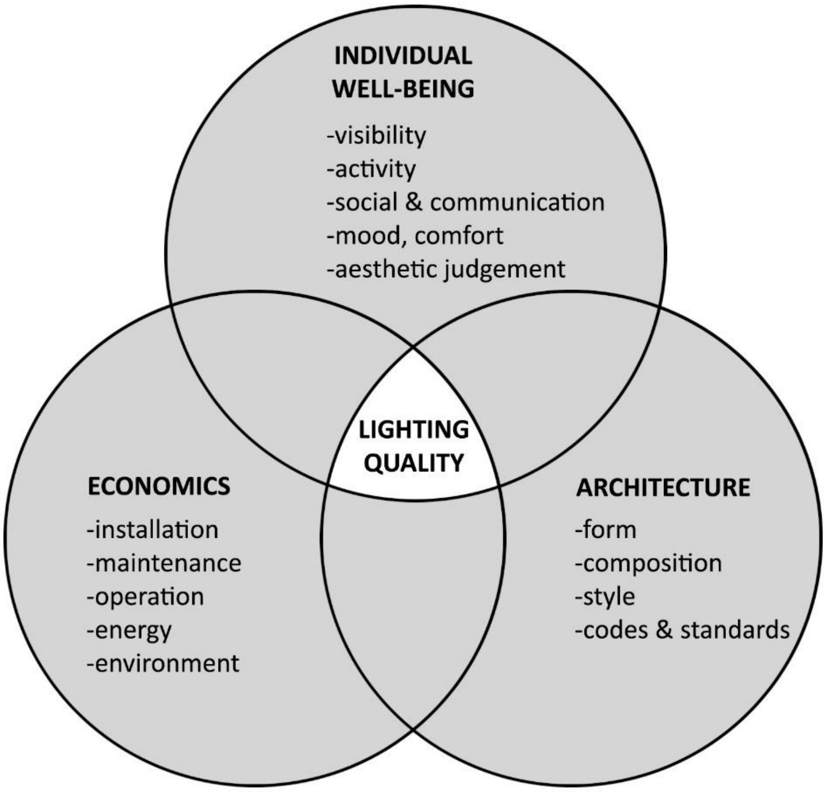


Figure 2-2: Veitch model (Veitch, 2004).

A study conducted in Canada and US cities during 2000–02 aimed to quantify worker satisfaction. Data was collected from 779 participants to show the relationship between the factors that affect their level of satisfaction such as lighting quality, ventilation, and thermal and acoustic settings (Canada Standards Association, 2013). A set of predicted variables were identified and analysed. Veitch (2004) found that four variables affect occupants' level of satisfaction: (1) illuminance, (2) glare, (3) uniformity, (4) lighting direction (Fig. 2-3). Interestingly, there is no mention of the impact of the outside view on overall environmental satisfaction. Therefore, this thesis works with a modified conceptual model, assuming that there is association between the predictor variables including the outside environment and satisfaction with view quality .

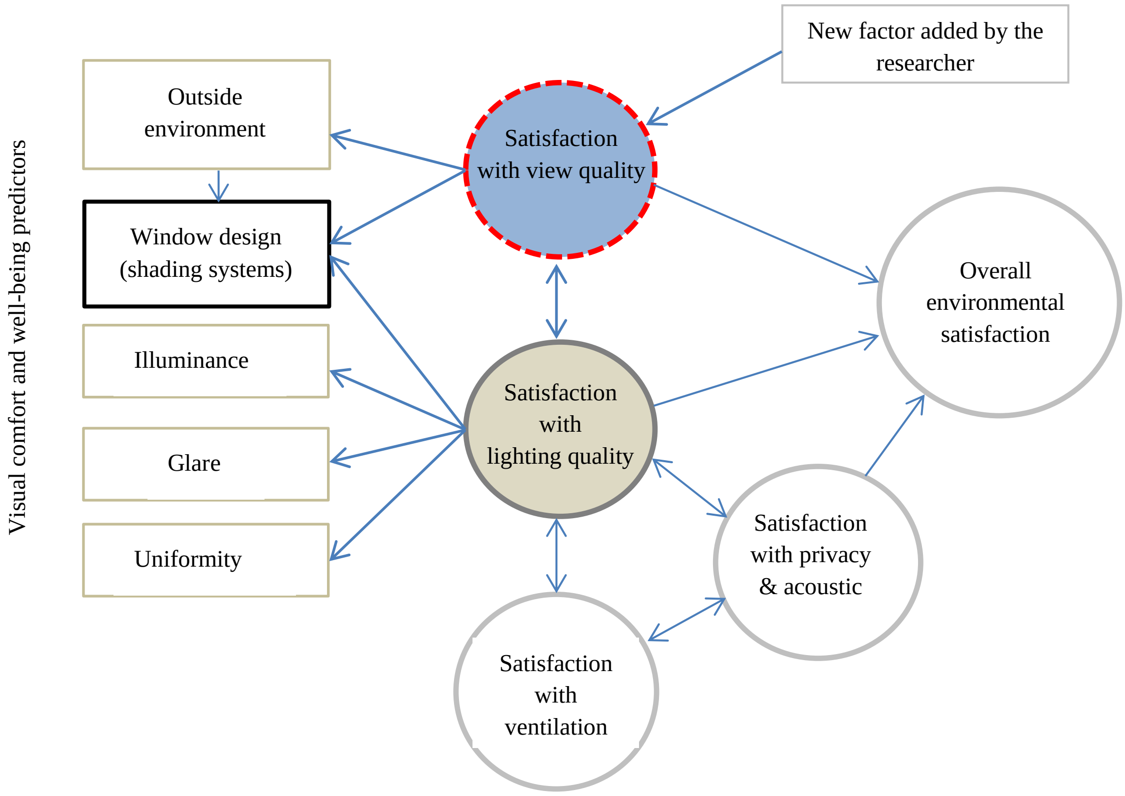


Figure 2-3: Conceptual model showing the relationships between the predictor variables for satisfaction with lighting (Adapted from Veitch, 2004).

Another study conducted by Rohde et al. (2020) shows that indoor environment quality affects occupant well-being in three ways: (1) emotional response, (2) dynamic environment of daylight, (3) reduced stress environment represented by outside views and contact with nature. In Rohde’s model, daylight and view quality have a direct impact on occupant visual comfort and well-being.

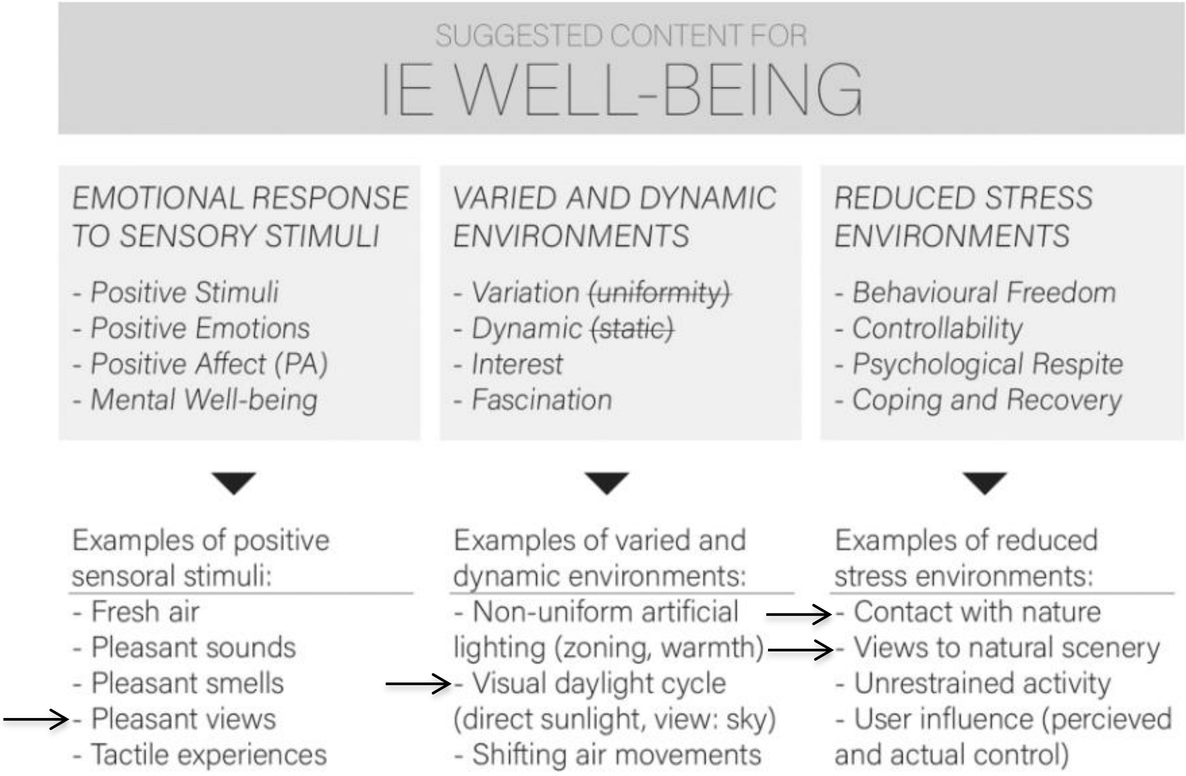


Figure 2-4: Well-being model by Rohde et al. (2020).

2-2-2 Comfort and Well-Being Related to Daylight and View

Comfort can be defined in terms of daylight quality as the absence of visual discomfort (Pettersson, 1998), and it has an impact on occupant perception of well-being and aesthetics. In general, comfort refers to a feeling of well-being and aesthetics (World Health Organization, 2022a). The term 'visual' relates to 'seeing' or the sense of sight. In the present study, comfort is defined as the absence of daylight issues such as glare, so the term used is visual comfort, which can also be defined as a positive feeling of well-being based on the Rohde's model (Rohde et al., 2020).

An experimental study conducted by Boyce & Cuttle, C., (1990) aimed to investigate the relationship between daylight illuminance and visual comfort. The participants were asked to choose the term ('too dark', 'good' and 'too bright') that most accurately represents their experience with light in general. As indicated in Figure (2-5), the largest percentage of 'good' was given when luminance was around 130 cd/m^2. Therefore, this experiment proves that light quality is not only represented by the higher light illuminance or luminance but is also related to other factors that affect participant satisfaction with lighting. Illuminance is the measure of light hitting a surface, quantified in lux, indicating how well-lit that surface is. Luminance, on the other hand, measures the brightness of light emitted or reflected from a surface in a specific direction, quantified in candelas per square meter, showing how bright the surface appears to an observer. In simple terms, illuminance refers to light falling onto a surface, while luminance refers to light leaving a surface.

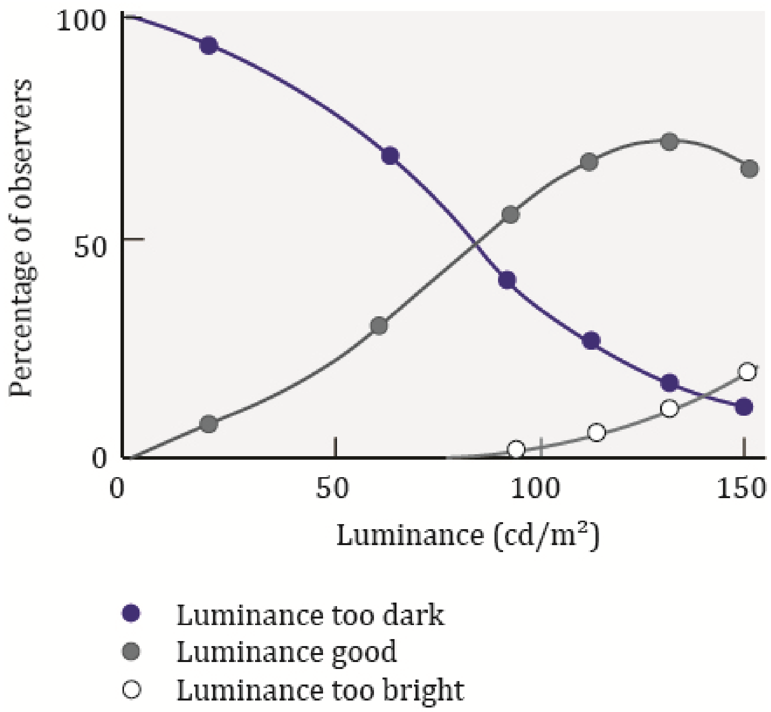


Figure 2-5: Relationship between different Luminance levels perception (Boyce & Cuttle, C.,1990).

Many prior studies focus on the relationship between daylight and view through windows showing a significant association in occupant surveys. The findings refer to a relationship between occupant location and level of satisfaction with the view: the further the occupant is from the view, the lower their level of satisfaction (Roche et al., 2000; Myriam et al., 2010). In addition, view to the outside can lead to visual discomfort and glare issues (Tuaycharoen & Tregenza, 2007). A study conducted by Roche et al. (2000) shows that daylight has a negative impact on the presence of windows as it affects the level of satisfaction with daylight. The authors found that the high daylight levels achieve less satisfaction due to glare issues (Roche et al., 2000). Myriam et al., (2010) shows that occupant satisfaction of sitting next to windows and being exposed to sunlight increases although having glare issues. These findings lead us to ask whether optimising daylight quality and view quality using shading systems can improve occupant satisfaction.

2-3 Review of Daylight and View Quality in Building Rating Systems and Standards

To design a healthy building, many systems and rating schemes use standards and metrics to achieve this goal. Although they all share the interest of improving occupant comfort and well-being, they are not similar in their overall scope metrics (McArthur & Powell, 2020). The following section illustrates the most crucial rating systems related to the building life cycle, focusing on extracting the relative recommendations on how these rating systems or standards match with the terms comfort and well-being for daylight and view quality factors. The following chronological overview presents a selection of the most important and forward-looking tools and their underlying methodologies. This overview shows their respective structures at a glance, focusing on how these rating systems or standards match with the terms comfort and well-being (Table 2-1).

2-3-1-1 Daylight Quality

The World Health Organization (2022a) has indicated that employee well-being must be a priority for solving mental health problems. Many studies show that one in four people have significant mental health issues from workplace disability (World Health Organization, 2022a; Valente, 2010; National Alliance on Mental Health, 2022). Every year the European Union spends over 135 billion euros on alleviating mental health problems of building occupants (Dewa & McDavid, 2011), the United States spends between 150 billion and 300 billion US dollars per year (American Psychological Association, 2013), and Canada spends around $50 billion each year (Mental Health Commission of Canada, 2022).

In the United Kingdom, work stresses, depression and anxiety account for more than 600 people in working environments and the average sick days per person is 21 days; well-being illnesses such as depression and stress affect more than 40% of employees in the United Kingdom after Covid (Gill & Butler, 2020). Daylight inside a building is associated with many physiological and psychological benefits that affect occupant well-being. Daylight conditions throughout an indoor environment directly affect the health and well-being of building occupants (Dobrica, 2020; Owl Labs, 2021; Kelloway & Cooper, 2021; Canada Standards Association, 2013; Zhou et al., 2020). Although light is predominantly perceived as a visual phenomenon, it also affects human physiology, behaviour and mood, summarised as non-visual effects (International Commission on Illumination, 2008). The visual effects of daylight refer to the photometric measurements used to analyse how much light is present in a given space for tasks. In contrast, non-visual effects are subjective assessments that evaluate how the light is perceived (colour, intensity, distribution, uniformity, etc.).

Many systems and rating schemes recommend standards and metrics to design a healthy environment. Different methods were used to test and evaluate these metrics. Simulation methods are generally used to analyse indoor daylight performance, calculating a range of metrics such as daylight illuminance (DI), daylight autonomy (DA), daylight factor (DF), annual sunlight exposure (ASE) and spatial daylight autonomy (sDA) (Pilechiha et al., 2020; Nabil & Mardaljevic, 2006) (Fig. 2-6).

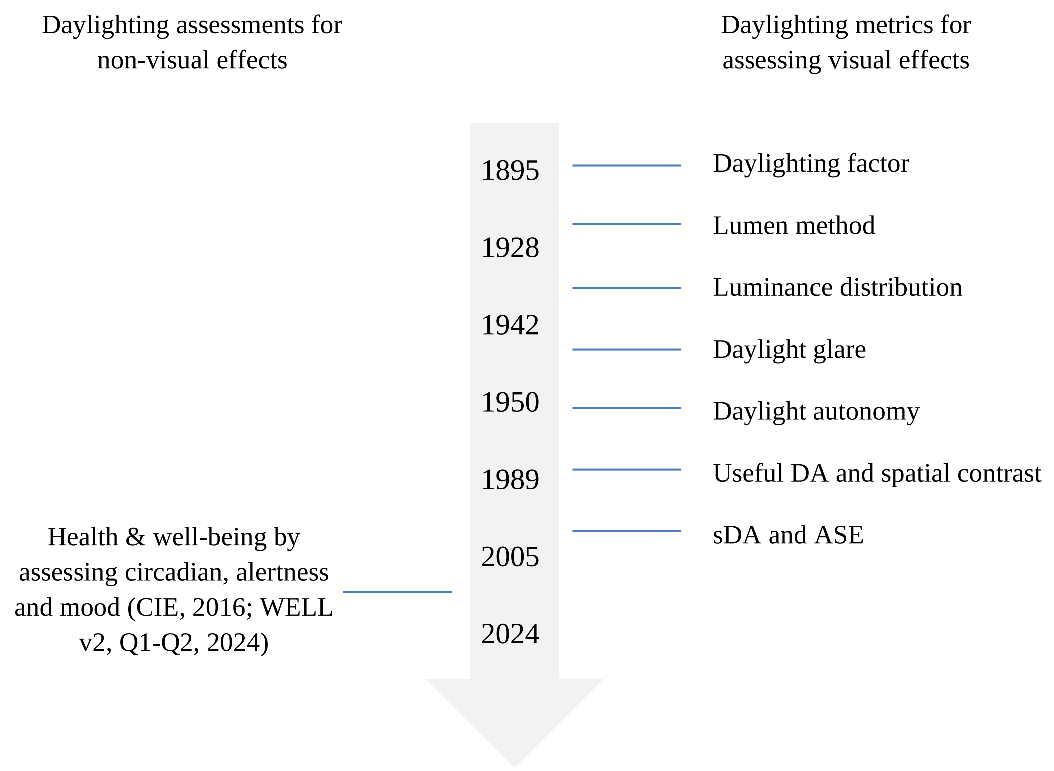


Figure 2-6: Daylighting non-visual effects in relation to measuring daylight metrics. (source: Author)

2-3-1-2 Photometric Measurements

Two common daylight indicators describe its performance in space, illuminance and luminance. The illuminance of a given surface is defined by the amount of light reflected by it; however, high luminance levels have a negative effect on our visual comfort due to glare issues. The luminous flux per unit area defines a surface's luminance and is measured by foot candles or lux in the International System of Units (SI).

2-3-1-3 Moving from Static Metrics to Climate-Based Metrics

1. Daylight Factor (DF)

Daylight measurements have played a significant role in assessing daylight quality and artificial lighting illumination of tall buildings (Hopkinson & Kay, 1972). Daylight factor (DF) was considered the first method to measure indoor illumination. It was defined as the ratio of light related to outdoor illumination under overcast sky quality (Hopkinson & Kay, 1972):

$$\text{DF} = \left(\frac{E_i}{E_o}\right) \times 100\%$$

where E_i is the daylight illuminance on working plane and E_o is outdoor illuminance.

A DF formula is defined by how much outdoor illuminance falls on a horizontal work plane inside a space; it was recommended to be between 2% and 6% for office spaces (Waldram, P., & Waldram, J. (1923). Metrics and analysis tools have changed dramatically over the past few decades thanks to computer simulation methods that allow designers to measure daylight at a definite time of the day with a single condition over a year. Therefore, daylight variability is evaluated in complex façades at definite point-in-time illuminance per year. Consequently, there was a shift in using daylight static metrics such as DF to using point-in-time measurements. Then, metrics were developed to include climatic change and were called climate-based metrics, such as daylight autonomy (DA), continuous daylight autonomy (cDA), useful daylight illuminance (UDI), spatial daylight autonomy (sDA) and annual sunlight exposure (ASE) (Although DF is still used in many research studies for its simplicity and stability, it does not present realistic climate quality because it does not consider changing the date, time, latitude, orientation of the building or glare (Mardaljevic et al., 2009; Reinhart & Walkenhorst, 2001; Lee et al., 2019).

2. Daylight Autonomy (DA)

Daylight autonomy (DA) is defined as 'the percentage of the operating period (or a number of hours) that a particular daylight level is exceeded throughout the year' (Rea, 2005). This metric is considered a dynamic climate-based metric that considers the dynamic weather at different locations over the year (Reinhart et al., 2013). An option that users have when running DA simulations is to specify a specific threshold at which DA calculations occur; that is, if DA is calculated with a limit of 300 lux, simulation results only present the area that exceeds this limit.

There are a few limitations to using DA. First, it works only to measure the area that exceeds the recommended limit. Second, this method does not measure the area below the recommended limit. Another limitation of DA is that it does not work alongside the recommended value by IESNA standards (Rea, 2005); therefore, achieving a high illuminance level could produce some thermal and glare issues for occupants (Nabil & Mardaljevic, 2006). Because of these limitations, DA did not give an accurate vision of daylight quality in space; another metric was developed to tackle this problem.

3. Useful Daylight Illuminance (UDI)

Useful daylight illuminance (UDI) is defined by the percentage between the periods that received adequate daylight levels per year to occupied hours in the same year (Nabil & Mardaljevic, 2005). The useful range of UDI is recommended to fall between 100 and 2000 lux. The benefit of using this metric is to define the spaces that have moderate illuminance. The moderate illuminance level can be achieved in three ways: first, if illuminance is 100 lux; second, if it falls between 100 and 2000 lux; third, if it exceeds 2000 lux (Reinhart, 2006).

4. Continuous Daylight Autonomy (cDA)

In 2006, Zach Rogers proposed a new metric called continuous daylight autonomy (cDA) using daylight autonomy as an essential guide. This metric can define the time when illumination is below the required minimum level. Thus, if 150 lux is the minimum illuminance for a certain time step and the required illuminance for that space is 300 lux, the cDA will score 0.5 credits (WELL v2, Q1-Q2, 2024).

5. Spatial Daylight Autonomy (sDA)

Spatial daylight autonomy (sDA) is defined by the ratio of floor area, which achieves the minimum daylight illuminance for a specified percentage of hours in a year and is mainly concerned with reducing visual disturbance (Pilechiha et al., 2020). It could be measured using daylight simulation engines that calculate the luminance levels for a space every hour per year. sDA can be achieved if at least 75% of regularly occupied floor area received 300 lux for 55% of the annual occupation hour (sDA 300 lux/50%). In addition, both the (WELL v2, Q1-Q2, 2024; LEED v.4.01, 2019) recommend using this metric. For example, to achieve the LEED v4 daylight credit, sDA should score at least 10% of the whole project space.

6. Annual Sunlight Exposure (ASE)

Annual sunlight exposure (ASE) is defined as the ratio between the floor area and the duration of the area's exposure to direct sunlight for more than the recommended illuminance per year (Pilechiha et al., 2020). LEED v.4.01and WELL v.2 recommend ASE to be 1000 lux per 250 hours per year for no more than 10% of regularly occupied space. LEED v.4.01 recommends using both sDA and ASE together to evaluate daylight quality because this combination can present an area that receives too much direct daylight; consequently, designers can identify the areas exposed to daylight performance and glare issues (LEED v.4.01, 2019; Heschong et al., 2012).

To comply with daylight quality credit in LEED v4.01, it is mandatory to carry out a dynamic computer simulation or accurate field measurements. In addition, two main things need to be achieved by any method: (1) to achieve sufficient daylight provision and (2) to avoid glare issues resulting from daylight levels. In the simulation method, there are two options used to achieve the daylight credit of four points. The first option will give four points if sDA achieved 300 lux for 50% of the typical floor area per year and ASE of 1000 lux per 250 hours per year for each regularly occupied space. The second option will give three points if the ASE is at least 1000 lux for at least 250 working hours per year) (WELL, v2, Q1-Q2, 2024). Both sDA and ASE metrics can be seen as complementary to each other with a note that spaces with view-preserving automatic (with manual override) glare-control devices may demonstrate compliance for only the minimum 300 lux illuminance level. BREEAM defines two alternatives to quantitatively assess daylight provision. The first approach is to achieve an average daylight factor of 2% for 80% of spaces on one typical floor (BRE Global. BREEAM, 2014). The second approach is to achieve uniformity in the daylight distribution by getting average daylight in the space of at least 300 lux for 2000 hours per year or at least 90 lux for 2000 hours per year.

7. Circadian stimulus (CS)

Circadian rhythm, or the circadian cycle, is considered a natural and internal process that affects our sleep–wake cycle every day (Gumport et al., 2019). Circadian stimulus (CS) is the average value of illuminance for each hour and time of a day per year. This value is represented by a credit score starting from 0 to 2 related to the ratio of CS per year that achieved a credit score of 24 %. Therefore, when the circadian stimulus is more than 35%, equivalent to 120 lux, the credit score is 2 and when CS is less than 10% a score of zero is achieved (Leslie et al., 2012).

One of the most critical aspects in current building standards is introducing the WELL Building Standard, which states new metrics related to occupant comfort and well-being. The WELL Building Standard is much more comprehensive than sustainability rating systems, as it addresses nearly all indoor health-related environmental concerns cited in academic research (WELL, v2, Q1-Q2, 2024). However, both LEED v.4 and WELL Building Standard recommend using sDA and ASE, but WELL put forward a new metric to measure—healthy sunlight exposure, which states that to stimulate occupant CS at least 75% or more workstations should achieve 200 Mlux between 9 a.m. and 1 p.m. daily per year.

Based on the model of human circadian phototransduction, circadian stimulus could be measured in the laboratory by counting the illuminance level falling on the occupant’s cornea and the duration of this exposure (Rea & Figueiro, 2016). This value of circadian stimulation presents the predicted percentage of melatonin suppression. Rea et al. (2016) developed a new model of human circadian response based on the measured value of neuroanatomy and neurophysiology and published psychophysical study results.

The graph in Figure 2-7 illustrates the relationship between circadian stimulus and melatonin suppression, with CS between 0.1 and 0.7 ((Rea & Figueiro, 2016). In addition, Figueiro et al., (2011) claims that ‘an exposure to CS of 0.3 or higher for 1 hour or more in the early part of the morning has been shown to effectively maintain office workers’ circadian system’. The WELL Building Standard recommends a metric to stimulate the occupant’s circadian system (WELL, v2, Q1-Q2, 2024). This metric is called the equivalent melanopic lux (EML) and is calculated by quantifying the amount of lux related to the spectral sensitivity of melanopsin (Erberich & Graeber, 2020). According to these findings, a healthy shading system should be designed to achieve at least 300 lux of daylight for at least 4 hours according to WELL v02 at a time between 9 a.m. and 1 p.m. for 75% of the floor area. This amount of daylight will be enough to stimulate the CS recommended level of 0.3. Therefore, useful daylight illuminance (UDI) simulation is needed to evaluate shading device solutions and select the shading device that gives this 300 lux between 9 a.m. and 1 p.m. for 75% of the floor area.

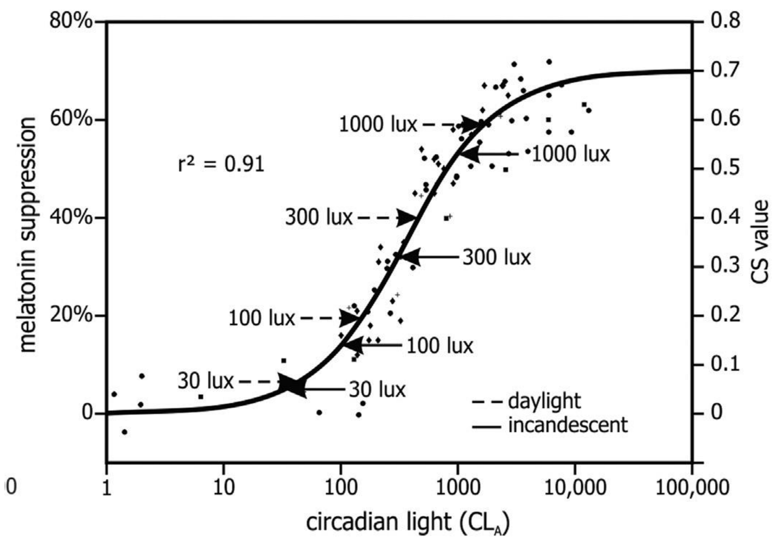


Figure 2-7: Relationship between circadian light and melatonin suppression (Figueiro et al., 2011).

2-3-1-4 View quality

“A picture is a multidimensional representation of an inner or external reality depicting the physical structure of the objects or events they represent”. (Pettersson, 1988)

A picture can be described as a sense of vision and awareness of the stimulation to the eye's vision perception cells by specific content (Pettersson, 1988). The term 'picture window' was established by the architectural ornamentor Kent Bloomer, who stated that a picture window and window frame panels could affect our sense of connection towards the outside environment (Ko et al., 2021). For example, in traditional window design, occupant view quality is affected by the small grid of many mullions and shading that divides the outside view into frames (Fig. 2-8). Views can be described as 'what you can see from a particular place' (Kellert et al., 2011).

View quality has been investigated through different building rating systems, such as LEED v4, WELL (LEED v4, 2019; WELL, v2,Q1-Q2, 2024), and the Building Research Establishment Environmental Assessment Method ((BRE Global. BREEAM, 2014), and with different standards, such as the Chartered Institution of Building Services Engineers (CIBSE, 2005) and the European norm (CEN, 2021), with given some guidelines and metrics used to measure view quality in a space. CIBSE illustrates three metrics for measuring occupant view quality according to the occupant's position in a space. These three metrics are (i) window-to-wall ratio (WWR), (ii) the distance from the view and (iii) the number of layers received by the occupant, such as sky, landscape and foreground. A score was given to rank the view quality: unacceptable, acceptable, good and excellent.

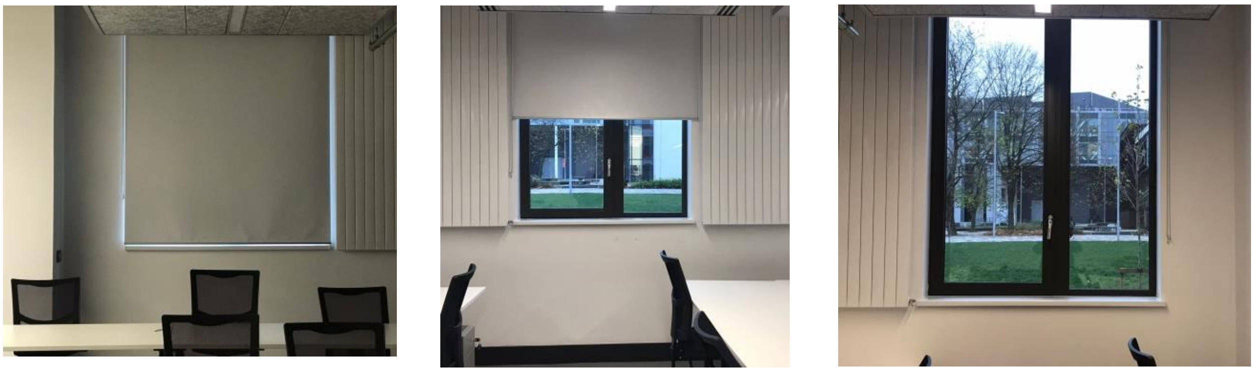


Figure 2-8: The impact of view clarity and picture window frame on our sense of connection towards the outside environment. (Hall SEE17 at the new SEE building at Salford University, UK. Source: author)

According to BREEAM, a good view quality credit can be achieved when 95% of the floor space areas fall within 7 metres from a window that enables the occupant to view the outside environment. The WWR must be more than 20% in the open external environment and more than 10% if there is an external solid block such as surrounding buildings or fences.

ASHRAE (2006) along with the International Green Construction Code (2021) state that view quality could be achieved if at least 50% of the occupied floor area has a direct line of sight (DLS) to the outside environment with 1.07 metres above the floor level and 6 metres away from the window. Also, for view clarity, the window-to-wall ratio WWR should be more than 7% of the floor area. In addition, European standard EN 17037 (CEN, 2018) presents a new method to measure the view clarity index for any shading device based on the visible visual contact to the outside in case this shading is installed for the worst scenario. The view clarity index was defined by two metrics: (i) direct visible transmittance (VT, n-n) and (ii) diffuse visible transmittance (VT, n-dif). The EN standard provides a metric to measure the view clarity of different shading systems based on the VT factor, but it does not show the acceptable levels of the VOV content that will be affected by installing the shading system.

In the European standard EN 17037 (CEN, 2018), three general principles have recently been introduced regarding horizontal viewing angle distances and visibility. For view access, the sight-seen angle should be at least 14 degrees and not more than 54 degrees related to the minimum and maximum field of view (FOV). In addition, a clear view to the outside within at least 6 metres away from the opening window for the view credit score is achieved if at least one of the outdoor layers sky, landscape or ground is visible (LEED v4, 2019; CEN, 2018).

The definition of a view quality differs between LEED versions 4.0 and 4.1. In version 4.0, a view quality credit could be achieved by two of the three view types as follow:

- *View type 01*: Multiple lines of sight: A view location with multiple lines of sight to vision glazing at least 90 degrees apart. This type is considered only in LEED v4.0.
- *View type02*, Context and sky: The definition of a Type 2 view differs between LEED versions 4.0 and 4.1. In version 4.0, a Type 2 view includes at least two of the following: (1) vegetation / sky, (2) movement, and (3) objects at least 25 feet from glazing (7.62 meters). In version 4.1, a Type 2 view includes at least one of these elements: nature/art/urban landmarks, or objects at least 25 feet (7.62 meters) from the glazing.
- *View type 03*: Unobstructed: credit could be achieved if the unobstructed views are located within a distance of three times the head height of the vision glazing (Table 2-1).

For LEED v4.1, a view quality score could be achieved if at least 75% of the regularly occupied building floor area complied with only Type 2 and Type 3 view recommendations. View quality could be measured based on some metrics related to view access, view content, and view clarity. Ko et al., (2021) indicate that view quality has three main factors: (i) view access, which is defined as the angle of sight seen to the outside (Wilson, 1984); (ii) view clarity, which refers to how an occupant can see the outside view content clearly (Wilson, 1984); and (iii) view content, which is related to layers found in the outside view such as sky, greenery and context (Farley & Veitch 2001).

Among all these measurements, no tool connects the view clarity and view content to quantify the visible outside view (VOV) content received in case the view clarity is affected by any shading system because the greater the view clarity index, the more view content will be received.

Table 2-1: Daylight and view quality recommendation in building rating systems (Source: author)

Certificates	Daylight quality	View quality
1-BREEAM (BRE Global. BREEAM, 2014)	1-Average daylight illuminance : not less than 300 lux achieved for 2000 h/year. 2- Daylight factor for 80% of floor space achieves an average of 2%. 3- At worst lit point, the daylight illuminance is: At least 90 lux for 2000 h/year.	1-View out available for 95% of a space away from the wall by 7 m at least. 2-A building, screen, wall, fence, or other solid object is 10m away. 3-The WWR must be more than 20%.
2-LEED (LEED v4, 2019)	1-Daylight levels between 300 and 3000 lux. 2-The spatial daylight autonomy 300/50%. 3-Annual sunlight exposure1000, 250.	1-View out available for 75% of a space. 2-View Quality for at least 75% of space with including two of these elements; (Flora, fauna, or sky; movement; objects away 7 m from the façade).
3-The Living Building Challenge (International Living Future Institute, 2019)	1-Daylight available 75%	1- Views outside and daylight achieved by not less than 75% of space.
4-WELL BUILDING STANDARD (WELL, v2, Q1-Q2, 2024)	-Visual task lighting achieved by min. 300 lux at the work plane with light intensity of 215 lux.	-Not less than 75% of workstation that from the opining by 7.5m at least has view to outside environment.

	- CIRCADIAN LIGHTING DESIGN: 75% or more of workstations achieve 200 Mlux between 9AM and 1PM day/ year. - The spatial daylight autonomy 300/50%. - Annual sunlight exposure1000, 250 achieved for no more than 10% of users.	

2-3-1-5 Shading Devices in terms of Daylight and Well-Being: Shading System Classifications

Shading systems are one of the most popular strategies used by designers to improve façade performance (Kirimtat et al., 2016), not only to protect a building from direct sunlight but also to control the penetration of natural light (Baker et al, 1993). Hence, the application of a shading system presents a crucial aspect in improving energy efficiency in buildings, particularly for cooling loads in hot climate regions (Kirimtat et al., 2016). However, an excessive amount of natural light can cause visual discomfort and glare problems (Kirimtat et al., 2016; Al-Obaidi et al., 2016). Furthermore, it can result in a considerable amount of solar heat gain that stimulates an increase in indoor air temperature and leads to thermal discomfort (Baker et al, 1993; Munaaim et al., 2014).

Baker et al. (1993) illustrate a classification to shading device systems that can protect the occupants close to the windows from the direct rays of the sun and at the same time make some of that sunlight available at the back of the room for daylight purposes. Their study states that there are seven kinds of shading devices. The first one is the Mediterranean blind system where a shading device is described as a ‘jalousie’, an element composed of small slats, movable or not. Traditionally, the slats are made of wood, plastic or steel.

The second is the shutter system where the shading device is an opaque surface that covers the whole dimension of the opening, obstructing completely any solar radiation and views. It is possible to find them inside and outside, attached to an opening; they are also operable. Generally, they are made of wood, aluminium or polyvinyl chloride (commonly known as PVC). When they are closed, the interior is wholly insulated visually and thermally.

The third is the louvres system where the shading device consists of a series of slats on the external elevation. Depending on the model, they cover just the opening or a larger area (Baker et al., 1993). Traditionally, there are two types of louvres in the Mediterranean countries, rolled louvres and unrolled louvres.

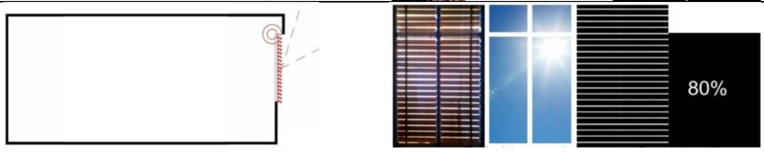
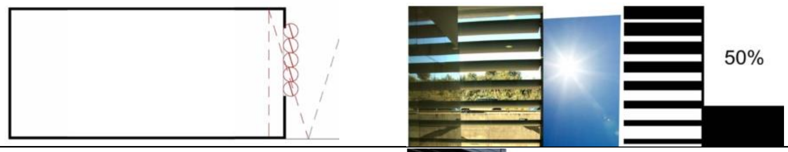
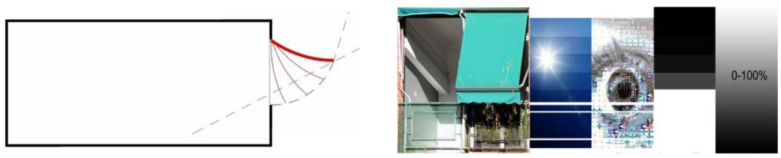
Brise-soleil is the fourth system in the Baker classification where the shading device is an open structure that can belong to the buildings or just be attached to them. It can be made of any construction material, such as steel, concrete or wood (Baker et al., 1993). It will allow ventilation, but since it is fixed, it will obstruct only certain angles of the direct solar radiation.

The fifth system is the awning system, where the shading device is the adaptable and flexible version of the overhang. It is a rolled flexible device usually made of textile materials, opaque or diffusing, depending on the performance and aspect that would be required. These are placed outdoors, covering the minimum width of the opening. Generally, the awning system is slightly more significant than the aperture it is protecting. It can only obstruct or diffuse direct solar radiation, depending on the material. The overhang decreases the light levels close to the protected opening while providing full or partial shadow to the window (Baker et al., 1993).

The sixth type is called the overhang system where the shading device can sometimes be an opaque device consisting of a fixed horizontal surface placed above the openings or other protected elements. It obstructs only the direct solar radiation, and if the dimension is not enough, it will not obstruct all of it (Baker et al., 1993). If it is protecting an opening, its dimension will be bigger than one of the openings in general, but the local seasonal solar angles will determine this. Commonly, it blocks the summer sun but not the winter sun. It can be a part of the building structure or an attached element. Therefore, it can be made of any construction material, from concrete to glass.

The last kind of device in the Baker classification is the light shelf system where the shading device is a horizontal and opaque surface placed above eye level across the opening. Its dimension depends on the latitude, orientation and sun angle of the location where it is placed, but it usually covers the whole width of the opening. With this device, the design intentions are to provide shadows on the parts of the room that are closer to the openings while not decreasing the illumination levels too much in other parts. It also provides a much more uniform light distribution (Baker et al., 1993) (Fig. 2-9).

Figure 2-9: Baker Classification of shading devices (Baker et al, 1993)

No.	Shading device system	View to outside
1	Mediterranean blind	
2	Shutter	
3	Rolled louvres	
4	Unrolled louvres	
5	Brise-soleil	
6	Awning	
7	Overhang	
8	Light shelf	

Al-Masrani et al., (2018) classify shading devices based on the design concepts of energy involvement and technological improvement. For energy involvement, the authors classify shading systems into three categories: (1) passive, (2) active and (3) hybrid (Fig. 2-10). These were also divided into three groups based on technology type: (1) design approach and design methodology (optimisation process), (2) control or mechanism, and (3) deformation. The passive shading system includes fixed and manual devices, the active system consists of mechanical devices that need energy to work and the third hybrid system is inspired by biomimetic approaches such as self-organized intelligent materials.

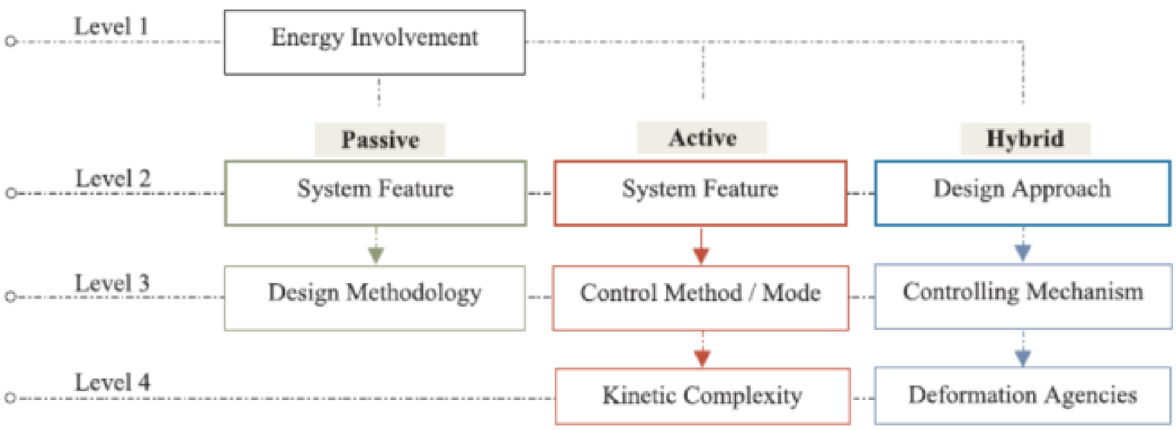


Figure 2-10: Classification logic of different shading systems through four levels of categorization by (Al-Masrani et al., 2018)

2-4 Review of Journals, Books and Related Studies

2-4-1 Methodology

This study presents a deep analysis to identify the most relevant publications on daylight, comfort, well-being and shading systems over the last 10 years. Numerous databases are widely available online, and the most prominent sources such as Scopus, Web of Science and Google Scholar were used for keyword searches. The literature was chosen after systematically searching Google Scholar and SCOPUS for recent daylight-related articles. The research was limited to journal theses, and combinations of the following keywords were used: daylight, comfort and well-being. Only articles exploring daylight effects on ‘occupant well-being’ were selected to form the thesis sample. Studies analysing daylight comfort in terms of thermal consumption, energy and artificial light, unless they refer to the interaction of occupant comfort and well-being, were excluded. The criteria matched with 31 published theses in essential daylight, shading and well-being (see Table 2-4).

Table 2-2: Search terms in Scopus and Google Scholar

	Search items
Scopus & Google Scholar	(Daylight and Well-being and View and Shading and Comfort [Title/Abstract] AND daylight, natural light [Title/Abstract]) NOT Thermal (All Fields)
	(Daylight and Well-being and View and Shading and Comfort [Title/Abstract] AND daylight, natural light [Title/Abstract]) NOT Thermal (Engineering filed)
	Daylight and View outside [Title/Abstract] AND daylight, natural light [Title/Abstract]) NOT Thermal (All Fields)

The first stage involved data extraction, including the first author, publisher name, publication year and geographical area of the study. The second stage involved separating the surveyed literature based on the study's focus into four categories (Table 2-4):

1. Focus of the study and scope
    - Daylight and comfort
    - Daylight and well-being
    - Daylight and shading devices
    - Daylight and energy efficiency
2. Methods used to measure
    - Simulation
    - Virtual reality
    - Survey
    - Questionnaire
    - Experimental
3. Daylight metrics
    - Daylight levels/intensity (illuminance levels)
    - Daylight distribution patterns (uniformity)
    - Daylight exposure
    - Diffuse daylight
    - Annual sunlight exposure (ASE)
    - Daylight autonomy (DA)/spatial daylight autonomy (sDA)
    - Daylight glare
4. Data extraction

The following data was extracted from the literature, if available: (1) research information including author name and year of publishing, (2) sky quality, (3) focus of study (i.e. well-being, comfort and people's satisfaction with daylight and view), (4) methods, (5) daylight standard and (6) daylight metrics. The data are enumerated in Table 2-3.

Table 2-3: Data extraction

1	2	3	4	5	6
Research information	Sky quality	Focus of study	Methods	Daylight standards	Daylight metrics
31 paper	3 conditions	5 themes	5 types	4 parameters	7 parameters

Table 2-4: Daylight and well-being literature

Research information		Sky quality			Focus of the study					Method					Daylight standards				Metrics						
No.	Authors	Clear	Overcast	Not indicated	Visual comfort and view quality	Daylight & health	Daylight & well-being	Daylight& shading	Daylight & energy	Simulation	Virtual reality	Survey	Questionnaire	Experimental	BSI standards	CIBSE standards	IESNA standards	EN standards	Daylight levels/intensity	Daylight distribution patterns	Daylight exposure	Diffuse daylight	Annual sunlight exposure (ASE)	Daylight autonomy (DA)/Spatial	Glare
1	Altomonte, 2009				Visual comfort (glare)																				
2	(Cantin & Dubois, 2011)						Satisfaction with daylight quality																		
3	Fathy et al., 2020						Satisfaction with ambience																		
4	Flores-Villa et al., 2020					Sleep quality																			
5	Leslie et al., 2012				Thermal comfort	Improve circadian stimuli			Solar heat gain																
7	Hellinga & Hordijk, 2014						Satisfaction with access to the outside view quality																		
8	Elzeyadi, 2012						Satisfaction with access to the outside view quality																		
9	Sherif et al.,2015				Visual comfort (daylit ratio)			Louvres																	
10	Pesenti et al., 2015				Visual comfort (glare)			Pattern	Total energy consumption																
11	Mahmoud & Elghazi, 2016				Visual comfort (glare)			Pattern																	
12	Bian & Luo, 2017				Visual comfort (glare)																				
13	Amundadottir et al., 2017				Visual comfort (glare)		Visual interest impressions in space (pleasant,																		

							interesting and exciting)																		
14	Heydarian et al., 2016						Productivity																		
15	Jayathissa et al., 2018							Pattern	Reduces solar heat gain																
16	Tabadkani et al., 2018				Visual comfort (glare)			Pattern																	
17	Amundadottir et al., 2017					Improve sleep comfort	Visual interest impressions in space																		
18	Acosta et al., 2019					Improve circadian stimuli																			
19	Jamrozik et al., 2019				Visual comfort outside view ratio	Assess eye strain	Satisfaction with amount of view																		
20	Sheikh et al., 2019				Visual comfort outside view ratio			Pattern	Reduces solar heat gain																
21	Kreutzberz & Naboni., 2019						Satisfaction with ambience	Pattern																	
22	Boubekri et al., 2020				Outside view ratio	Sleep duration	productivity																		
23	Flor ., et al 2020						Visual interest impressions in space																		
24	Hegazy et al., 2021						Visual interest impressions in space and satisfaction with ambience																		
25	Chamilothori et al., 2022						Visual interest and excitement Satisfaction with the amount of view																		
26	Jaeha et al., 2022				Visual comfort by assessing outside view quality																				
27	Cho et al., 2023				Visual comfort by assessing dynamic movements																				

28	Rafati et al., 2024								Reduces solar heat gain and improve daylight quality																
29	Kim et al., 2024				Visual comfort (glare), and improve daylight quality																				
30	Yao et al., 2024				View quality																				
31	Rizi, et al., 2024				View content			Dynamic Shading																	

The second part of the literature is a thematic analysis to extract the relative recommendation on how daylighting standards and building rating systems define Comfort and wellbeing in terms of daylight. Regarding daylight standards, the theme used was to identify the word “Wellbeing” and select the Approach and Recommended Value and Metric used to assess wellbeing in terms of daylighting. The same method was used in Building Rating systems to extract the theme of ‘Wellbeing’ in terms of daylighting.

Keyword in context method was used by MAXQDA tool, as a quantitative text analysis, to find the Keyword-in-context feature to display all word locations and their context in an interactive result table. The choice to work with qualitative data is particularly appropriate when there is little information about the topic to be addressed in the fitness objective (Kuckartz, U., & Rädiker, 2016). Critical evaluation was conducted to extract the most relevant context related to wellbeing in terms of daylight practice.

Table 2-5 Wellbeing in context results using quantitative analysis by MAXQDA software.

Theme of “Wellbeing”			
Daylight standards	Theme of “Wellbeing”	Rating systems	Theme of “Wellbeing”
1-BS/US	1	1-BREEM	65
2-IESNA	14	2-LEED	6
3-CIBSE	1	3-The Living Building Challenge	1
		4-WELL building Standard	27

2-4-2 Critical Review

2-4-2-1 Themes Associated With Comfort and Well-Being

Several experiments have been performed to assess the impact of daylight's non-visual effects such as measuring circadian rhythm, visual interest and mood (Thapan et al., 2001; Brainard et al., 2001; Berson et al., 2002; Khademagha et al., 2016). These experimental studies help to understand the non-visual effects of daylight and provide guidelines for designs systems that positively affect human comfort and well-being. The International Commission on Illumination released a technical report on healthy interior daylight recommendations that provided researchers with a research roadmap (Veitch et al., 2016) (Fig. 2-11). Therefore, the non-visual effects of daylight that affect occupant's comfort and well-being consist of three main components: (i) the impact of circadian rhythm, (ii) visual interest and (iii) feeling and satisfaction (Veitch et al., 2016; Hui et al., 2021).

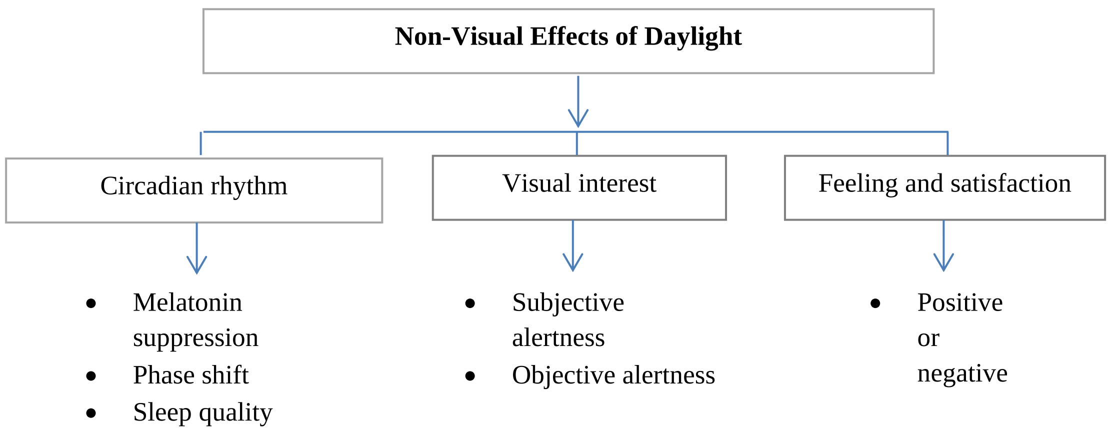


Figure 2-11: Daylight non-visual effects parameters (Veitch et al., 2016).

Based on these parameters, the selected samples classified to three themes of well-being associated with the non-visual effects of daylight as follows: (i) circadian rhythm (Acosta et al., 2019; Boubekri et al., 2020); (ii) visual interests and impressions (Amundadottir et al., 2017); and (iii) feeling and satisfaction with access to the outside view content (Elzeyadi, 2012), view access (Jamrozik et al., 2019; Boubekri et al., 2020) and daylight quality (Sherif et al., 2015).

***Theme 1**: Circadian rhythm*

Some studies have focused on how better daylight conditions can improve human health and well-being by improving the occupants' biological clock, which affects their circadian stimulus (Acosta et al., 2019; Boubekri et al., 2020). Acosta et al. (2019) discussed the minimum window-to-wall ratio (WWR) effects on the colour temperature in a classroom. In this study, circadian stimulus autonomy was measured as the percentage of days per year that circadian stimulus exceeds a threshold in a classroom. However, natural and electrical light can improve circadian stimulus. The experiment occurred in a classroom with large windows of variable WWR of 30%, 45%, and 60% with different positions and orientations and under three typical sky conditions. Comparing the circadian stimulus values for the three window sizes reveals that, in comparison with the medium-sized window, when the window-to-façade ratio is 60%, it shows an average increase in circadian stimulus of about 15%, whereas when the window-to-wall ratio is 45%, there is an increase in circadian stimulus of 14% over the small window. This approach could be helpful in showing how window design parameters and daylight conditions can improve occupant well-being. In another study, Boubekri et al. (2020) illustrate the advantages of daylight exposure and the clear view of the outside environment. Their study linked the impact of daylight exposure to circadian rhythm, which can affect occupant well-being by improving sleep quality and productivity in working spaces.

***Theme 2**: Visual interests and impressions*

Quantitative studies on the visual effects of daylight measure daylight metrics, such as daylight factor, glare, luminance distribution, and daylight autonomy in a given space for task performance, whereas qualitative studies on the non-visual effects of daylight aim to explain health and well-being themes, such as circadian rhythm, visual interest, and mood on occupant satisfaction, impressions, and cognition. Amundadottir et al. (2017) introduced a new approach for improving occupant well-being in the working space by recording their visual interest behaviour. This new approach considers that field of view received at occupant eye level plays an essential factor in occupant perception of daylight conditions. Amundadottir et al. (2017) used Virtual Reality to assess three factors: (i) non-visual health aspects, (ii) visual interest and (iii) gaze motion. Comparing the results of each factor illustrates how humans respond to daylight in a space. This experiment was implemented in a controlled laboratory where gaze movements were scored using an immersive spatial approach. The results show that daylight distribution has a variable effect on non-visual health aspects and visual interest.

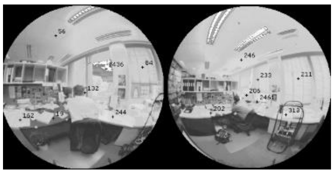
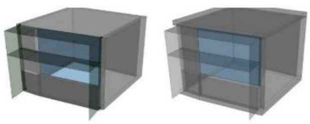
***Theme 3**: Feeling and satisfaction with view and daylight quality*

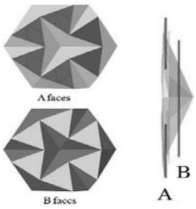
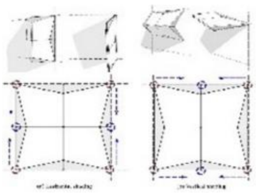
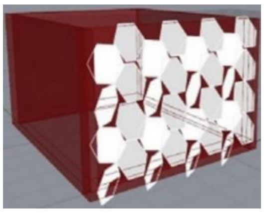
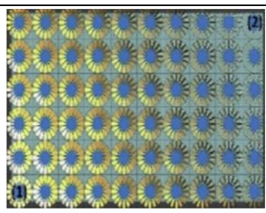
Another type of research aimed to investigate the ability of shading systems with non-visual effects (Altomonte, 2009; Elzeyadi, 2012; Sherif et al., 2015). The shading parameters became dependent parameters, aiming to improve occupant comfort and well-being by improving daylight visual comfort aspects such as glare and distribution and occupant perception of the outside view quality that will enhance occupant comfort and well-being. The complexity of this type of research that connects quantitative and qualitative measurements is needed for further investigation. Altomonte (2009) studied the impact of using a blind as a shading device to improve occupant perception towards daylight conditions in a workspace. This impact aimed to assess human perception and well-being by defining a framework showing some recommendations on which type of blind configuration will suit the type of work. Altomonte's (2009) experimental study was conducted in two seasons, winter and summer, at 10 a.m. with a fixed orientation to the east. In the winter, glare was an issue because of the low sun angle. It was observed that occupants preferred to do thesis work tasks rather than screen tasks during the morning. Their perception of daylight provision and the view outside made them feel better and increased their activity. Altomonte (2009) also tested two configurations (vertical and horizontal) of this blind to assess the luminance ratio and colour temperature as the most critical indicators that affect occupant perception in a workspace.

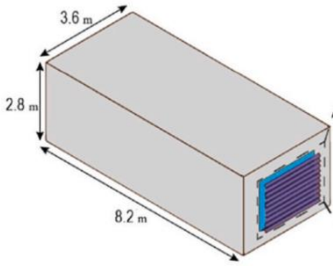
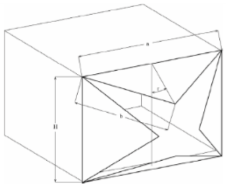
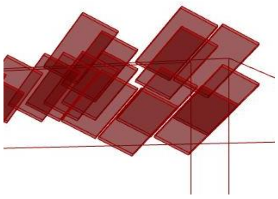
Subsequently, context impact and outside view composition became dependent parameters in investigating the non-visual effects of daylight. Elzeyadi (2012) conducted a study to quantify how daylight conditions and outside view quality could affect employee health and well-being. To illustrate this effect, the author relied on the biophilic approach to show the relationship between natural outside view and daylight and their impacts on sick leave for employees. Elzeyadi (2012) used different pictures from different locations and 98 full-time employees to assess outside view quality. The employees were asked to rank 12 selected photographic images of different outside views surrounding the working area. After that, a questionnaire was administered to know what employees preferred to see while sitting in offices on campus, including forest, urban, and street view scenes. In addition, Elzeyadi (2012) made a daylight analysis using high dynamic range (commonly, HDR) images taken from the set point for each employee to define the glare issues associated with outside view. Elzeyadi (2012) used multiple qualitative sorting techniques. Further, qualitative multiple sorting techniques were conducted following an interview with the participants to connect the sick leave ratio with the outside view content. Participants were asked to rank the outside view scenes. Elzeyadi (2012) argued that the highest ratio of employee sick leave was scored in workspaces with no access to a natural outside view such as a forest or urban greenery scenes. Hellinga & Hordijk (2014) developed a new method to describe the relationship between daylight and the view to the outside through a window in the workspace. This method uses the 180° equidistant projection technique to show the view through a window to the outside environment. Furthermore, Hellinga & Hordijk (2014) used the luminance ratio to quantify the daylight level inside the workspace. The mean value of the luminance ratio to the working area should not be more than 1:10 and to avoid visual discomfort, that of the background of the working area (called the 'inner field of vision') should be 1:30. Their study assessed view quality via a questionnaire that asked participants to rank 23 pictures taken in different outside view environments. These pictures have different view content such as greenery view, street view, context and sky view.

By investigating the ability to perceive the outside view while using a shading system, shading system parameters become dependent values to control what daylight is brought indoors and what the occupant well-being is to the outside environment. Jamrozik et al. (2019) conducted an experiment using two shading devices – dynamic tint and motorized mesh shades – for the window in the working space. These devices show the impact of different daylight and views of the outside environment on occupant satisfaction. Although having a window in the working space has many advantages, occupants may suffer from glare. Therefore, the authors implemented an actual experiment in a working space using two types of shading devices. The first type of shade was manual-automated control shading. The second one used material advantages for the tinting glass as a shading device. This experiment aimed to reach the optimal values to achieve the appropriate amount of daylight in a workspace and view the outside with minimal glare issues. Jamrozik et al. (2019) concluded no significant differences from using dynamic tint or motorized mesh shades based on occupant perception. Their study demonstrates how different shading systems can improve occupant well-being by improving performance and reducing eye strain in office environments by providing access to daylight and outside views. Boubekri et al. (2020) implemented an experiment using two different shading systems in two separate office environments. The first room had an electrochromic glass that acted as a shading device. The other room used a traditional blind. To measure sleep quality improvement, Boubekri et al. (2020) used a wrist-worn actigraph device, which contained a light sensor that measures light exposure (lux) at the wrists of each participant and the duration of time asleep. Their experiment concluded that achieving optimal daylight and outside views can improve occupant well-being by increasing sleep time by 37 min. The review also found a different approach to improving occupant health and well-being by simultaneously focusing on achieving better daylight conditions and outside view quality. This was based on a verbal questionnaire administered to occupants to rank different outside view scenes based on their feelings. Table (2-6) summarises the selected papers highlighting themes of well-being by assessing non-visual effects, detailing the methods, shading devices, and daylight metrics used.

Table 2-6: Themes of well-being identified across the sample – assessing non-visual effects (Source: author)

No.	Studies	Methods	Shading potential (found/not found)	Daylight metric	Themes of well-being
1	Altomonte, 2009	Experimental (HDR analysis)	 Found	Daylight levels/intensity (illuminance levels) lux/glare (visual comfort)	Not found
2	Elzeyadi, 2012	Questionnaire and survey methods	 Not found	Daylight Glare Probability (DGP)	Satisfaction with access to the outside view content
3	Sherif et al., 2015	Computational methods using simulation	 Found	Daylight levels/intensity (illuminance levels) lux	Satisfaction with daylight quality (daylight distribution ratio)
4	Amundadottir et al., 2017	Computational simulation and experimental validation	 Not found	Daylight exposure, daylight distribution patterns (uniformity)	Improve sleep comfort/visual interests and impressions in space
5	Acosta et al., 2019	Questionnaire and survey methods	 Found	Daylight levels/intensity (illuminance levels) lux, daylight distribution patterns (uniformity)	Circadian rhythm
6	Jamrozik et al., 2019	Questionnaire and experimental validation	 Found	Daylight levels/intensity (illuminance levels) lux	Satisfaction with view access

7	Boubekri et al., 2020	Questionnaire and survey methods	 Found	Daylight levels/intensity (illuminance levels) lux	View clarity effect, sleep quality and productivity
8	Pesenti et al., 2015	Computational methods using simulation	 Found	Daylight levels/intensity (illuminance levels) lux (visual comfort)	Not found
9	Sheikh & Asghar, 2019	Computational methods using simulation	 Found	Daylight levels/intensity (illuminance levels) lux (visual comfort)	Not found
10	Jayathissa et al., 2018	Computational methods using simulation	 Found	Daylight levels/intensity (illuminance levels) lux (reduce solar heat gain)	Not found
11	Mahmoud & Elghazi, 2016	Computational methods using simulation	 Found	Glare index (visual comfort)	Not found
12	Tabadkani et al., 2018	Computational methods using simulation	 Found	Daylight distribution patterns (uniformity) (visual comfort)	Not found

13	Rafati et al., 2024	Computational methods using simulation	 Found	Useful daylight autonomy (UDI)	Minimising energy use intensity and maximizing daylight use.
14	Kim et al., 2024	Computational methods using simulation	 Found	, Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)	Enhancing daylight performance
15	Abdelrahman et al., 2024 (Proposed by author)	Computational methods using simulation	 Found	Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), Useful daylight autonomy (UDI) and Daylight Glare Probability (DGP)	Minimise Glare issues and Annual sunlight exposure (ASE), Maximise View access.

2-4-2-2Metrics for Measuring Daylight and View Quality in Related Studies

1. Daylight quality and shading systems

The purpose of daylight visual effects studies is to quantify the amount of light in a given space for task performance studies, while daylight studies assess the quality of light (colour, intensity, distribution and uniformity) and its impact on the satisfaction, impressions, cognition and behaviour of occupants.

This type of research aimed to investigate the ability of shading systems with non-visual effects (Altomonte, 2009; Sherif et al., 2015; Elzeyadi, 2012). The shading parameters became dependent parameters, aiming to improve occupant comfort and well-being by improving daylight visual comfort aspects such as glare and distribution and occupant perception of the outside view quality that will enhance mood, perception and well-being. The complexity of this type of research that connects quantitative and qualitative measurements needs further investigation.

Altomonte (2009) studied the impact of using blinds as a shading device to improve occupant perception towards daylight quality in a workspace. This study assesses human perception and well-being by defining a framework of recommendations on types of blind configuration for different types of work. The experimental study used a sample blind as a shading device in a workspace. The experiment was conducted in two seasons, winter and summer, at 10 a.m. with a fixed orientation to the east. In the winter, glare issues arise from the low sun angle, but study participants preferred to do paper work tasks rather than screen tasks during the morning. Their perception of daylight provision and outside view makes them feel better and increase their activity. The study also tested two different blind configurations to assess the luminance ratio and colour temperature as the most critical indicators that affect occupant perception in a workspace. The most important factor in this experiment is that occupants preferred to close the blinds in summer because they already benefited from sufficient exposure to daylight; therefore, the psychological stimulation started to be inactive from the morning and it was not necessary to get so much luminance inside their workspace to feel better.

Sherif et al., (2015) illustrated how to improve daylight quality and occupant well-being in hospital patient rooms using vertical and horizontal shading devices. To achieve occupant well-being, the author introduced a parametric workflow and optimisation to achieve optimal outside view ratio and decrease the conflict aspects related to daylight. This optimisation aims to generate and evaluate different façade configurations. Based on the approach proposed in this study, a range of unconventional façade designs were generated to achieve 100% daylight both on the patient's bed and in the room, with 0% of partially daylit and overlit areas. This approach may not be suitable for assessing occupant perception in the room. However, the methodology in the study can be used to develop other strategies related to occupant perception.

Lottrup et al.,(2015) argued that there is a relationship between worker job satisfaction and the outside view content. The research findings resulted from doing an exploratory case study on six companies in Denmark to investigate the effect of visual interest and outdoor scenes on employees. A questionnaire was administered by sending emails to 402 employees asking them some questions about their satisfaction with the outdoor scenes. Although this study confirms a relationship between job satisfaction – as a subjective well-being element – and outside view content, it was limited to showing the office space proportion, level, window-to-wall ratio and façade configuration. Therefore, future studies are needed to cover this gap by relying on an actual experiment's results. This experiment could answer other questions such as 'what is the impact of the office level on the outside view content?'. Employees may have some daylight issues such as glare as a result of maximizing the window-to-wall ratio. As a consequence, a shading device is needed. That raises another question: 'How does this shading device affect occupants' feeling and satisfaction with the outside view and daylight quality inside the space?'.

2. View quality metrics

Most related studies shown in table (2-7), standards and recommendations emphasise view quality research on measuring three factors: view access, view clarity and view content; however, qualitative research studies (Elzeyadi, 2012; Konstantzos et al. 2015; Matusiak & Klöckner, 2016; Ko et al., 2021; Lin et al., 2022; Boubekri et al.,2020) confirm that following the recommendations and guidelines do not guarantee the subjective evaluation of view quality and suggest further research on the impact of installing any kind of shading on view quality that will affect the well-being of occupants. Researchers generally divide view quality research into quantitative measurements and subjective assessments. Quantitative measurements analyse how much view (access, content and clarity) is present. In contrast, subjective assessments evaluate how the view quality is perceived and how it affects occupant satisfaction, perception, cognition and behaviour. A new metric was developed by Konstantzos et al. (2015) to measure the view clarity through any fabric shading system. The results indicated that darker fabrics usually scored higher for view clarity when they had greater openness or porosity. There are two limitations in this study. The first one is that the study only used fabric shading devices to measure the view clarity; however, vertical and horizontal shading systems are the most preferred systems in hot regions (Mehmood et al., 2019). The second limitation is that the study developed a metric to only measure the view clarity through the shading device without referring to the impact of the visible view content to the outside environment (greenery, sky, context).

Some researchers used subjective methods to quantify view quality (Matusiak & Klöckner, 2016; Ko et al., 2021; Lin et al., 2022; Li & H. 2020). Matusiak and Klöckner investigated the outside view quality by asking occupants to rank some images of the outside view scenes according to their preferences. A qualitative metric was given to each view: not satisfactory, satisfactory, good and very good. In addition, a new study conducted by Ko et al. states that 'the views that windows provide from inside a building affect human health and well-being'. Their study provides a new framework for a conceptual index that can evaluate the quality of a window view by combining the three primary variables: view content, view access and view clarity:

$$View\ quality\ index\ (VQI) = V_{content} \cdot V_{access} \cdot V_{clarity}$$

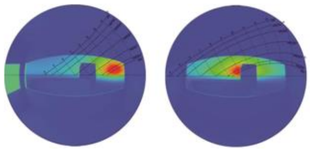
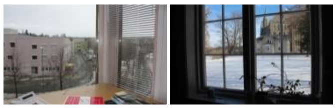
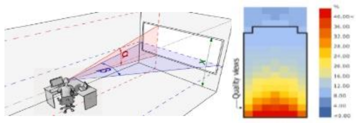
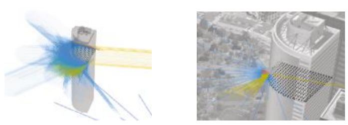
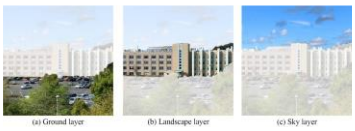
Some other researchers used a quantitative approach based on simulation and optimisation results to quantify view quality (Bluyssen, 2009; Hellinga & Hordijk, 2014; Turan et al., 2021; Lee & Matusiak 2022). A new method was developed by Hellinga and Hordijk to describe the relationship between daylight and view access through a window by showing the view through a window to the outside environment and referring to the sun's position using the 180-degree equidistant projection technique. A view quality score was calculated by answering a series of questions related to different outside view scenes. Li and Samuelson examined the urban and environmental fields, but they used a new digital method to quantify the outside view content using Cesium platform (version 1.78), Tensorflow (version 2.4) and Python (version 3.6). Their study opened the gate to the wide benefits of analysing view content using digital tools that are considered a missing part in previous research. New research conducted by Pilechiha et al., (2020) provided a method of optimising outside view access with daylight quality received using a multi-optimisation simulation technique. The results revealed that several factors should be considered simultaneously when measuring view quality, including view access, view angles, FOV and view depth.

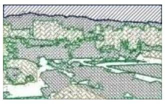
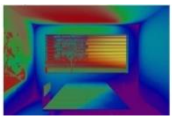
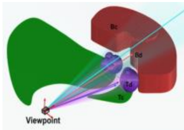
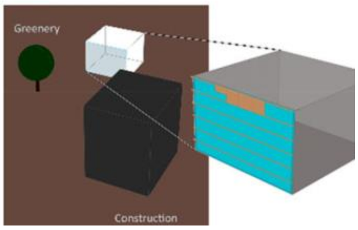
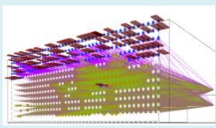
Lin et al. (2022) provided a new mixed method for measuring outside view content based on quantifying three different factors: (i) view composition, (ii) horizon layers and (iii) for elements of the landscape to be at a distance of no more than 50 metres. Their study used a qualitative approach and asked participants to rank some outside view images according to their preference. Their method was based on desktop analysis using computer-aided design (CAD) software to calculate the view content area in each picture without taking into consideration the shading configuration.

Turan et al. (2021) proposed a spatially distributed view access metric for open unobstructed floor plans based on calculations from viewpoints throughout an indoor space. An extensive computer simulation process is required to trace rays to all outside elements; therefore, the outdoor environment needs to be fully built, which will take more time, cost more to be finished and more work is needed to get accurate results. In another study to tackle this issue, Lee & Matusiak (2022) proposed a new approach to quantify view quality based on rendering photorealistic views of the outdoors for windows with shades. However, this method seems to be not simple; the results rely on participant opinions to rank the rendered images and rendering virtual images needs the outside environment to be fully built using 3D models (trees, context, ground), the same as the method by Turan et al. (2021). Lee and Matusiak (2022) also recommend that future research is needed to better understand how shading can affect view quality and discomfort glare, which are related to occupant comfort and WP.

Assessing the quality of a view in an image involves several steps in image processing. Jaeha et al., (2022) developed a new tool to evaluate occupant view satisfaction through windows. The author used a machine-learning (ML) method to train a tree-regression model to predict view satisfaction. The data needed to train the proposed system was results from a 181 participant view satisfaction survey with 590 window views. Furthermore, the authors developed a new tool that extracts only view content from 3D CAD models. Rizi et al., (2024) developed a new design methodology for adaptive façade design that includes occupant and view content to the outside. The methodology involves modelling environments, capturing images from hypothetical occupants' locations, and using a machine-learning (ML) processing to analyse view content. However Rizi et al., and Jaeha et al., used image processing language but they still need to build a full 3d model for the outside environment to evaluate the view content (Table 2-7).

Table 2-7: View quality assessment in related studies (Source: author)

Researcher	Methodology	Method	View quality assessment
Hellinga & Hordijk, 2014	Quantitative: Simulation		View quality scores range low to high ≥ 8: high 5 to 7: medium ≤ 4: low
Elzeyadi, I. 2012	Mixed method: Experimental (HDR), Questionnaire and survey methods		Subjective assessment to measure Satisfaction with content.
Matusiak, B. S., & Klöckner 2016	Qualitative: Questionnaire and survey methods		Subjective assessment: 1: not satisfactory 2: satisfactory 3: good 4: very good
Boubekri, M. et al., 2020	Qualitative: Questionnaire and survey methods		- Subjective assessment to the view clarity.
Li & Samuelson, 2020	Quantitative, Computer-aided design tools (CAAD).		Subjective assessment to view content: -100: undesirable views -100: undesirable views - 50: remained views
Peiman Pilechiha, 2020	Quantitative: Simulation		View access and view content to the sky
Turan et al., 2021	Quantitative: Simulation		Ray tacking method to all outdoor environment elements, a full 3d model is needed.
Ko et al., 2021	Qualitative: Questionnaire and Computer-aided design tools (CAAD)		Subjective assessment View Quality Index (VQI), ranges 0 to 1

Lin et al., 2022	Qualitative: Questionnaire and Computer-aided design tools (CAAD)	 	Quantitative Element analysis, Layer ration % Green, Sky, Building, far objects.
Lee & Matusiak, 2022	Quantitative: Simulation	 	Rendering images and subjective evaluations to render output. View clarity
Jaeha et al., 2022	Quantitative: Simulation and machine learning	 	View access and view content.
Cho et al., 2023	Qualitative: Questionnaire and survey methods	 	Assessing dynamism in view content.
Yao et al., 2024	Qualitative: Questionnaire and survey methods		View content.
Rizi, et al., 2024	Quantitative: Simulation		View access and view content.
Proposed method by the author (Abdelrahman et al., 2023b)	Quantitative: Image sampler using series of visual scripting analysis	 	Visible outside view content [VOV] VOV greenery ratio, VOV context ratio, VOV sky ratio, VOV blind ratio (for shading)

2-4-2-3Multi-objective Optimisation Systems Related to Daylight Simulation

1. Daylight Simulation

Daylight simulation is a process that aims to evaluate the quantity and distribution of daylight in a space. Wong (2017) reviewed various methods to evaluate the daylight performance of buildings, including scale models with a simulator, mathematical models, full-scale models for field measurement and computer simulation software. This extensive literature review evaluated the strengths and weaknesses of each method and found that the computer simulation method is the most commonly used in the building design stage because of its capability of involving several design variants in the simulation and obtaining accurate results at the same time. Wong (2017) also found that Radiance, Adeline, DOE, Daysim and Energy Plus were the most used programs. Yu & Su (2015) also indicate that the ray-tracing and radiance daylight algorithm was the most used in daylight-related research topics.

2. Optimization

The experimental approach is considered one of the most common approaches used in research to get the optimal solution for a design problem by defining variables, dependent and independent, and then making a comparison between different groups. One of the disadvantages of the experimental approach is that the researcher seeks to find the best solution for their design problem but may not explore all solutions due to time limitations and cost (Mahmoud & Elghazi, 2016; Pilechiha et al., 2020). Optimisation can provide more flexibility and control to all design parameters in the virtual model. Optimisation is the process of making a trading system more effective by adjusting the variables used for technical analysis (Corne & Bentley, 2001).

The optimisation system has the ability to run a complex mathematical process to select the optimal solution that achieves the design objectives. The advantage of using optimisation is that the designer can explore a wide range of solutions efficiently in a limited time; however, it is a challenge for the designer to formulate the variables in a mathematical sequence. One of the common methods used to formulate design problems is implemented by using parametric design (Corne & Bentley, 2001). Parametric design can be used to code a mathematical equation using the visual programming language. In computing, a visual programming language (VPL) is considered a visual programming system that gives the users the ability to manipulate their design variables graphically rather than by specifying them textually. In any optimisation system, two kinds of data are required: variables and objective functions that drive the system. Variables are the parameters that can control the design elements such as controlling the geometry shape, daylight levels, shading parameters, window-to-wall ratio or location. Objective functions are the values that drive the system through proposed assessment criteria to find the best solution for the designers (Machairas et al., 2014).

There are two types of optimisation systems: (1) two-objective optimisation systems and (2) multi-objective optimisation systems. In the two-objective optimisation system, designers try to find the optimal solution by implementing two objective fitness functions such as minimum heat gains and maximum window-to-wall ratio. The two-objective systems are based on the weighted sum approach by defining a scale for each goal and then multiplying the weight for each objective to find the best solution (Deb, 2008). This approach is not complicated and is easy to formulate because the designer only deals with two fitness objectives. In the second type of optimisation system, the multi-objective optimisation system, genetic algorithms show strong advantages in solving multi-objective problems (Nguyen et al., 2014).

In an extensive literature review, Nguyen et al., (2014) found that many types of algorithms can be developed and they classified them as follows: (1) local or global methods, (2) deterministic or stochastic methods, (3) heuristic or meta-heuristic methods, (4) derivative-based or derivative-free methods, (5) bio-inspired or non-bio-inspired methods, (6) trajectory or population-based methods, and (7) single-objective or multi-objective methods. Nguyen et al., (2014) found that a genetic algorithm was the most commonly used to evaluate building performance.

3. Genetic Algorithm

In the designing process, ‘problems’ are often defined as related to ideas used to determine ‘solutions’ by setting out a thinking model of the ideal design process that will lead the designer to achieve the optimum solutions (Cross, 2023). The traditional design process follows a linear process of exploration of a problem and solutions to this problem that will lead to an adequate outcome (Schönborn & Junge, 2021). The experimental approach, on the other hand, is considered one of the most common design processes used in research to get the optimal solution for a design problem by defining variables and then making a comparison between different groups (Fig. 2-12).

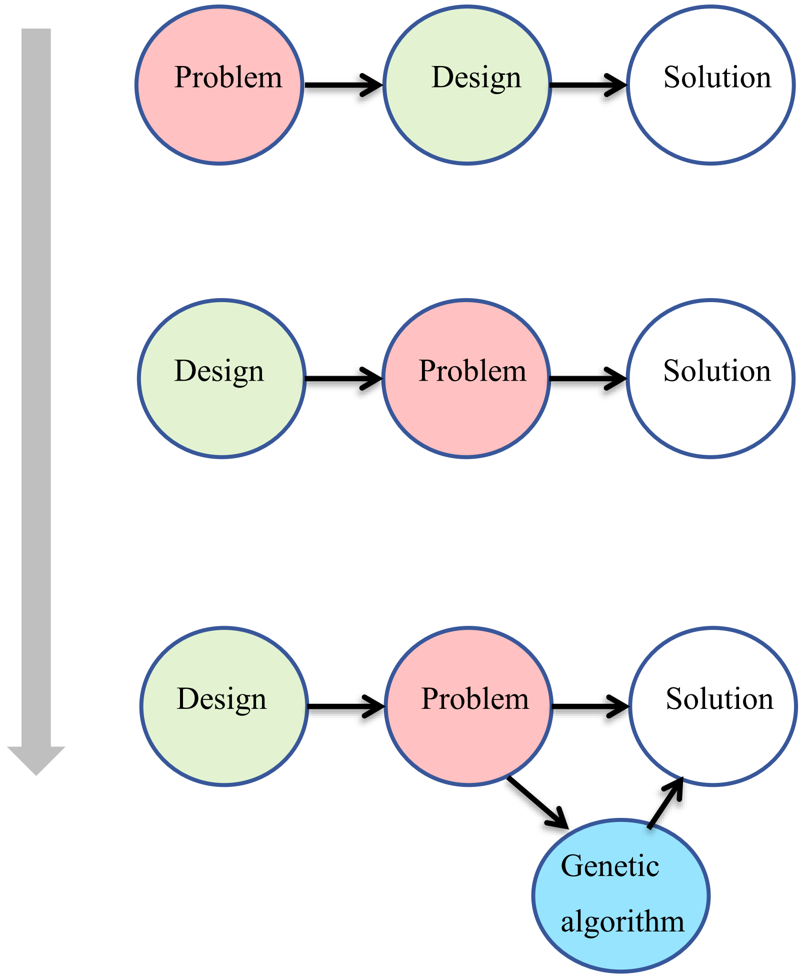


Figure 2-12: Genetic algorithm role. (Adapted from Schönborn & Junge, 2021)

Genetic algorithms (GAs) were developed by John Holland in an attempt to explain the adaptive processes of natural systems and to design artificial systems based upon these natural systems (Holland, 1984). The genetic algorithm, today, is probably, the most widely used of evolutionary algorithms (EAs). Having become widely used for a broad range of optimisation problems in the last 15 years (Holland, 1984), the GA has been described as being a 'search algorithm with some of the innovative flair of human search' (Goldberg & Holland et al.,1988). A GA makes use of two separate spaces: the search space and the solution space. The search space is a space of coded solutions to the problem, and the solution space is the space of actual solutions. Coded solutions, or genotypes, must be mapped onto actual solutions, or phenotypes before the quality or fitness of each solution can be evaluated (Fig. 2.13). GAs maintain a population of individuals, where each individual consists of a genotype and its corresponding phenotype. Phenotypes usually consist of collections of parameters and genotypes consist of coded versions of these parameters. A coded parameter is normally referred to as a gene, with the values a gene can take being known as alleles.

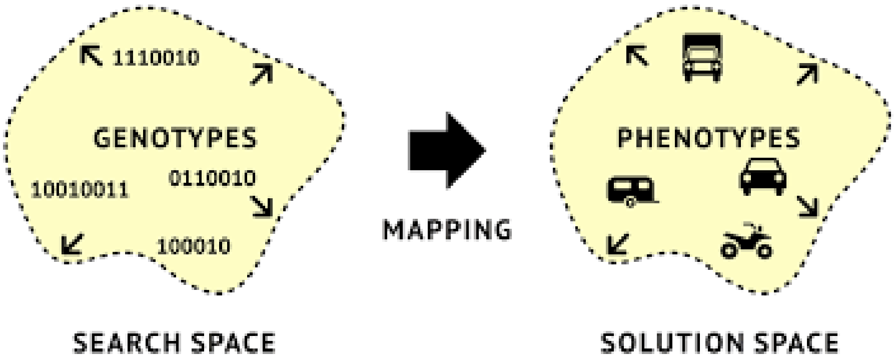


Figure 2-13: Mapping from search space to solution space (source: Corne & Bentley, 2001).

4. Advanced Genetic Algorithms

It is in the nature of complex problem-solving that we can never guarantee that an evolutionary algorithm or any other algorithm will find an optimal solution in a reasonable time. The importance of using Multi-objective GAs is that it allows multiple objectives to be optimised with GAs (Corne & Bentley, 2001). Evolution strategy (ES) means that there is no use for a crossover operator and the selection process is somewhat simplified. The entire algorithm begins with the generation and evaluation of an initial random solution. Mutation plays an important role in ES and is regarded as the primary search operator. There are some significant differences between evolution strategies and genetic algorithms. For example, although ES maintains populations of solutions, it separates the parent individuals from the child individuals. In addition, as mentioned above, ES does not manipulate coded solutions like GAs.

Due to the conflicts among objectives, a multi-objective optimisation problem (MOP) usually does not have a single optimal solution for all objectives but trade-off optimal solutions known as Pareto-optimal (P-O) solutions (Deb, 2008; Corne & Bentley, 2001). Classical methods transform the MOP to a single-objective optimisation problem by constructing aggregation functions and obtaining one P-O solution at a time. Multi-objective evolutionary algorithm (MOEA) is the main method to solve MOP. EA is a heuristic search algorithm, which has been successfully applied in the field of multi-objective optimisation (Corne & Bentley, 2001), and these EAs are called MOEAs. Population-based search and information exchange among individuals are the two characteristics of EA. It can obtain multiple P-O solutions in a single simulation run and does not have to know the derivative information or aggregate different properties, which effectively overcomes the limitations of the classical method.

In architecture, there are two methods to create a new genetic algorithm: (1) custom programmed and (2) optimisation packages (Machairas et al., 2014). The custom programmed method is the most flexible one but it needs more advanced programming skills to be produced (Chantrelle, et al., 2011). The optimisation packages are the most used to produce a genetic algorithm because the user can formulate their problem using VPL using the Grasshopper plugin Rhino as a cutting-edge parametric modeling tool that works with Rhino to allow a powerful and efficient new way of designing. Grasshopper is used by many researchers as a parametric engine that can be used to formulate the genetic algorithm (variables and objectives) to solve their design problems, such as achieving the recommended level of daylight illuminance and address the glare issue at the same time (Fig. 2-14).

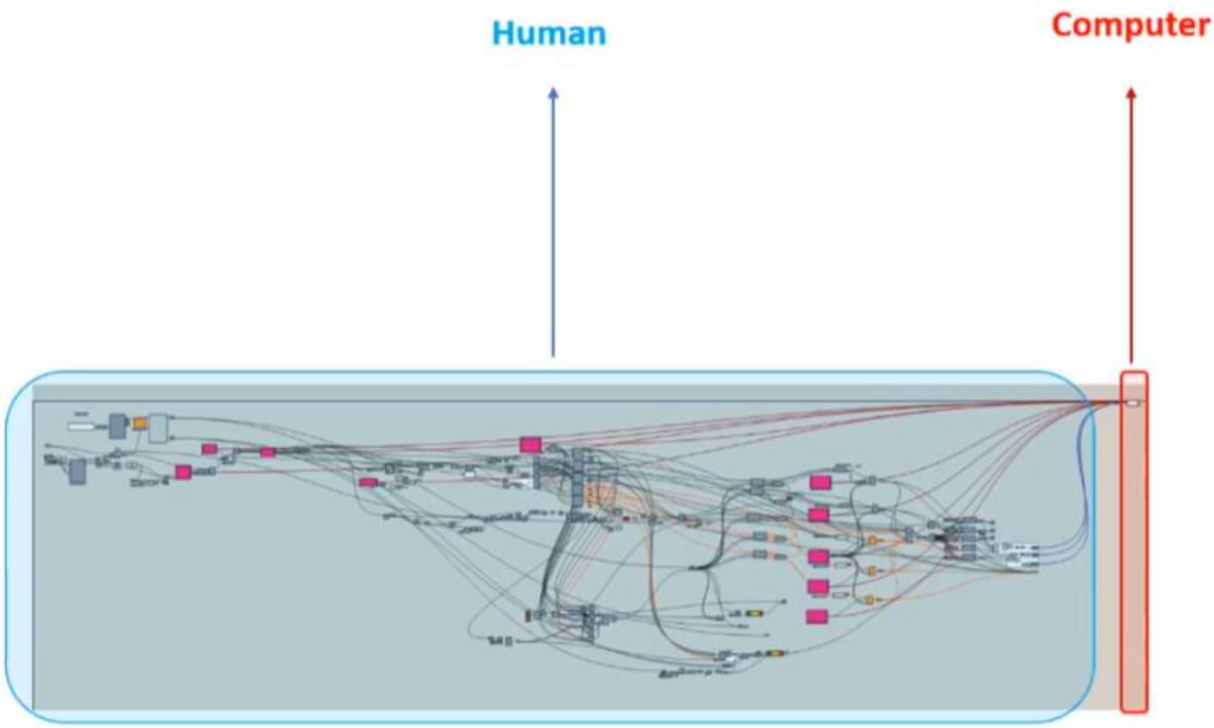


Figure 2-14: Human role and computer role. (Source: Author)

A genetic algorithm or evolutionary algorithm is a system inspired by a natural biological evolutionary process (Corne & Bentley, 2001). This algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction in order to produce offspring. Nature uses principles that can be observed to modify a population of solutions over time, such as selection, crossover and mutation.

The present research uses multi-objective evolutionary algorithms (MOEAs) to solve and optimise multi-conflicted objectives together in one system. These conflicted targets in this research are related to daylight quality, outside view quality and shading parameters. Wallacei plugin for Grasshopper, provided by Makki et al., (2022), is used in the optimisation process as it has the ability to optimise up to four objective fitness values.

5. Review of Optimisation System Objectives in Related Studies

Among the recent studies about daylight optimization, Evins (2013) found that the genetic algorithm is the most common strategy used in the optimisation process as it was used in nearly 60% of all related studies. The use of optimisation in design started in 1980, but most research and studies about using mathematical optimisation and energy performance simulation for building design were only published since 2000. Designers of the optimisation process seek to find optimal solutions by using parametric design variables and quality to work together as a system.

Many studies used the multi-objective system to optimise daylight with the internal environment using building morphology (Showkatbakhsh & Makki, 2022), window properties (Elzeyadi, 2012; Hellinga & Hordijk, 2014) and shading systems (Sherif et al., 2015; Eltaweel et al., 2020; Lee & Matusiak 2022) as independent variables to achieve the daylight level. Regarding building morphology, Zhang et al. (2016) developed a new approach for optimising the shape of free-form buildings according to the efficiency of the indoor environment and outdoor solar radiation. Also, Caruso & Kämpf (2015) developed an optimisation process for the building form to achieve the minimum rates of energy consumption that arise from solar irradiation. The optimisation process depends on calculating the total solar irradiance that falls in the building envelope and tends to change the shape and form of the building to have the minimum values. An evolutionary algorithm was used as an optimisation tool to identify the best solution.

Regarding window properties, Azari et al. (2016) adopted an optimisation process depending on the genetic algorithms for optimising window properties for building performance. In their study, the optimisation process depended on many design variables such as window type, window material, window-to-wall ratio, insulation material properties and thermal resistance of the building envelope. Carlucci et al., (2015) proposed an optimisation process of window properties for a residential house in Italy. The study aimed to minimise the visual discomfort that arises from either unsuitable daylight levels or glare and to minimise thermal discomfort during summer and winter. The optimisation variables for this study included window type, window-to-wall ratio, wall type, shading devices strategies, glazing material properties, roof material properties and floor material properties. Lartigue et al. (2014) proposed a new methodology for optimising building envelope to maximise daylight and maximise cool or heat loads in the space. The optimisation variables were assigned to both the window type and window-to-wall ratio of the space.

Many studies investigate the ability to optimise shading with daylight by considering shading parameters as dependent values to control daylight quality. Ercan & Elias-Ozkan, (2015) used multi-objective optimisation to identify the optimal dimension and properties of shading devices in offices. The main objective of the optimisation process was to achieve the maximum level of daylight in the office building and decrease the heat gains inside the space. Mahmoud & Elghazi, (2016) conducted an experiment using virtual reality to assess daylight performance by achieving the optimal design proposal for a kinetic envelope design.

As shown in Figure (2-15), related studies are divided into three types: the first type focuses only on assessing daylight and view quality; the second focuses on daylight and shading design; and the third type focuses on daylight, view and shading devices in some cases. Most studies focus on only two factors such as daylight and outside view or daylight and shading systems, neglecting the important role of the shading systems that can optimise and control both daylight and view quality. Therefore, there is a need to design a system that can combine these three factors: daylight quality, view quality and shading design. The present study aims to assess and improve daylight and outside view quality by using shading systems as a means to establish potential comfort and well-being inside the working space.

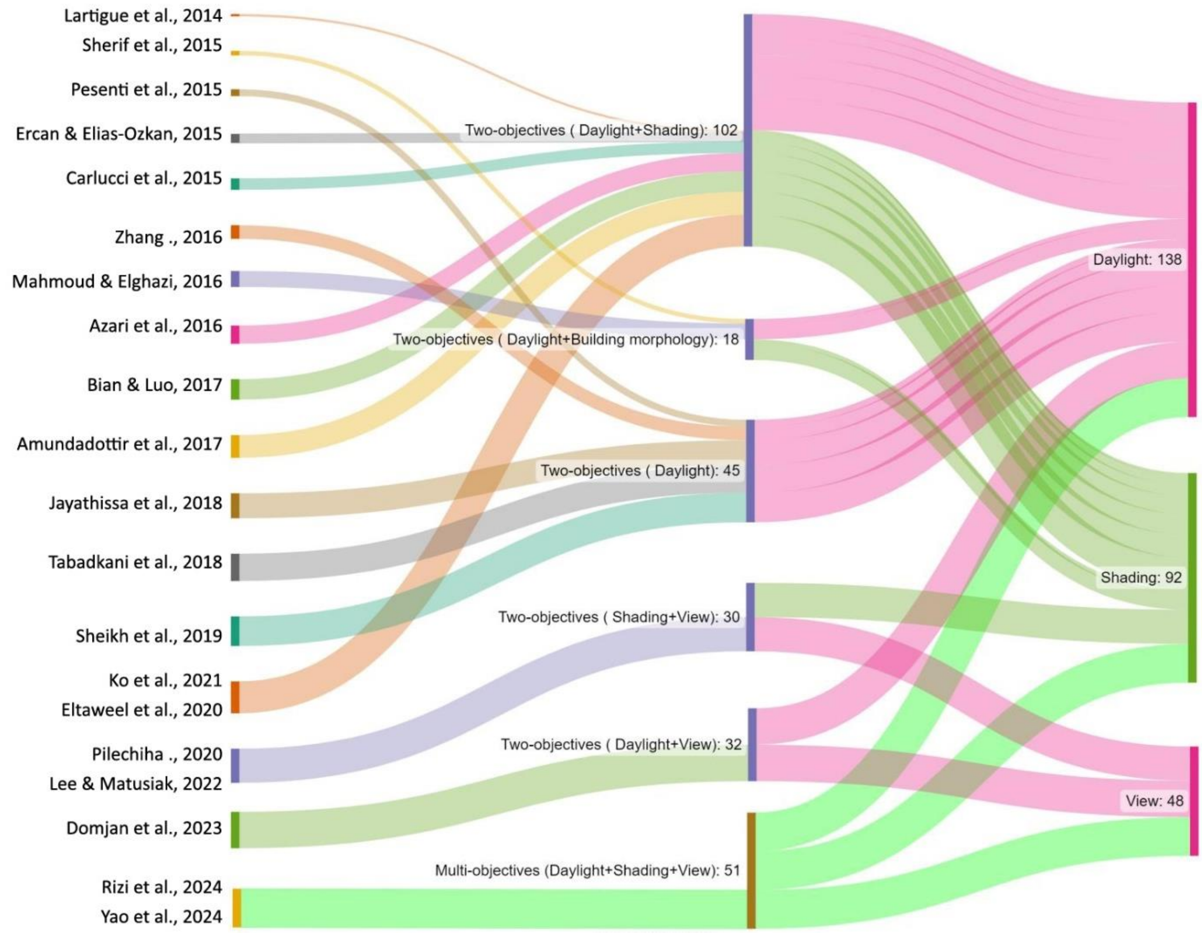


Figure 2-15: Multi-objective systems in related studies and the systems proposed in the present study (Source: author).

6. Application and Software Limitations to Quantify VOV

There are a few applications and software in the market that are designed to be used by engineers and architects to assess view quality. Each application is designed to assess some elements using a different platform. For instance, the DIAL+ software, developed by Estia SA (BEST Directory, 2022), is a dedicated tool for evaluating view quality. It uses a method that calculates the ratio of visible sky area accessible through window openings, similar to the approach used by the Integrated Environmental Solutions Virtual Environment (IES, 2022). The difference between DIAL+ and IES VE is that DIAL+ can optimise between shading parameters and view to sky ratio, and thermal and daylighting levels, but this optimisation is limited to application capabilities (Table 2-8).

Table 2.8: Multi-objective systems in related studies and the systems proposed in the present study (Source: author)

Researcher	System	Fitness Objectives	System objectives			
			Daylight	Building I	Shading	View
Sherif et al., 2015	Two objectives using Simulation methods	Developing solar screens for use in front of windows under the clear desert skies.	✓		✓	
Lartigue et al., 2014	Three-objectives using Multi-objective optimisation	Maximizing the daylight and minimising cool and heat loads in the space.	✓	✓		
Pesenti et al., 2015	Two objectives using Simulation methods	Daylight levels/ intensity (illuminance levels) lux (Visual Comfort)	✓			
Ercan & Elias-Ozkan, 2015	Two objectives using Multi-objective optimisation	Optimal dimension and properties of an office building shading device.	✓		✓	
Carlucci et al., 2015	Two objectives using Multi-objective optimisation	(Two objectives)- Improve thermal and visual discomfort	✓			
Zhang ., 2016	Two objectives using Multi-objective optimisation	(Two objectives)-- New approach for optimising the shape of free form.	✓	✓		
Mahmoud & Elghazi, 2016	Two objectives using Simulation methods	(Two objectives)- Investigated the best performance of daylight and shading systems	✓		✓	
Azari et al., 2016	Two objectives using Multi-objective optimisation	(Two objectives)— Daylight quality and improve the performance of building envelope design	✓		✓	
Bian & Luo, 2017	Two objectives using Multi-objective optimisation	(Two objectives)- Improve daylight levels for office space in hot arid by optimising the best skin configuration.	✓		✓	

Amundadottir et al., 2017	Two objectives using Multi-objective optimisation	(Two objectives)- Daylight exposure and distribution (uniformity) to improve Sleep comfort/ visual interest and impressions in space.	✓		✓	
Jayathissa et al., 2018	Two objectives using Simulation methods	-Daylight levels/ intensity (illuminance levels) lux (Reduce solar heat gain)	✓			
Sheikh et al., 2019	Two objectives using Simulation methods	Daylight levels/ intensity (illuminance levels) lux (Visual Comfort)	✓			
Tabadkani et al., 2018	Two objectives using Simulation methods	Daylight distribution patterns (uniformity) (Visual Comfort)	✓			
Eltaweel et al., 2020	Two objectives using Multi-objective optimisation	Improve daylight distribution using automated prismatic louvres	✓		✓	
Pilechiha ., 2020	Two objectives using Simulation methods	View access and view content to the sky			✓	✓
Ko et al., 2021	Two objectives using Computer-aided design tools (CAAD)	View content and context			✓	✓
Lee & Matusiak, 2022	Two objectives using Simulation methods	Rendering images, subjective evaluations to View clarity and daylight	✓			✓
Domjan et al., 2023	Three-objective optimisation using genetic algorithms.		✓		✓	✓
Rizi et al., 2024	Two-objective optimisation using machine learning.	Evaluate view content and location using machine learning				✓
Yao et al., 2024	Two objectives, window design and the outside view.	Subjective evaluation for one objective using VR		✓		✓
Qi et al.,2024	Two- objective optimisation using Machine learning	Subjective evaluation factors regarding visual effects of daylight				✓

Proposed system By Author October 2022	Three-objective optimisation using genetic algorithms.	(Three objectives)- Improve daylight quality aSE, SDA and UDI and 5- visible outside view (VOV) using automation shading systems.	✓		✓	✓

The lack of consideration of obstruction elements such as shading devices to outside view may be explained by the difficulty of measuring this factor. Currently, a few software in the market, such as ClimateStudio (ClimateStudio Solemma, 2022) and CoveTools (Cove.Tools, 2022), measure view quality according to LEED version 4.01 (LEED v4, 2019) and EN 17037 (CEN, 2018), with the function to measure blind factor via the visible view access to the outside, but shading device is not connected to the VOV content (greenery, art, context, sky) (Table 2-9).

Table 2-9: Applications used to assess daylight and view quality

Application	Developer	Type	Platform	Elements	Outside view input
DIAL+ software	Estia SA	Software	Application	Only sky	Sky ratio
ClimateStudio	Solimane	Plugin	Rhino and Grasshopper plugin & Revit	Green, sky, movement, art, landmark	3D modelling
IES VE	IES Ltd	Software	Application	Only sky	3D modelling
Cove.tool	Covetool company	Software	Application	Sky, Context , Unobstructed View	3D modelling
Multifactor system	Author	Visual programming scripting workflow	Rhino and Grasshopper plugin	Green, sky, , art, landmark	Image sampler

2-5 Literature review findings

The literature review studies were investigated under three categories: (1) well-being themes, (2) shading system functions, (3) daylight rating systems and metrics. In addition, the following analysis will identify the gaps in literature found in focus of each study, methods and metrics, according to occupant well-being.

The literature showed that evaluating the outside view quality is often based on questionnaire results (Fig. 2-16, 2-17). In some cases, these questionnaires ask participants to rank pictures to different outside views (Hellinga & Hordijk, 2014; Elzeyadi, 2012, Rohde et al. 2020). In other cases, an indicator is given to each natural element. Then each outside view composition takes an overall indicator that shows the amount of sky, green, water, etc., as observed by the surveyors or researcher (Turan et al., 2021; Hellinga & Hordijk

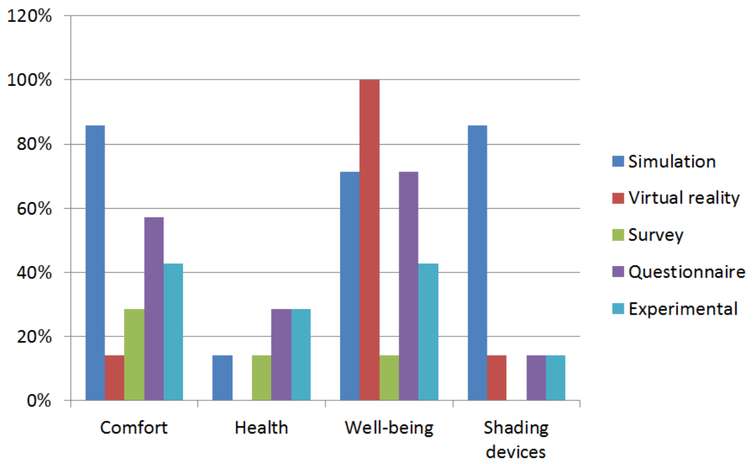


Figure 2-16: Relationship between methods and focus of study.

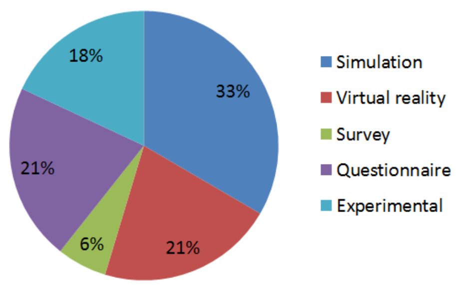


Figure 2-17: Focus of study ratio

In addition, the literature shows little interest in studying shading devices to improve occupant well-being. Few studies focus on shading devices and daylight improvement simultaneously and few studies discuss how shading devices could affect the occupant's well-being (Jamrozik et al. 2019; Boubekri et al. 2020). This effect is assessed by improving visual interest or satisfaction with ambience or the amount of outside view.

The impact of daylight, comfort and well-being on occupant feeling and satisfaction has been the subject of several studies (Elzeyadi, 2012; Amundadottir et al., 2017; Boubekri et al., 2020; Jamrozik et al., 2019; Fathy et al., 2020). This literature review shows that more than 50% of these studies use satisfaction with ambience and amount of view as an indicator to quantify occupant perception and most researchers who want to evaluate the impact of daylight on occupant feeling and satisfaction aim to quantify visual interests and impressions (Fig. 2-19). In addition, the majority of the literature focuses on glare issues to quantify occupant comfort (Fig. 2-18).

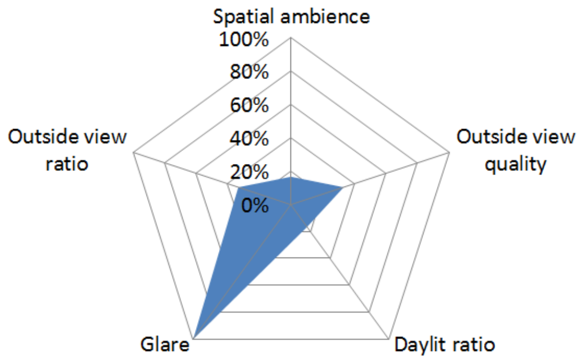


Figure 2-18: Research gap in comfort parameters.

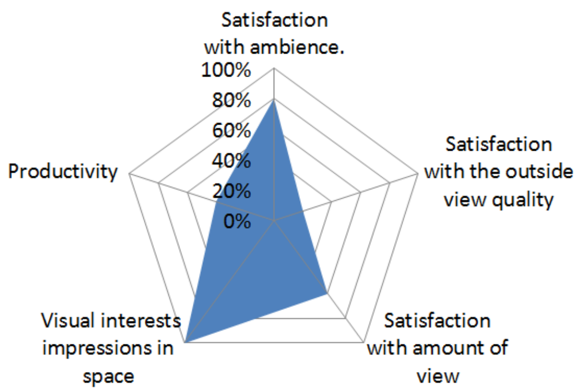


Figure 2-19: Research gap in well-being parameters.

2-5-1 Gaps in Metrics to Quantify View Quality Related to Shading Systems

It is evident in the reviewed literature that outside view content has been measured using quantitative and qualitative methods (Table 2-7). The review showed that evaluating the outside view content is often based on questionnaire results by asking participants to rank some pictures to different outside views (Matusiak et al., 2020; Ko et al., 2021; Lin et al., 2022; Li & Samuelson., 2020; Domjan et al., 2023; Yao et al., 2024). In other cases, an indicator was given to each natural element to assess the quality of outside view content using computational methods (Pilechiha, 2020; Hellinga & Hordijk, 2014; Turan et al., 2021). Limited studies provide a qualitative method to measure outside view quality based on ray-tracking simulation methods or render photorealistic views (Lee& Matusiak, 2022; Jaeha et al., 2022; Rizi et al., 2024). Most researchers evaluate view quality by analysing the geometry outside using 2D CAD-aided design tools. There are drawbacks to each method; using ray-tracking methods requires the outdoor environment to be fully built into the simulation software which will take more time and may cause a system crash to run the simulation depending on the machine's capability. Also, the measurement accuracy is still based on the outside build accuracy to match the context of the real environment such as tree scale and position and also the surrounding buildings. The recently proposed method provided by Lee& Matusiak, (2022) aims to evaluate the outside content based on rendering the internal scene and then evaluate this scene by asking participants to rank their photos. In Lee's study, the render photorealistic views method will replace the ray-tracking method provided by Turan et al., (2021) but both methods have the same drawback which is related to the time consumed and level of accuracy needed to build the outside view environment (trees, context, arts and the faraway objects).

There is no research found yet to combine outside view content and clarity in one metric. However, view clarity and view content are related to each other as conflicted targets, but most researchers only focus on assessing view quality factors (content, clarity and access) separately. In this study, a new facilitation tool was defined to quantify the outside view quality based on combining view content and view clarity together in one indicator called visible outside view (VOV).

The assessment criteria will follow LEED v.01. Also, a new method will be applied to quantify the outside view quality based on the Image Sampler method with an index representing the visible outside view (VOV) content. This metric can quantify the view quality by combining visible view content and visible view clarity in one metric (VOV SKY, Green, Mass + Blind ratio).

2-5-2 Gaps in Systems to Integrate Daylight Quality, Outside View Quality and Shading Systems

In related studies, little attention was given to obstruction elements to outside view such as shading devices. This may be explained by the difficulty of measuring the visible outside view content (green, art, context, sky) through the shading device. However, applications outside academia are limited; some software can be used to measure the view quality with different approaches. ClimateStudio (ClimateStudio by Solimane, 2022) and Cove.tools (Covetool Company, 2022) are considered one of the most beneficial tools that measure view analysis and daylight quality according to LEED v4.01 and EN 17037. ClimateStudio software can measure the blind factor to the outside view but it is not connected to the actual visible outside view content. That means the blind factor is only used to measure the view access ratio, not the visible view content ratio. The present research assumes that this factor should be added to view quality assessment criteria in building rating systems.

The literature review shows that there is no tool, application or software found yet to integrate daylight quality, outside view quality and shading devices in an optimisation process. Therefore, to fill this gap, a new multifactor system is needed. This study produces a novel shading system by using multi-objective evolutionary algorithms (MOEAs) connecting daylight quality and outside view quality to improve and predict the level of comfort and well-being potential (Fig. 2-20).

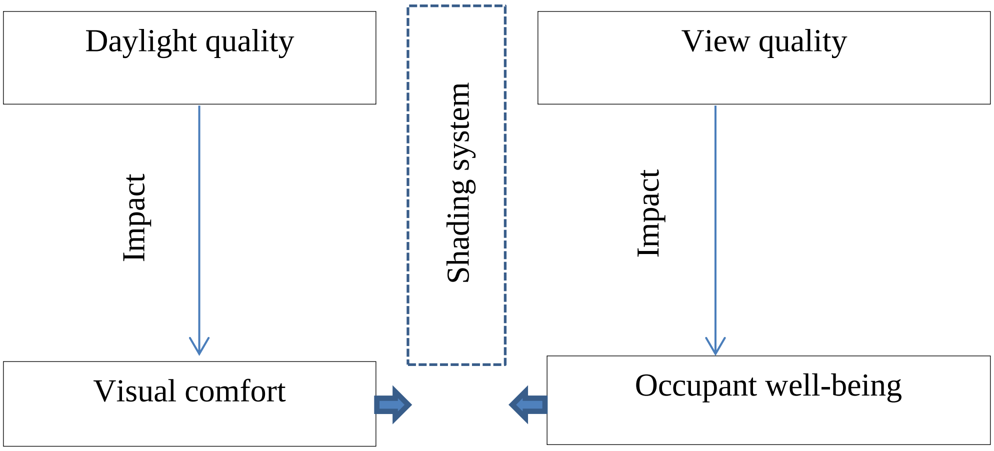


Figure 2-20: Multifactor system (DVS)

This study proposes a new multifactor system using a multi-evolutionary optimisation (MEO) method embedded with a dashboard to be used and improved in the future and to be made available in the market. This dashboard aims to combine daylight quality and view quality in one track with reefing to the optimum shading device parameters to achieve this goal. The measurements and metrics used in this system comply with the most updated assessment criteria provided by LEED v04.01.

This multifactor system consists of two levels of the multi-optimisation process. The first level occurs by using MOEAs techniques to establish the optimal daylight quality inside a working space. This optimisation defines the best shading device solutions related to five selected objectives: (1) to minimise annual sun exposure (ASE), (2) maximise spatial daylight autonomy (sDA), (3) maximise useful daylight illuminance (UDI), (4) maximise view access, and (5) minimise daylight glare probability (DGP).

After that, a new parametric algorithm is defined to create the facilitation tool to quantify the visible outside view (VOV) ratio while using the optimised shading system. This facilitation tool aims to measure the visible outside view quality by using the Image Sampler and Isovist ray-tracking technique found in the Grasshopper plugin Rhino to quantify occupants' sightlines through the shading device to the outside view content. A new indicator is produced to measure the view clarity and content together called $VOV_{Sky,\ Green,\ Mass}$. This new indicator is a percentage starting from 0% to 100% showing the well-being potential for different zones inside the workspace. The second level of optimisation aims to create a comfort and well-being potential 2D map (CW_{map}) by integrating the optimum fitness solution of the shading device (resulting from optimisation level 1) with the VOV values (resulting from the facilitation tool).

2-6 Conclusion

In conclusion, studies on occupant well-being and daylight in the workspace show a strong relationship between daylight illuminance received and outside view quality. Daylight quality for visual efficiency is determined by how it is delivered and how it is integrated with other conflicting issues such as view to the outside. Therefore, shading systems should work to not obscure the view clarity value. Most researchers have evaluated the impact of daylight on view quality and on well-being separately; moreover, the method of evaluation of the outside view quality has been often based on questionnaire results. In some cases, these questionnaires are administered by asking participants to rank some pictures with different outside views to choose the most preferred outside view content. In other cases, an indicator is assigned to each natural element and each outside view composition takes an overall indicator that shows the amount of sky, green, water, etc., as observed by the surveyors or researchers.

Several studies have focused on discussing the impact of daylight, comfort and well-being on occupant perceptions. The literature indicates that shading devices are being studied to enhance well-being of occupants. The majority of studies analysed focused on both shading devices and daylight improvement at the same time, but little attention was given to discussing the effect of shading devices or outside view quality on occupant well-being. Shading devices can improve visual interest or satisfaction with ambience. Therefore, there is a need to define a new multifactor system to investigate the possibilities of using shading systems to improve daylight quality and outside view quality inside the working environment.

Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analysing the geometry outside using 2D and 3D software. The present study shows there are drawbacks to each method; well-being is a subjective matter and the study needs to be objective to be more scientific; therefore, there is a need for both qualitative and quantitative data. In addition, using ray-tracking methods needs the outdoor environment to be fully built into the simulation software, which takes more time to complete the simulation and iteration process. Although prior research has identified a few methods that could be used in assessing view quality, both methods have the same drawbacks related to the time consumed and the level of accuracy needed to build the outside view environment (trees, buildings and other objects).

Based on the literature review findings, four types of daylight simulation have been found to measure daylight quality: (1) annual sunlight exposure (ASE), (2) spatial daylight autonomy (sDA), (3) useful daylight illuminance (UDI) and (4) daylight glare probability (DGP).

- **Regarding Daylight Quality:**
  1. ASE: 50% of the floor plan exceeds the threshold of 1000 lux with more than 250 occupied hours per year. Complies with (WELL, v2,Q1-Q2, 2024 & LEED v4.01 2019) criteria.
  2. UDI: the percentage between the periods that received adequate daylight levels per year to occupied hours in the same year between 100 lux to 2000 lux. (Complies with LEED v4.01 criteria.)
  3. DGP: it ranges from 0 to 1 and indicates whether a glare situation will be imperceptible ($DGP \leq 0.35$), perceptible ($0.35 < DGP \leq 0.40$), disturbing ($0.40 < DGP \leq 0.45$) or intolerable ($DGP > 0.45$) to a majority of occupants. (Complies with LEED v4.01 criteria.)
- **Regarding View Quality:**
  1. View Type 2: at least 75% of the regularly occupied building floor area design should achieve at least one of the following: nature, art, urban landmarks, or objects at least 25 feet (7.62 meters) from the glazing. (complies with LEED v4.01 criteria.)
  2. View Type 3: unobstructed lines of sight view location with a line of sight to vision glazing from within three times its head height and view. (Complies with LEED v4.01 criteria.)
  3. View content: the literature review failed to find a tool to measure the visible outside view content through shading devices. Therefore, there is a need to define a new facilitation tool for an analysis of visible view content VOV (green, context and sky) (discussed in Chapter 6). Also, there is a need to define a new system to integrate the new facilitation tool with daylight simulation to define the best shading parameters (discussed in Chapter 7).

CHAPTER 3: Methodology

3.1 Introduction

This chapter aims to provide a description of and a justification for the chosen research methodology to achieve the aims and objectives stated in Chapter 1. Also, it provides a review of each factor of the research methodology, such as research design, data collection and data analysis. After discussing each factor, a statement is provided to justify the research choices. A series of data analysis methods were employed to address the research question, including descriptive analysis, correlation coefficient analysis, likelihood ratio test (LRT) and network analysis. This chapter is structured as follows. The first section aims to define the research model adopted based on the onion research model (Saunders et al., 2009). Subsequent sections in this chapter provide more understanding of research choices, methods for data collection, validation and reliability techniques used in this research.

3.2 Research Model

Research methodology refers to methods of conducting research and interpreting the results (Grix, 2002). The methodology provides a general view of what the research is focused on and how to answer the research questions. It is important in this research to bind all elements of research methodology coherently (Saunders et al., 2009), allowing justification of the general pattern of research and aiming to achieve the objectives of the research. The methodology for this research must also be clearly interpreted. In this study, the onion model is being used as suggested by Saunders et al. (2009). The benefits of the research onion are that it creates a series of stages through which the different methods of data collection can be understood and illustrates the steps by which a methodological study can be described.

As indicated in Figure 3-1, Saunders et al.'s (2009) process consists of six stages:

1. Research philosophy
2. Research approach
3. Research strategies
4. Research choice
5. Technique and procedures

The following sections describe each area of research methodology.

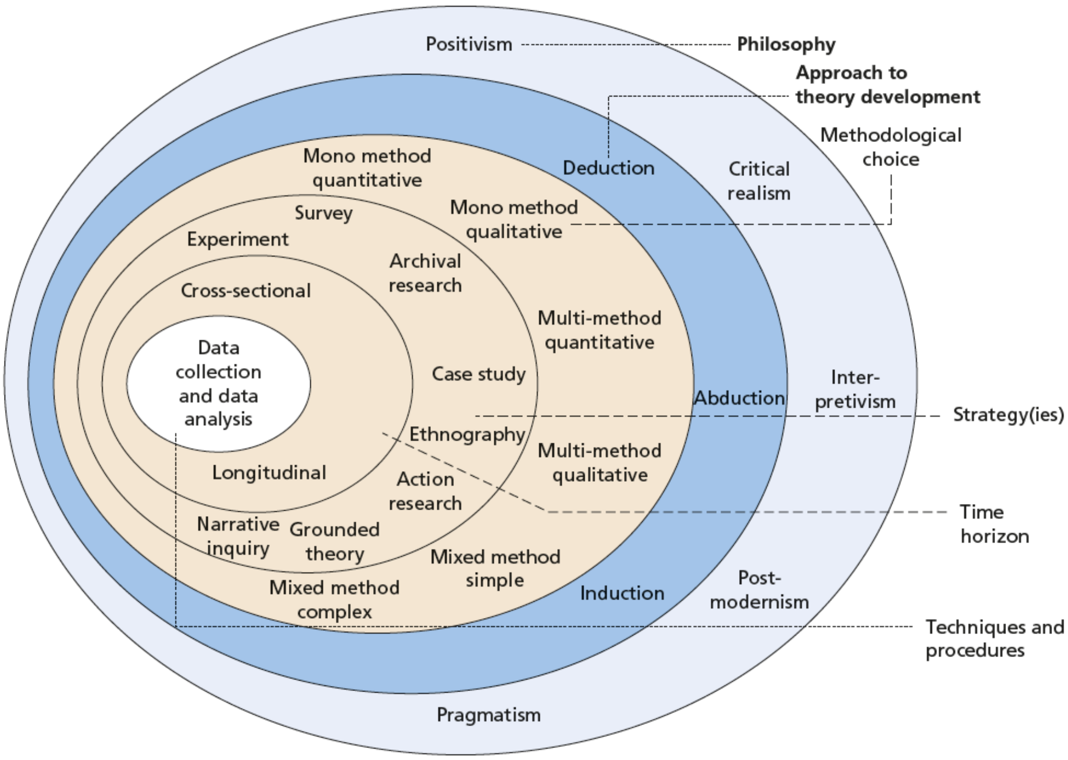


Figure 3-1: The holistic approach (Source: Saunders et al., 2009)

3-2-1 Justification for the Research Philosophy

This section provides a clear justification for the research aim, which is to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms as a means to enhance occupant comfort and well-being potential related to daylight quality and view quality (see Section 1.6.1 in Chapter 1). Saunders et al. (2009) indicate that research philosophy is a comprehensive term that relates to increasing knowledge and the nature of knowledge. Many authors argue that researchers should adequately understand the philosophy of research to apply it appropriately.

In general, defining a research philosophy has three advantages. First, it simplifies and explains the research design. Thereafter, it determines whether a design is suitable for implementation and makes a selection of tools needed. Consequently, it helps researchers to classify and generate new ideas. Saunders et al. (2009) indicate that research philosophies can be divided into three types: (1) ontology, (2) epistemology and (3) axiology (Fig. 3-2).

In the following section, these three types of philosophies will be discussed in more depth to give a clear understanding of the present research philosophy, process and tools.

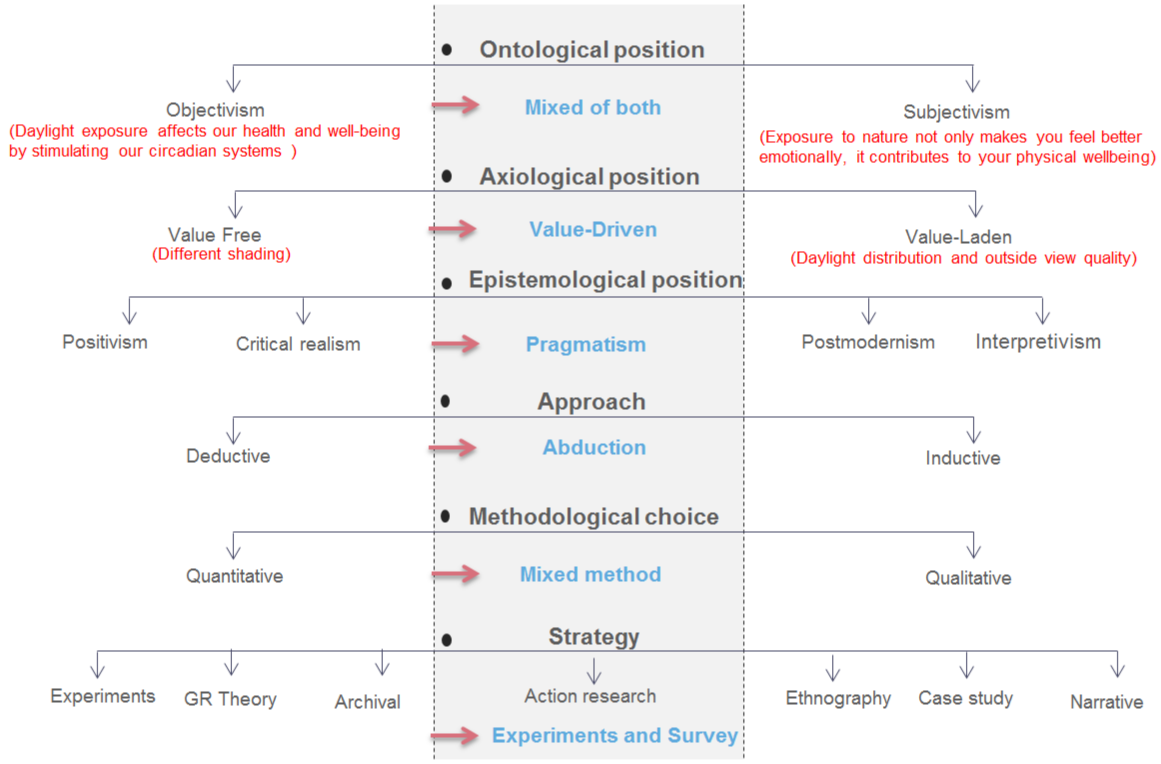


Figure 3-2: Research methodology. (Source: Author)

3-2-2 Ontology

Ontology is based on the nature of existence and reality (Lee & Cassell, 2013). At this stage, I have chosen two positions: objectivism and subjectivism. Regarding the objectivist position, the research hypotheses are based on an external reality that occurs separately from the social actors. However, the subjectivist position does not accept the idea of an independent reality. A subjectivist perspective of the humanistic and existential perspectives also emphasises the importance of subjective experiences (Saunders et al., 2012). That means subjectivism-based research is based on people's opinions and actions (Saunders et al., 2012). Regarding objectivism, there is a reality that daylight quality factors such as illuminance, glare and view outside affect our visual comfort and daylight exposure affects our well-being by stimulating our circadian system (WELL v2, Q1-Q2, 2024; LEED v.4.01, 2019). Regarding subjectivism positions, the view to the natural outside environment has a significant direct impact on occupant well-being and satisfaction (WELL v2, Q1-Q2, 2024). Therefore, a mix of both objectivism and subjectivism is appropriate for this research.

3-2-3 Axiology

Axiology is defined as the study of values, which plays an important role in the research results. This research considers three types of axiology: value-free, value-laden, and value-driven. As Lewis (1994) indicated, if the research is based on a hypothesis, then it is mandatory to conduct an empirical method of research that is also called values-free research. Conversely, interpretivism or social constructionism helps to plan the research, which is driven by a value in such a way that the researched items are interlinked. The determination of the real existence facts within the human and social world is based on human interpretation (Healy & Perry, 2000). Hence, value-free research is always determined by the criteria of objectivity. On the other hand, value-driven research is always determined by the criteria of subjectivity, human views and experiences. The present research aims to define a new multifactor system to enhance occupant comfort and well-being inside the working environment by optimising shading systems and daylight quality and outside view quality. Therefore, occupant comfort and well-being are considered a subjective approach (questionnaire) and daylight quality and shading systems need a quantitative approach (simulation). This research can be both values-free, with the use of quantitative methods measuring daylight quality, view quality and defining shading parameters, and value-laden, with the use of qualitative methods to quantify occupant comfort and well-being related to daylight and view quality.

3-2-4 Epistemology

Epistemology enables researchers to understand the nature of knowledge and how to achieve it by explaining the process of understanding the knowledge and using it to compare reality with fiction (Saunders et al., 2009). Saunders et al. (2009) indicate that there are two types of epistemological philosophies: positive and interpretative. The positivist assumption does not offer a rich and complex explanation for occupant well-being as a subjective factor because it is different in individual contexts and experiences. Critical realism is considered value-laden research, more in-depth and historically situated. Interpretivism always focuses on narratives and stories. Pragmatism is the best choice because it is based on the researcher’s doubts and beliefs, starting from the research problem and research question to the range of research methods: mixed, multiple, qualitative and quantitative.

3-3 Research Approach

There are two types of research reasoning: deductive and inductive (Saunders et al., 2012). Saunders et al. (2009) illustrate that the deductive approach is based on natural sciences, where the researcher can define a phenomenon through a set of rules and laws to organise it. Conversely, the inductive approach aims to collect data to understand the phenomenon. The inductive approach provides the best understanding of the research problem. Philosophically, the inductive approach lies at the end of objectivity and fits with the interpretation of the cognitive position. Saunders et al. (2012) advocated the application of combined inductive and deductive methodologies. The present research, based on the hypothesis that the multifactor system integrating daylight quality, view quality and shading system can improve people’s comfort and well-being potential internally, assumes that there is an association between daylight quality, view quality and shading parameters that could affect occupant satisfaction and feelings inside their working environment. An inductive approach fulfills the research aim, whereas a deductive approach detects the impact of daylight and view quality on occupant satisfaction and feelings inside their working environment. Therefore to understand each factor, the study used a mix of methods (inductive and deductive): on the one hand, to be able to explain the subjective impact of daylight quality and view quality; on the other hand, to define a new multifactor system to design the health shading systems that is considered an inductive approach.

3-4 Research Choices and Strategy

The aim of this research is to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms as a means to enhance occupant comfort and well-being potential related to daylight quality and view quality. This study has a subjective factor because the researcher selected and interpreted the results for occupant experiences of daylight impact on occupant comfort and well-being. The study needs to be objective to be more scientific; therefore, both qualitative and quantitative data are appropriate (Collis & Hussey, 2014).

Quantitative research is defined as the investigation of a social issue by choosing some variables, testing the relative hypothesis, measuring it with numbers and examining it by using statistical tools and methods to determine the authenticity of the formulated hypothesis (Creswell, 1994). Comparatively, qualitative techniques cannot be used for data collection, which is an advantage of quantitative techniques. Accordingly, qualitative research supported by quantitative methods is suggested in this study (mixed method approach), such as questionnaires.

In this study, the mixed method approach is conducted to explain the relationship between qualitative and quantitative results. The mixed method characteristics will help develop the rationale for mixing methods and integrating objective quantitative and subjective qualitative data (Creswell, 2009). Combining both quantitative and qualitative data and analysis is mandatory to answer the research question: ‘Is it possible to improve occupant comfort and well-being by defining new healthy shading systems?’

An online questionnaire, administered to collect variables that people use in the daylit zone to describe their perception of daylight and outside view quality in their working environment, helps to identify participants’ spatial cognitive map (SC_{map}) towards well-being and comfort. After that, a daylight parametric simulation will be driven based on these variables to achieve the optimal solution using shading systems. Then, semi-structured interviews will be conducted through the virtual reality experimentation process to investigate participant experiences in assessing their feelings and satisfaction towards visual comfort and daylight quality with different shading systems.

An exploratory sequential mixed research method was used in this research in four stages: (1) qualitative, (2) quantitative, (3) qualitative and (4) interpreting the connected results. The research starts with a questionnaire to collect and analyse the qualitative data to determine the terms used by occupants to describe their experience in daylit zones. In the second step, which illustrates the point of integration between dependent and independent variables, the results identified on which the quantitative simulation and optimisation process will be built by using Rhino and Grasshopper as parametric platforms. In the third step, a quantitative strand of the study is conducted to examine occupant experiences using the virtual reality method with a new sample of participants. This virtual reality experiment is conducted using Unreal software to validate and test occupant experience in a workspace built virtually to achieve the daylight standard metrics recommended by daylight standards and building rating systems. These daylight standards are extracted from the literature review stage. Finally, research results are analysed to show to what extent the multifactor system of DVS (daylight, outside view quality, shading systems) affects occupant comfort and well-being in workspaces.

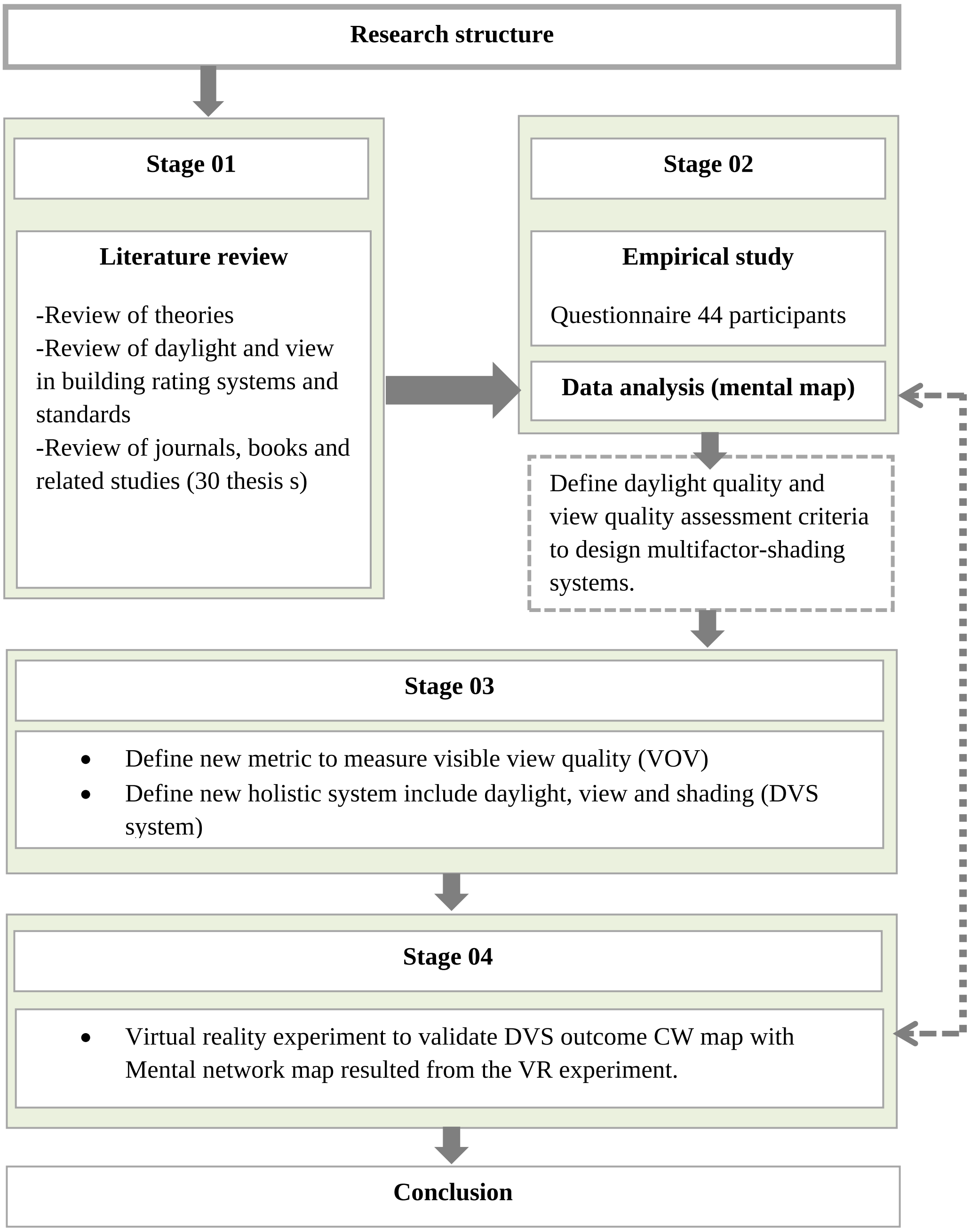


Figure 3-3: Research structure.

The four stages, adapted from Creswell and Plano Clark (2011), are as follows (Fig. 3-3):

- *First stage*: qualitative analysis for comfort and well-being in terms of daylight (online questionnaire)
- *Second stage*: quantitative analysis of daylight, outside view and shading systems (multifactor system)
- *Third stage*: Quantitative approach used to:

  - define a new facilitation tool to measure visible view quality (VOV)
  - define new multifactor system including daylight, view and shading (DVS system)
  - create a comfort and well-being map (CW_{map})
- *Fourth stage*: qualitative assessment to validate the DVS system by conducting a virtual reality experiment and interpreting participant's feelings and satisfaction with daylight and view quality to mental network map (MN_{map}) and then to be compared with the CW_{map} resulting from the DVS system.

3-5 Research Techniques

In the process of generating data, research techniques often combine qualitative and quantitative inputs (Collis, 2013). This stage aims to obtain data that is used to justify or investigate research variables and could be applied to the different research areas. There are many ways of collecting data, such as questionnaires and structured or unstructured interviews (De Vaus, 2001). In the context of this research, a new multifactor system is defined by using virtual simulation and virtual reality techniques to enhance occupant comfort and well-being potential related to daylight quality and view quality. For data collection, quantitative and qualitative documentation techniques can be used to collect and analyse data (Collis, 2013). The next section discusses how the data for this study were collected and analysed.

3-5-1 Data Collection

According to Yin (2003), there are six ways of collecting data in research: archival records, documents, interviews, direct observation, participant observation and physical artifacts. In the present study, questionnaires were used to collect the relevant preliminary data to determine the terms used by occupants to describe their feelings and well-being factors related to daylight and view quality inside their working environment. The target participants were identified from among those working in any space with access to daylight. The data were extracted qualitatively and analysed qualitatively and quantitatively using different data analysis techniques discussed in the following sections.

In the architecture field, daylight and well-being have long been recognised as potential problems in space, and many researchers try to define themes of well-being. The first stage of this research starts with a literature review to define themes of well-being in the literature related to daylight. The literature was divided into four sections.

1. The first section reviews theories and definitions about well-being and comfort related to daylight and view quality.
2. The second section reviews daylight and view in building rating systems and standards, such as CIBSE, British standard, Europe standard, IESNA standard, LEED, BREEAM and WELL Building Standards, to understand different assessment criteria used to evaluate daylight quality and view quality.
3. The third section examines related studies through a review of journals, books and related studies.
4. The fourth section shows the research gaps found in the literature.

The second stage aims to define terms and variables that affect occupants' feelings and satisfaction with daylight quality and view quality inside their working environment using online questionnaires.

After that, a quantitative analysis of daylight and outside view was conducted using Rhino and Grasshopper as a parametric platform to define a new metric to qualify view quality called visible outside view (VOV) quality. Next, a simulation and optimisation process was conducted using the DVS system which is defined as a new system to integrate daylight, outside view and shading system parameters in one optimisation process to increase the daylight quality and view quality at the same time using shading systems.

The combination of these three variables (DVS) gives a clear overview for evaluating the workspace to identify the most zones that have a good outside view and that, at the same time, achieve the standards of daylight luminance, exposure and glare. This optimisation process aims to define the optimal parameters that can be used in shading systems to improve occupant comfort and well-being on the one hand and to maximise the daylit zone on the other hand. The visualisation of these simulation and optimisation results will be used to define the comfort and well-being map (CW_{map}) to show which area has more comfort and well-being potential.

To test and validate the DVS system, an experiment was conducted to compare the simulation results and the human responses by evaluating participants' feelings and satisfaction levels related to daylight quality and view quality. This experiment took place at Maxwell Building, University of Salford, UK, to collect qualitative data using virtual reality. This virtual reality experiment was conducted by using Unreal software to validate and test occupant experience in a workspace built virtually and tested using the DVS system (Fig. 3-4).

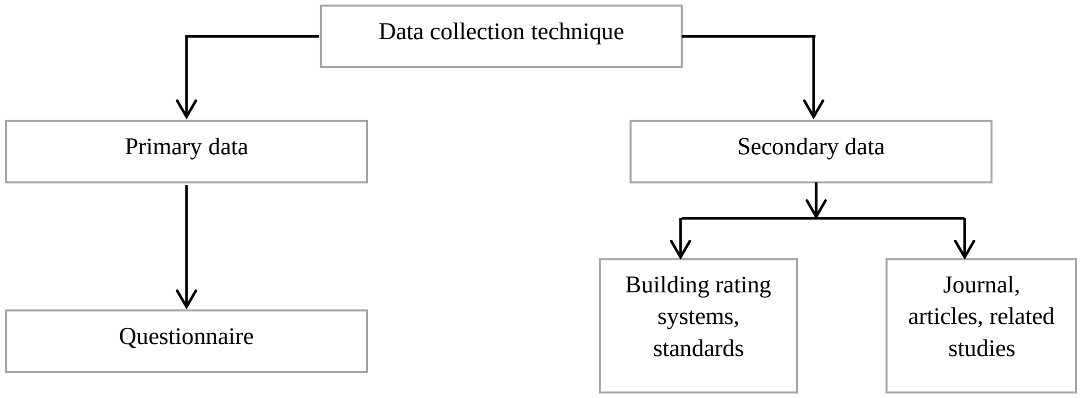


Figure 3-4: Data collection techniques (Source: Author)

3-5-2 Questionnaire Survey

The study at this stage intended to evaluate participants' perception of daylight quality and outside view in their work environments. This evaluation illustrates the qualitative aspects of daylight quality and outside view that will help to identify the parameters related to comfort and well-being in certain zones inside the sample working space. To achieve the aims of this research to bring natural light into deep-plan buildings to improve workplace daylight quality for occupant comfort and well-being, it is necessary to get accurate data from study participants about which zones they work in, known as a 'spatial map', and their perception towards daylight and outside view quality, known as a 'cognitive map'.

An online questionnaire was administered to collect terms that people use in the daylit zone to describe their perception of daylight and outside view quality in their working environment. These terms identify participants' spatial cognitive map (SC_{map}) toward well-being and comfort. A spatial cognitive mapping (SC_{map}) methodology was used to obtain participants' hierarchical knowledge structure and mental model of daylight and outside view quality in a daylit zone. A cognitive map of 35 participants was created using SC_{map}. The results present qualitative data about parameters most related to comfort and well-being in the daylight zone. These parameters drive the simulation process to improve occupant comfort and well-being and to maximise the daylit zone.

In built environment research, questionnaires are widely used to collect data (Bryman, 2012). In the present study, a questionnaire was used as the main research method to create a mental map representing occupants' feelings and satisfaction regarding daylight quality and view quality inside their working environment by referring to their daylight zone which will help to define their mental map. The questionnaire was designed from three sections after the pilot study, these sections were designed to answer the research questions and achieve the research objectives. This research study was divided into three phases: the first deals with respondents' description, the second applies the open-ended SC_{map} method to collect terms that people use to describe daylight and outside view quality in work environments related to their daylit zone, and the third uses quantitative analysis to define the most significant factors affecting occupant daylight and view satisfaction and then inputs these factors to present the relationship between terms using Gephi to create network analysis presenting participants' mental map. The results of this analysis will help to define the most significant factors that affect occupant satisfaction with daylight quality and view quality.

3-5-3 Participants

The research study was divided into two phases: the first phase aims to visualise occupants' mental map to collect terms that participants use to describe daylight and outside view quality in work environments; the second phase aims to apply quantitative analysis methods to define the correlation and level of association between terms using SPSS software.

All participants in both phases were unpaid volunteers over 18 years of age, recruited by email or in person. In selecting a sample to study, it should represent the full set of cases in a way that is meaningful and that we can justify (Yin, 2003). According to the research question and objectives, the sample selected corresponds to the target population.

3-5-3-1 Sampling techniques

- Probability sampling: Probability sampling (or representative sampling) is widely used with survey research strategies. It is important to select the appropriate sample size to get an accurate answer to justify research questions and objectives. Data are sampled when it is impractical or unnecessary to collect them from the entire population. Also, probability sampling defines the target population for generalisation by defining the sampling frame. The process of probability sampling can be divided into four stages:
    1. Defining the sampling frame
    2. Determining the sample size
    3. Choosing the sampling technique
    4. Ensuring the sample reflects the target population

Generalisations about target populations from data collected using any probability samples are based on statistical probability. In statistical probability, generalisations about target populations are based on data collected using any probability samples. It has been shown by Tennent (2013) that a sample size of 30 or more will usually result in a sampling distribution for the mean that is very close to a normal distribution. Therefore, Tennent (2013) recommends at least 30 participants for good statistical analyses and provides a useful rule of thumb for the smallest number. In the present research, 44 participants answered the questionnaire survey.

- Volunteer sampling: The self-selection sampling method can be used for conducting questionnaire surveys. Usually, allowing individuals the choice to take part in the questionnaire will give accurate results as they express their opinions and feelings freely and voluntarily. In this study, an advertisement was done, by publishing a call to participate through the most used social media platforms in Egypt, such as Facebook and Twitter (now called X).

  The experiment study was conducted at an office space in the Maxwell Building at Salford University, UK. To test participants' feelings and satisfaction with daylight and view quality that improved by using a healthy shading device from applying the DVS system, 60 participants were asked to do this experiment using virtual reality. As Creswell (2009) suggests, 15–25 interviews are enough for an interpretive study.

3-6 Data Analysis

The data collection instruments used in this research are as follows (Fig 3-5):

Stage 1: Building rating systems, standards

- In this stage, a keyword-in-context analysis using MAXQDA software was implemented to extract all themes related to ‘well-being’ and ‘comfort’ in building rating systems.

Stage 2: Journal, articles and related studies

- A flowchart is a picture of the separate steps of a process in sequential order. It is a generic tool that can be adapted for a wide variety of purposes and can be used to describe various processes. In this research, a flow chart was used for thematic analysis to define well-being themes associated with daylight in related studies.

Stage 3: Questionnaire

- 3a Descriptive statistics: aims to provide a summary of the sample details using tables and graphs to simplify understanding.
- 3b Statistical analysis using SPSS software: aims to define the level of association for test research hypotheses variables, likelihood ratio tests will be discussed in the next section.
- Mental map network analysis using Gephi software: enables us to consider the structure of interactions and interconnections between participants in the analysis.

Stage 4: Multifactor system DVS

- -Standard deviations and parallel coordinate plots of the Pareto front: used together to select the optimal shading device solution using multi-objective evolutionary algorithms.
- Visualising comfort and well-being map (CW_{map}) using Origin software.

Stage 5: VR experiment

- HTC VIVE VR glass, Unreal software.
- Mental map network analysis using Gephi software.

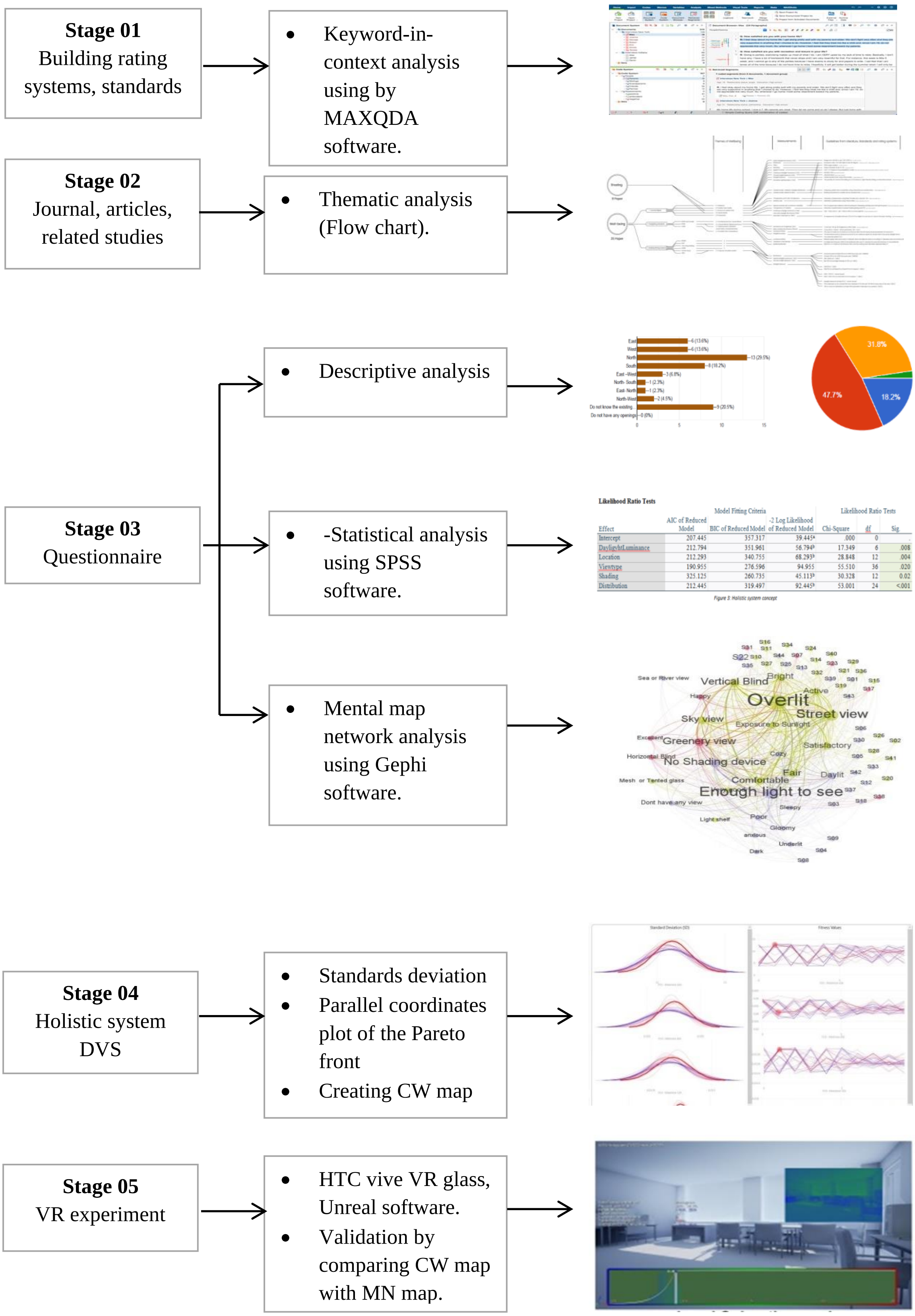


Figure 3-5: Data collection technique (Source: Author).

3-7 Conclusion

This chapter presented the model adopted for this research (based on Saunders's research onion). The chosen research methodology that provided the integral components of this research was discussed. Based on the approved model layers, including the philosophical stance of this research, research approaches and research strategies, the study area and choice of study samples (case study), research choices and research techniques were presented as the research strategy of this study, a case study strategy.

The next chapter (Chapter 4) presents a qualitative analysis of comfort and well-being in terms of daylight using online questionnaires.

CHAPTER 4: Qualitative Analysis for Comfort and Well-Being in Terms of Daylight (Online Questionnaire) (Stage 1)

4.1 Introduction

This chapter presents the first phase of data collection before developing the facilitation tool and the multifactor system. This stage aims to define occupants' feelings and level of satisfaction with daylight quality and outside view quality related to the daylight zone inside their working space (overlit, daylit and underlit zones). An online questionnaire was administered to evaluate participants' perception of daylight quality and outside view in their work environment. The evaluation of questionnaire responses illustrates the qualitative aspects of daylight quality and outside view that will help to identify the most associated and significant parameters of comfort and well-being. The findings of this chapter aim to answer the research questions Q02 posed in Chapter 1. This is based on completing the data collection using the research methodology described in Chapter 3.

The questionnaire used with respondents for the first source of data collection is shown in Appendix 1. To achieve the aim of the questionnaire, a series of statistical techniques is used to define the most significant factors that affect occupant satisfaction with daylight and view quality inside their workspace. This chapter is structured as shown in Figure 4-1:

- 4.1: Questionnaire design
- 4.2: Frequencies statistics of participants' responses
- 4.3: Questionnaire reliability
- 4.4: Test research hypotheses and level of association (likelihood ratio tests)
- 4.5: Visualise the mental map of the participants (mental network map analysis)

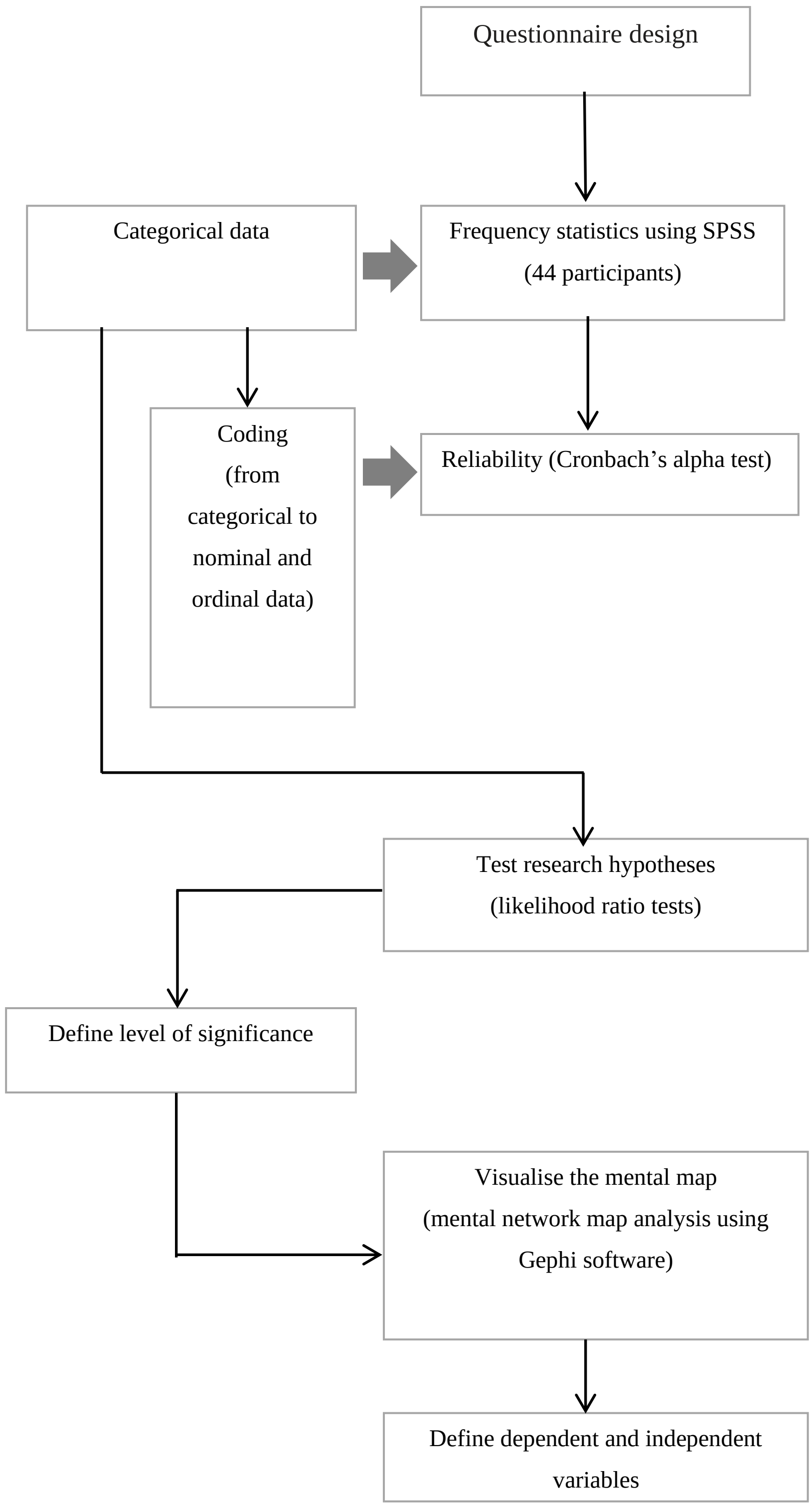


Figure 4-1: Data analysis techniques (Source: Author).

4-2 Questionnaire Design

4-2-1 Spatial Cognitive Map as a Concept

A cognitive map is a mental representation of the layout of one's previous or current environment (Tolman, 1948). It is also considered a type of mental representation that helps an individual to acquire, code, store and recall information about the relative locations and attributes of phenomena in their everyday or metaphorical spatial environment (Tolman, 1948). Cognitive maps serve the construction and accumulation of spatial knowledge, allowing the 'mind's eye' to Visualise images (Kitchin, 1994).

A cognitive map has information about the spatial relationships of individuals to understand their behaviour towards something. It could be defined as the ability to be aware of your relationships with the environment. Spatial awareness is made up of two processes: (1) the exteroceptive process, which creates representations about space through feelings, and (2) the interoceptive process, which creates representations about our body, such as its position or orientation; in this research, the latter refers to the daylight zone (overlit, daylit and underlit zones).

The study at this stage intended to evaluate participants' perception of daylight quality and outside view in their work environments. This evaluation illustrates the qualitative aspects of daylight quality and outside view that will help to identify the parameters related to comfort and well-being in certain zones inside the sample working space. To achieve the research aims to define a new multifactor shading system to improve and predict occupant comfort and well-being inside the working environment, it is necessary to get accurate data from participants about which zone they worked in recently (i.e. a spatial map) and their perception of daylight and outside view quality (i.e. a cognitive map).

An online questionnaire was used to collect terms that people use in the daylit zone to describe their perception of daylight and outside view quality in their working environment. These terms identify participants' spatial cognitive map (SC_{map}) for comfort and well-being.

4-2-2 Participants

This study was broken down into two phases: the first applied the open-ended SC_{map} method to collect terms that people use to describe daylight and outside view quality in work environments related to their daylit zone; the second used the quantitative analysis method to define the relationship between terms using SPSS software. All 44 participants (36 male and 8 female) were unpaid volunteers over 18 years of age, recruited by social media advertising, via email or in person.

4-2-3 Data Collection

A spatial cognitive mapping methodology was used to obtain participants' hierarchical knowledge structure and mental model of daylight and outside view quality in a day-lit zone. The results present qualitative data about most parameters related to comfort and well-being in the daylight zone. These parameters will drive the simulation process later to improve occupant comfort and well-being on one hand, and on the other hand to maximise the daylight zone.

A cognitive map helps participants feel their physical surroundings. Introduced by psychologist Edward Tolman (1948), a cognitive map refers to the way humans make sense of their surroundings. Though Tolman originally intended the concept to describe something that we do automatically, you can follow discrete steps to generate a cognitive map that helps you navigate the world. Four steps of question categories were used to identify a spatial cognitive map (SC_{map}) (Tolman, 1948):

1. Move through your surroundings (spatial map)
2. Analyse with your senses (cognitive map for comfort and well-being)
3. Decide on directional cues (define the daylight zone)
4. Note positional landmarks (shading system configuration and outside view content)

The first set of questions aimed to help participants to define their daylit zone, creating a 'spatial map' (Fig. 4-2). The second set of questions aimed to create participants' cognitive map towards their feelings about daylight quality and outside view quality. The third set of questions related to the defined façade configuration in the participants' working environment. In the fourth set of questions, participants were expected to define the façade configuration for their work environment in detail, including information such as the type of shading device, the type of glass used (i.e. if it is tinted glass or something else), etc. In the last stage, participants selected or added the terms most related to their current feelings about daylight quality and outside view quality. In this questionnaire, 44 people participated, and each created a list of terms relating to daylight in their working environment that they commonly use and perceived as important.

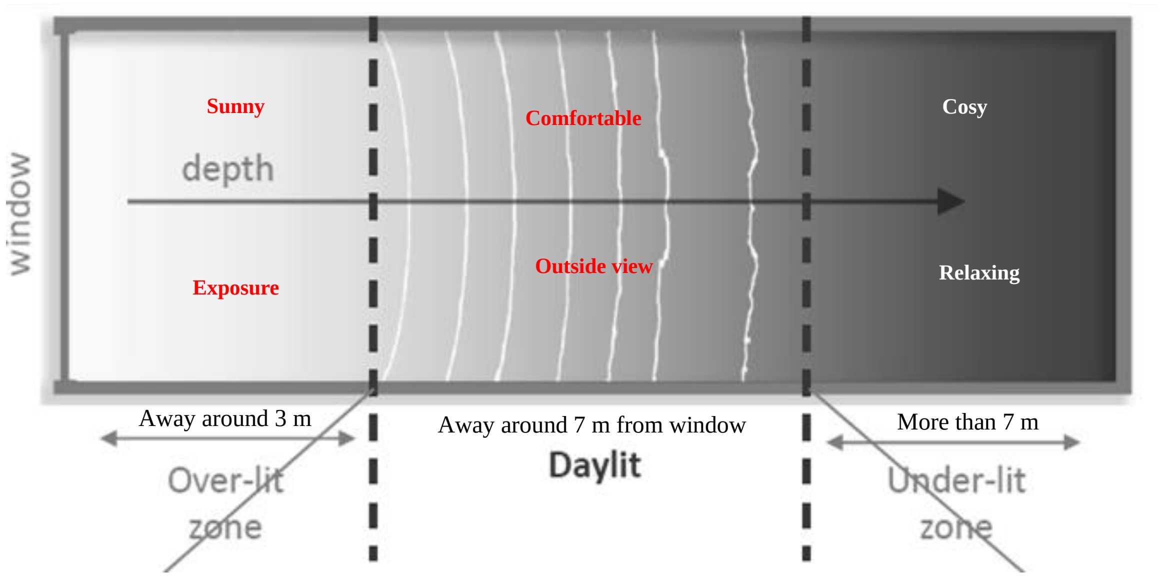


Figure 4-2: Daylight zones (Source: Author).

4-3 Frequency and Descriptive Analysis

The purpose of this section is to provide information about respondents and target age groups to make sure that those targeted in this research are actually the ones who will participate in the study. A frequency and descriptive analysis is provided to describe participants' gender, level of education and profession.

4-3-1 Gender

According to the data in Figure 4-3, 81.8% of respondents (the majority) are male and 18.2% are female.

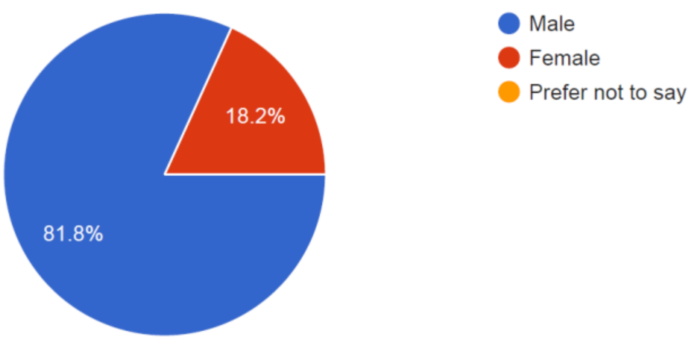


Figure 4-3: Gender.

Regarding participants' age, the responses are predominantly from the 25–40 years age group, comprising 95.5%. This research aims to define the most significant factors that affect occupant satisfaction with daylight and view quality; therefore, relying on one group of the same generation is an important factor in decreasing the tolerance of view acuity as the lens inside the eye begins to lose its ability to change shape after the age of 40 years – a process called presbyopia (Neil S et al., 1986).

4-3-2 Level of Education

Figure 4-4 shows data on the maximum level of education achieved by each respondent, which is considered to be an important factor that affects their level of satisfaction with daylight and view quality inside their working environment.

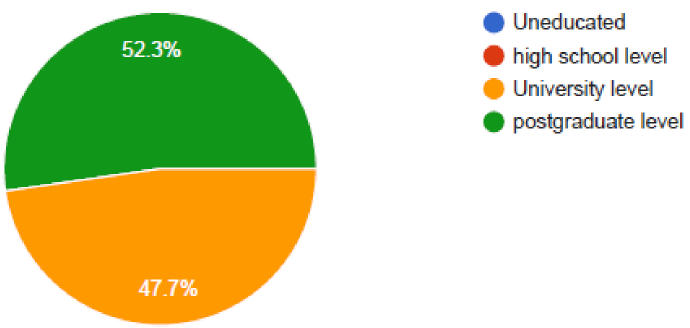


Figure 4-4: Level of education.

According to the data in Figure 4-4, all participants are university educated, 47.7% of respondents have a postgraduate level and 52.3% have graduated with a university degree.

4-3-3 Profession

Figure 4-5 shows that 84.1% of participants are employees, 11.4% are technical professionals, only one is a student and one is unemployed. As the aim of this questionnaire is to define the factors that affect occupants' satisfaction with daylight and view quality inside their working environment, it is important to have a study cohort with the majority of participants employed, and not retired or unemployed, to get realistic responses.

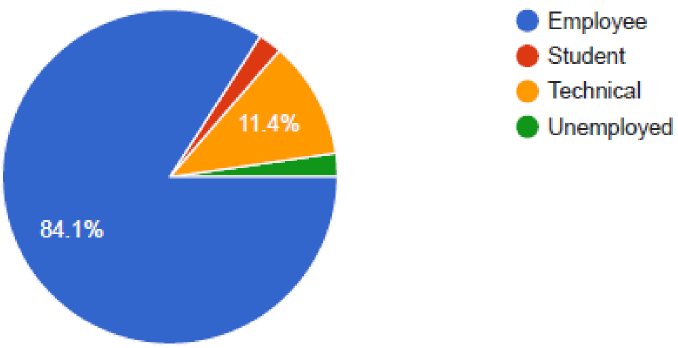


Figure 4-5: Profession.

4-3-4 Move Through Your Surroundings (Spatial Map)

Creating a cognitive map requires you to explore the space you are attempting to map. This means moving through that space with no clear destination in mind. To achieve this purpose, participants were asked the following six questions.

Q1: What type is your working environment?

The study found that the most commonly used working space was the office space (72.7%) followed by the working station (20.5%).

In this context, a workstation refers to a specific, dedicated area within a larger space (like an office, home, or studio) set up with the necessary tools and equipment for focused work. Unlike an entire office or studio, which can encompass multiple areas and functions, a workstation is typically a single desk or area equipped with items like a computer, specialized tools, or ergonomic seating to support specific tasks. It emphasises functionality and task-specific setup rather than a general-purpose space

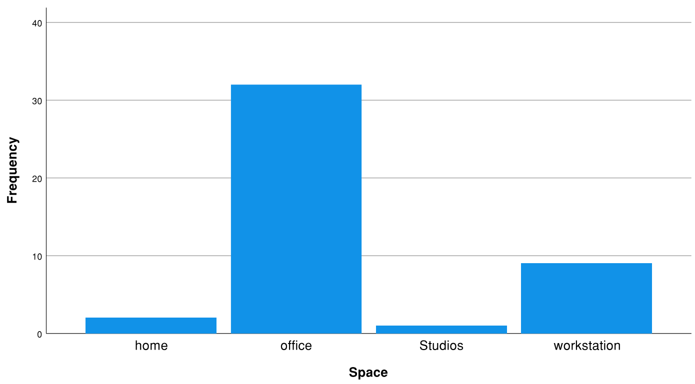


Figure 4-6: Working environment.

Q2: Can you describe the façade of your working space?

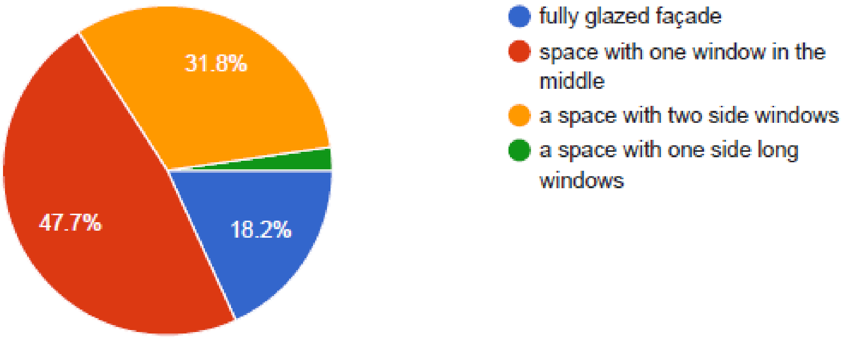


Figure 4-7: Façade description.

Figure 4-7 shows that 47.7% of participants have only one window in the middle of their working space, 31.8% of them have two side windows, and 18.2% have a fully glazed façade. This study is limited to the window-to-wall ratio and only focuses on shading device parameters.

In a hot country such as Egypt, the worst-case scenario is to have a fully glazed façade because it increases heat gains inside the working space, and controlling the daylight quality indoors and the outside view quality becomes a challenge.

Q3: Do you have access to the outside view environment from your working desk location?

As the aim of this questionnaire is to define the factors that affect occupants' satisfaction with daylight and view quality in their working environment, it is important to ensure that the majority of participants (70.5%) have access to the outside view to get realistic responses.

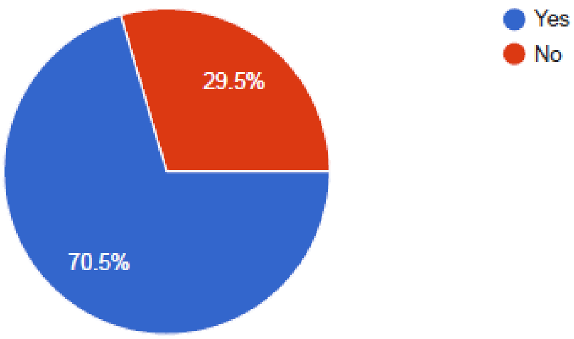


Figure 4-8: Access to outside view.

Q4: Can you describe your desk location in your current working space?

Participants' responses to this question show that most of them are seated in the overlit zone, 29.5% are seated next to a window, and 20.5% are seated next to a side wall nearer to the window. The study found that 11.4% and 20.5% of participants are located in the middle of the space represented by the daylight zone and 18.2% of participants are located in the underlit zone.

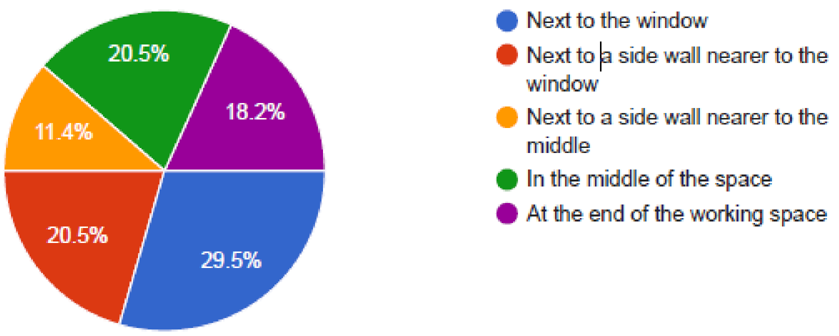


Figure 4-9: Zone location.

Q5: How far are you from the window of your working environment (in metres)?

Figure 4-10 shows that most participants (63.6%) are located less than 2 metres from a window and 34.1% of participants are located 3–7 metres from a window. This means that most participants are located in the overlit zone that has the most daylight issues but has good view access and clarity because participants are close to the outside view. It is important to decrease daylight issues by using a shading system without blocking the outside view. A new multifactor system – the DVS system – is defined in this study to optimise three factors together: daylight, outside view and shading system.

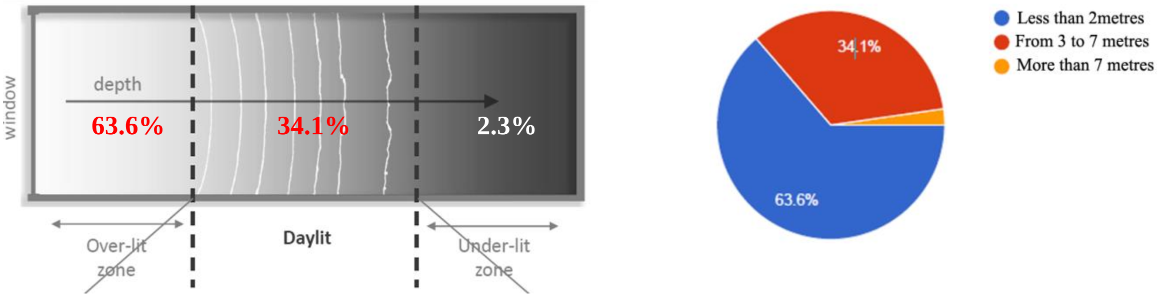


Figure 4-10: Daylit zone location.

Q6: Please select the best plan (from the options provided) that fits with your current working space.

Participants' responses to this question show that rectangle is the working space type most related to their current working space. This justifies why the standard model for testing the multifactor system in this study uses a rectangle shape with a standard dimension related to travel distance regulation to get the maximum office space unit (discussed later in Chapter 5).

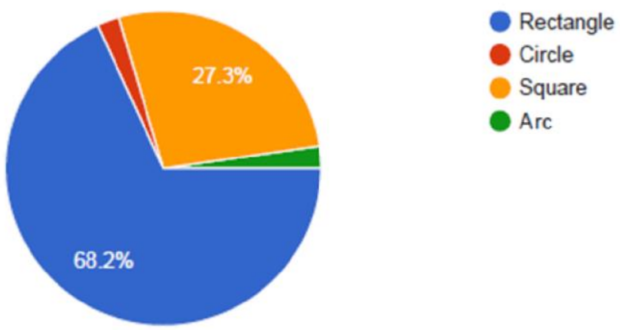


Figure 4-11: Working space plan.

4-3-5 Analyse with Your Senses (Cognitive Map for Comfort and Well-Being)

At this stage, the questions aimed to stimulate participants to imagine features found in their working space. Participants needed to analyse these features using one, some or all of their senses. They cognitively mapped the interior of their working environment, observing the location of the windows, feeling the warmth or coolness and remembering whether they experienced visual comfort or discomfort while sitting and doing ordinary tasks. This analysis aimed to orient participants to different spots on their map and help them to understand their relationship to their surroundings. To achieve this purpose, participants were asked the following four questions.

Q1: What is your working space opening orientation? You can select more than one choice if you have an opening on more than one side.

A study conducted by Elhadad et al. (2018) in Egypt shows that the optimal orientation related to energy consumption is a north façade. In contrast, the south façade represents the worst orientation as it consumes the largest amount of energy. Participant responses reflect these findings as north is the most frequent orientation at 29.5%.

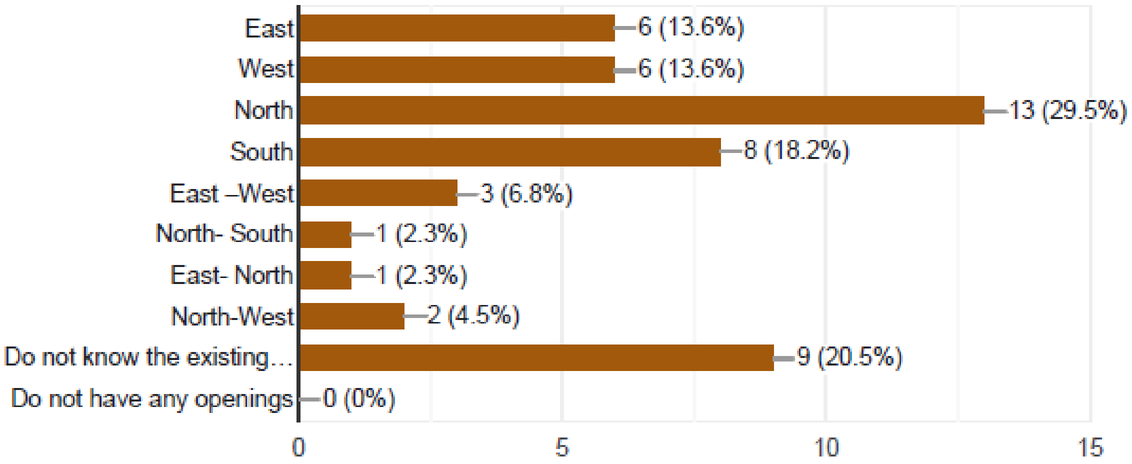


Figure 4-12: Opening orientation.

Q2: Can you carry on with your work relying on daylight illuminance available inside your working environment? If your answer is 'Yes', then please state the work duration in hours using daylight illuminance.

Participants' responses show that the majority of them (75%) use daylight and 25% of them do not rely on daylight. This makes sense because the earlier question Q5, asking about the distance from the window, shows that 34% of participants are located in the daylit zone at a distance of 3–7 metres from a window. This means that 25% of participants do not have good daylight.

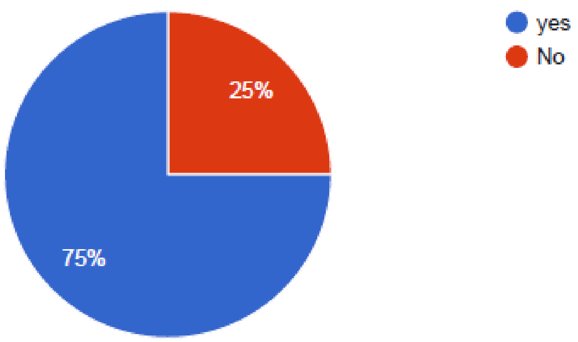


Figure 4-13: Daylight relying on daylight.

Q3: While you are working on a sunny day, what are the major effects of daylight you have inside your working environment?

Figure 4-14 shows that glare, daylight exposure and heat gains are the most common daylight issues for participants. Of the participants, 13.6% said they do not have issues with daylight, which may be because they have a shading system or they are located in the underlit zone where the daylight levels score is minimal.

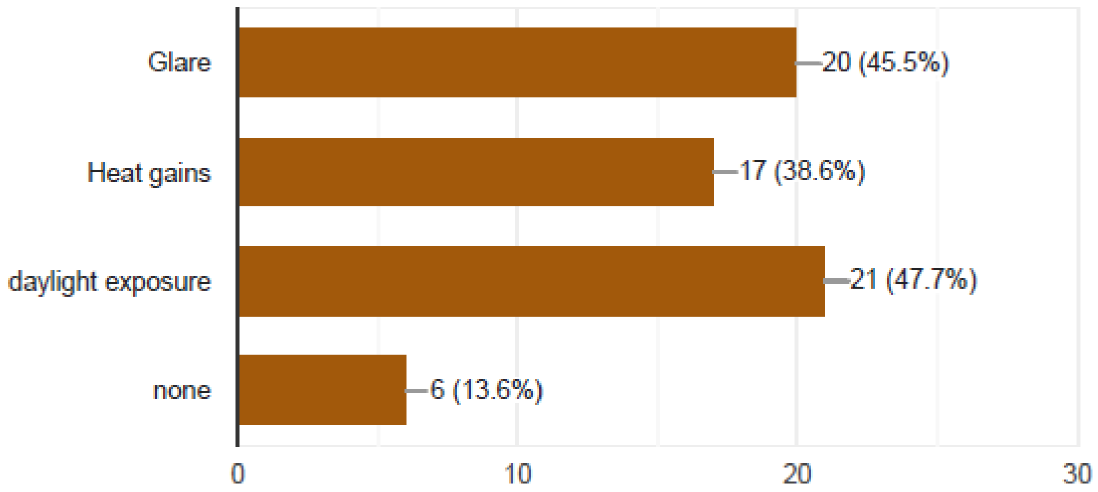


Figure 4-14: Daylight issues.

Q4: How can you overcome daylight issues such as glare inside your working environment?

The majority of participants (47.7%) chose to use a shading device to overcome daylight issues inside their working space. This means that most participants have a shading system that will help to validate the questionnaire results and get accurate answers.

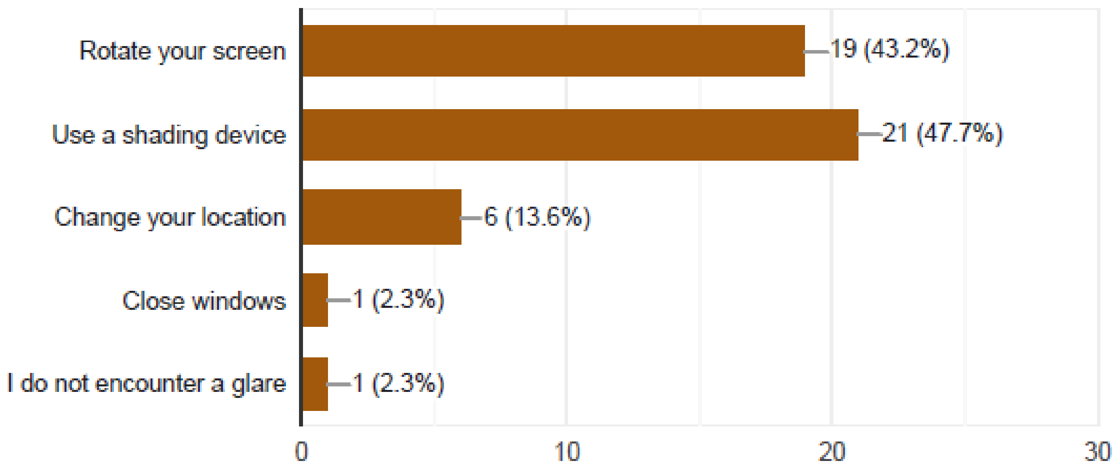


Figure 4-15: Overcoming daylight issues.

4-3-6 Decide on Directional Cues (Define the Daylight Zone)

As participants' cognitive map of a location expands, they need to define which daylight zone they anticipate. A closed-ended question was asked to help choose their daylight zone from a set of drawings such as a schematic section or plan and allow the participant the right to give another answer. The participants' directional cues supplement their sensory analysis and provide a clearer way of navigating through their cognitive map. To achieve this purpose, participants were asked the following four questions.

Q1: What is your type of work?

Figure 4-16 shows that 52.3% of participant work was a computer task and 45.5% was both a paper and computer task. The smaller percentage was given to paper tasks only. Therefore, daylight design needs to comply with the recommended illuminance levels for both paper and computer tasks based on daylight standards IESNA (see Chapter 2 findings). A daylight illuminance of 500 lux for a variety of tasks is selected as a recommended illuminance level (IES, 2006).

Task	Illuminance Recommendatior
Reading (Computer Screens)	30 lx
Meeting Rooms	300 lx
General Classrooms	300 lx
Office Spaces (intensive computer tasks)	300 lx
Office Spaces (variety of tasks)	500 lx
Fine Machine Work	3,000 – 10,000 lx

Figure 4-16: IESNA illuminance guidelines.

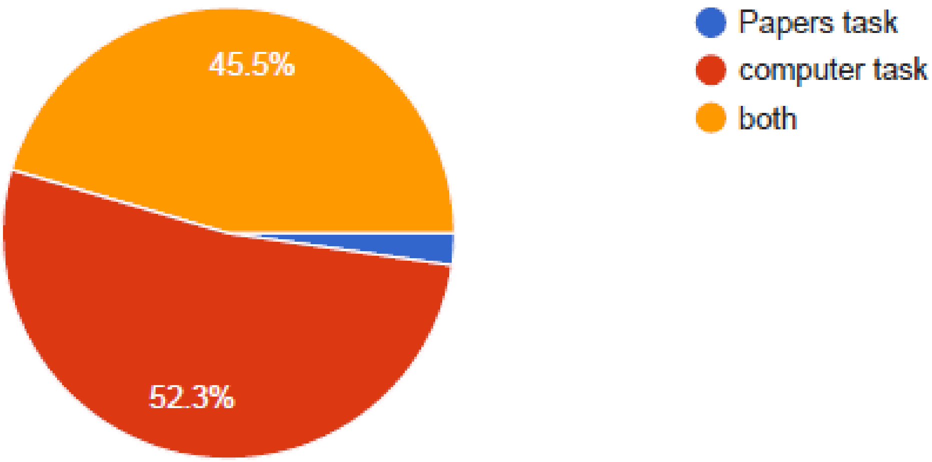


Figure 4-17: Work type.

Q2: Can you select or add the most appropriate terms that reflect your answer regarding daylight illuminance?

As the aim of this questionnaire is to define the factors that affect occupant satisfaction with daylight and view quality inside their working environment, it is important to have a scale to measure the daylight levels inside their working environment.

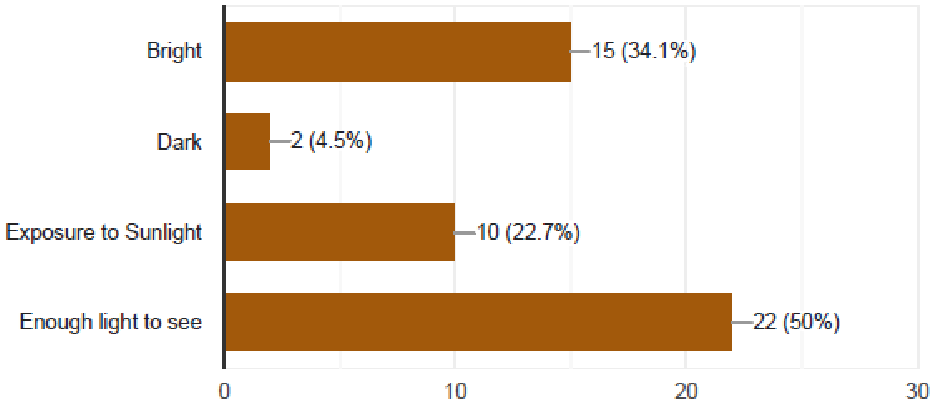


Figure 4-18: Daylight illuminance satisfaction.

Although all participants are located in Egypt where there is daylight almost throughout the year, the majority of participants (50%) selected ‘enough light to see’. For daylight issues such as ‘bright’ and ‘exposure’, 34.1% of participants selected ‘bright’, 22.7% selected ‘exposure to sunlight’ and 4.5% selected ‘dark’. This means there is a need to improve daylight illuminance and decrease issues such as exposure and glare.

Q3: Can you select or add the most appropriate terms that reflect your answer regarding daylight distribution inside your working space?

This question aims to measure participant satisfaction with daylight distribution. The results show that 31.8% of participants feel that the daylight distribution is fair and only 9.1% feel it is excellent. It is important to link these results and their location inside the working space to understand the relationship between daylight zones (overlit, daylit and underlit zones) and participants' feelings. (A network map analysis is discussed at the end of this chapter.)

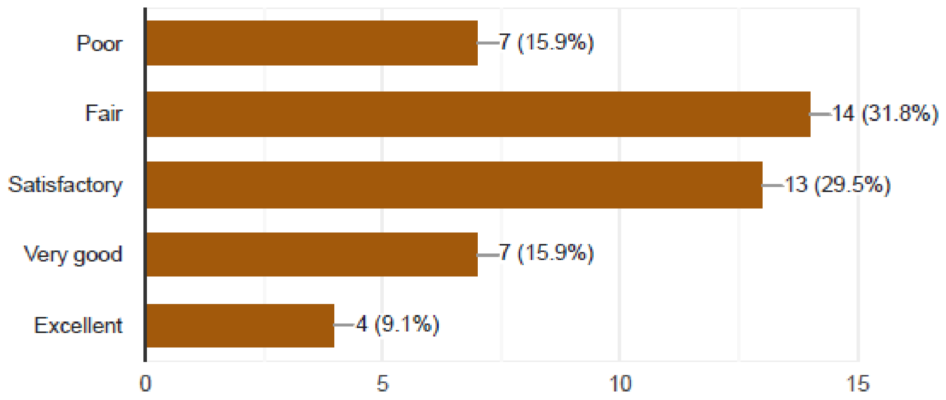


Figure 4-19: Daylight distribution satisfaction.

Q4: Can you describe your feelings inside your working environment during daylight time?

As indicated in Figure 4-18, most participants (34.1%) feel comfortable and fewer of them feel anxious (4.5%). To illustrate the importance of each term, a visual representation of each term is created using a network analysis technique. This will give us a better understanding of the factors that affect participants' feelings.

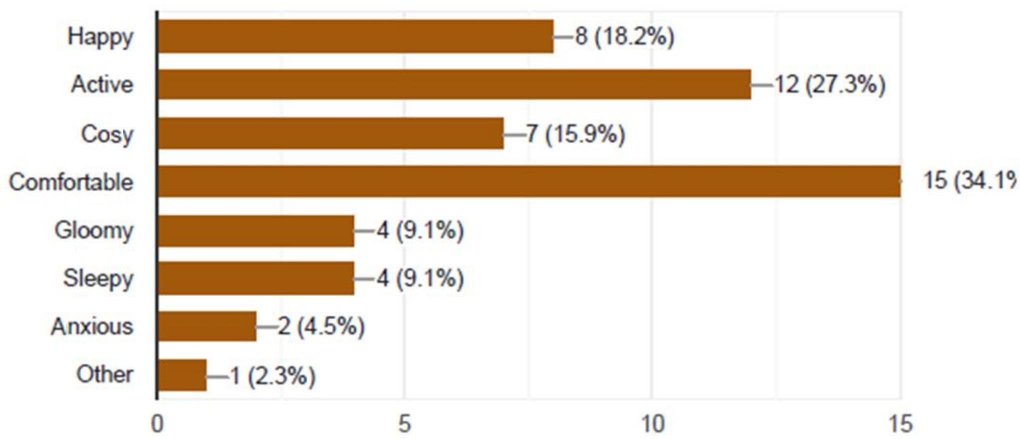


Figure 4-20: Feelings related to daylight quality.

4-3-7 Positional Landmarks (Shading System Configuration and Outside View Content)

The ability to recognise and remember positional landmarks helps to effectively use one's cognitive map no matter where you find yourself in the space you have mapped (Tolman, 1948). Using positional landmarks in this way allows for expanding one's cognitive map. To achieve this purpose, participants were asked the following four questions.

Q1: Can you describe the outside view content from your working position?

The results show at (Table 4-1) that the most frequent outside view content was street view and greenery view (29.5% and 22.7%, respectively). Mixed view means that participants have a sky, street and greenery view from their location. Outside view content is an important factor to quantify view quality and also affects occupant well-being (Yildirim et al., 2024). Therefore, there is a need to link view content and daylight zone to explore whether the relationship between them is significant or not. A correlation coefficient analysis using SPSS software is presented in Section 4-4-2.

Table 4-1: Frequency of outside view type

View type	Frequency	Percentage
Greenery	10	22.7
Mixed	8	18.2
None	5	11.4
River	1	2.3
Sky	7	15.9
Street	13	29.5
Total	44	100.0

Q2: Do you have a shading device installed on the window of your working space?

Figure 4-21 shows that 43.2% of shading devices used are vertical shading devices and 11.4% are horizontal shading devices. A related study conducted by Ahmed et al. (2013) in Egypt illustrates that the most common shading devices used are horizontal ones because of the high position of the sun in south-facing façades. The next question is designed to give us a better understanding of whether or not this shading type affects view access to the outside environment.

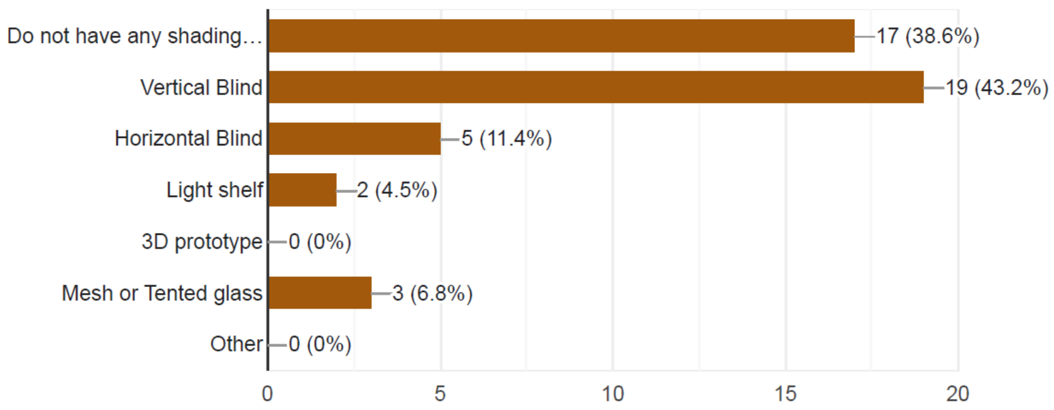


Figure 4-21: Shading devices.

Q3 On an extremely sunny day to overcome glare issues you have to use a shading device that will block the outside view. Do you feel comfortable not using the shading device and consequently having glare issues or not?

Participants were asked to choose between having daylight issues such as glare and using a shading device in their office that will obscure views of the outside environment. The majority of participants said they prefer to have glare rather than block the outside view.

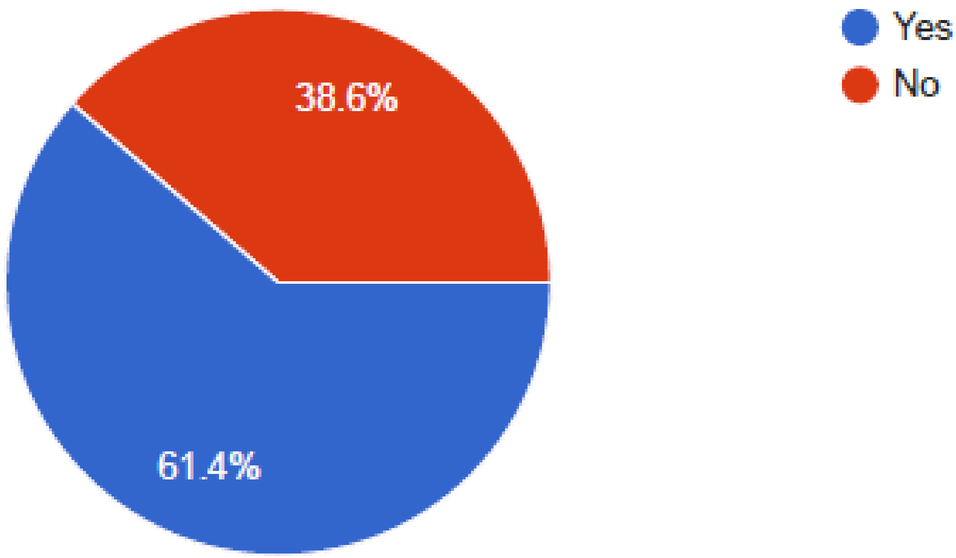


Figure 4-22: Outside view versus glare.

4-3-8 Participant Opinion

In the open-ended spatial cognitive map (SC_{map}) phase, participants were asked their opinion to understand whether there is a new term that affects their satisfaction with daylight and view quality. Participants expressed their opinions by answering the following two questions.

Q1: Do you think a shading system is important for working environments?

Responses to the first question show that the majority of participants consider shading devices important for their working space.

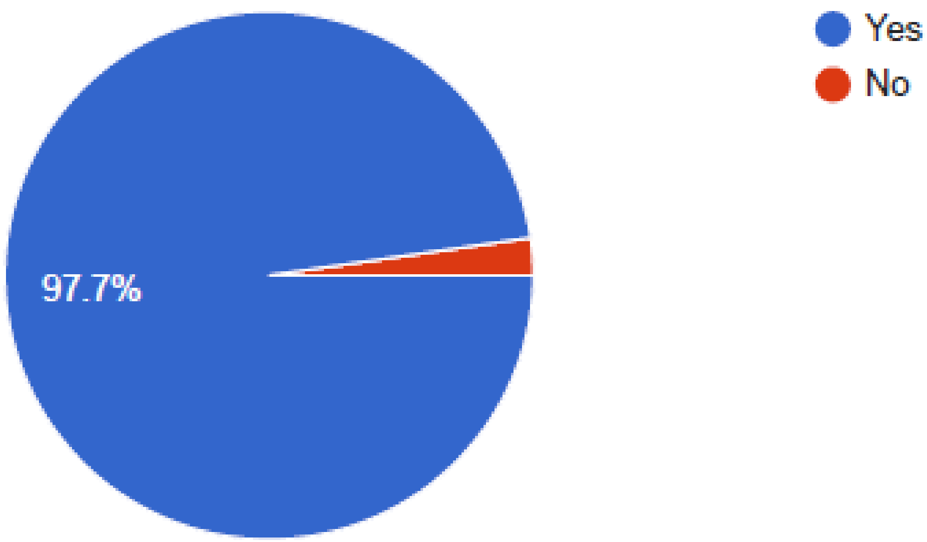


Figure 4-23: Importance of shading systems.

The second question asked participants to share suggestions for increasing comfort in their working environment with regard to daylight.

Q2: What are your suggestions to be more comfortable inside your working environment with regard to daylight? (See Appendix 1 for all participant responses.)

The keyword-in-context method was to find the keyword-in-context feature to display all word locations and their context in an interactive results table. As indicated in Table 4-2, most of the suggestions were related to defining a new shading system that can increase view and decrease daylight issues. New terms were found related to thermal comfort, skylight design and working period. These new terms will be used in future studies.

Table 4-2: Participant suggestions

Suggestions no.	Keyword in context	New terms (limited to the study)
1	Window size, good curtains, active	View quality
2	Outside shading technique, more indirect illumination, did not block outside view	Shading system, view quality
3	Vertical blind and insect screens	Shading system
4	Shading devices to avoid glare, enhance the distribution of daylight inside, without blocking outside view	Daylight quality and view quality
5	Receive light without glare or heat	Daylight quality
6	Horizontal shading, to reduce glare, rearranging furniture	Rearranging furniture, shading system
7	Increasing window size	Daylight quality and view quality
8	Skylights designed	
9	Use shading system	Shading system
10	Outside environment temperature, outside view, movable shading devices	shading system and outside view quality
11	Avoid high heat gain	
12	Avoid glare	Daylight quality
13	Big window	Daylight quality and view quality
14	Dimmable glass to adjust the light into the building	Daylight quality
15	Windows orientation and size	Daylight issues and view access
16	Shading device for clear days to still have the view of outside area	Shading system and outside view quality
17	Sun screens	Shading system
18	Have a clear view	View quality
19	Change the working period	
20	Good distribution and view availability	Daylight quality and view quality
21	Desk orientation, dynamic shading device	Daylight quality
22	Greenery view	Greenery view
23	More accessibility to the outside view	View quality
24	Put plants on desk	Greenery view
25	Screen orientation	Daylight issues
26	Fully glazed façade	View quality

4-4 Questionnaire Statistics Analysis

4-4-1 Questionnaire Reliability

It is important to use a reliable questionnaire to obtain accurate results. Therefore, achieving a good reliability score for collected data means decreasing the error in interpreting data (Sarantakos, 2013). Cronbach’s alpha coefficient is the most commonly used coefficient to determine the reliability of questionnaires (Pallant, 2006). As Taber, K.S. (2018) point out, a Cronbach’s alpha from 0.5 to 0.7 shows moderate reliability. As shown in Table 4-3, Cronbach’s alpha is 0.651, which means the questionnaire is reliable.

Taber, K.S. (2018) state that in justifying a Cronbach's alpha of 0.65 for this type of questionnaire, it's important to consider the structure and diversity of the questions used, as well as the nature of categorical and subjective data collected:

1. Heterogeneity of Question Types and Constructs: The questionnaire covers a range of topics that relate to occupants' interactions with their environment. These include demographic and background information (like gender, age, profession), specific environmental parameters (distance to window, façade type, orientation), and subjective assessments of comfort, visual satisfaction, and shading needs. Since these questions are not all designed to measure a single underlying construct (e.g., "satisfaction with daylight"), it's natural for the internal consistency, as measured by Cronbach's alpha, to be slightly lower.

2. Categorical and Nominal Data: Many items in the questionnaire are categorical, including nominal variables (like gender, profession, and façade type) and binary responses (such as "Yes/No" to having a shading device or feeling comfortable with certain daylight conditions). Cronbach's alpha is traditionally most effective for interval or ratio scales, so including categorical items can reduce the internal consistency value. In your case, because the questionnaire explores various categories rather than a continuous scale, achieving a very high alpha may not be realistic or necessary.

3. Diverse Aspects of Daylight Satisfaction and Environmental Perceptions: The questionnaire explores multiple distinct yet related aspects of the occupant's environment, from the physical layout and lighting conditions to subjective comfort. This variation means that not all questions will strongly correlate with one another. Instead, each question contributes uniquely to an overall picture of occupant satisfaction and interaction with daylight. Since some items are expected to provide distinct insights (e.g., describing the outdoor view versus evaluating glare), a moderate alpha can be justified.

4. Exploratory and Context-Specific Nature: Given that the study explores occupant satisfaction in the context of Cairo commercial buildings—a specific environment—this alpha level is sufficient for an exploratory understanding of factors that influence satisfaction with daylight and views. In such cases, values in the range of 0.6–0.7 are commonly accepted in social and environmental research as they provide meaningful, though not excessively rigid, measures of consistency. This allows the analysis to maintain a balance between capturing diverse responses and deriving a generalized sense of environmental comfort.

In summary, the value of 0.65 is justifiable because the questionnaire's diverse structure, categorical data, and exploratory purpose make it less suited to very high internal consistency values. This alpha level adequately reflects the heterogeneous nature of the constructs measured, allowing for a nuanced view of occupant satisfaction in a specific, contextually rich environment.

Table 4-3 : Reliability statistics – Cronbach's alpha test

Cronbach's alpha	No. items
0.651	12 Items (Profession , Working space , Location , Plane , Orientation , Daylight luminance , Daylight distribution , Task type , Feelings , View type , Overcome issues , Shading used)

4-4-2 Validity and Significant Factors

Validity is the amount of systematic or built-in error in a questionnaire (Saunders et al., 2009). The validity of a questionnaire can be established using a panel of experts who explore theoretical constructs. This form of validity exploits how well the idea of a theoretical construct is represented in an operational measure (questionnaire). This is called translational or representational validity. Two subtypes of validity belong to this form: face validity and content validity. In addition, some authors include hypothesis-testing validity as a form of construct validity (Saunders et al., 2009). hypothesis-testing validity is a measure of how well questionnaire findings stack up against another instrument or predictor. It also provides evidence that a research hypothesis about the relationship between the measured concept (variable) or other concepts (other variables), derived from a theory, is supported.

Likelihood Ratio Test (LRT) is applied for this questionnaire. . The values of the selected variables are converted into ranks and then correlated. As indicated in Table 4-4, each factor has a correlation coefficient and significant factor. The questions are coded into one or two words at least to work with the SPSS system.

Table 4-4: Labelling variables

Selected Questions	Factors
How far are you from the window of your working environment in metres?	Location
Can you select or add the most appropriate terms that reflect your answer regarding daylight illuminance?	Daylight illuminance

Can you select or add the most appropriate terms that reflect your answer regarding daylight distribution inside your working space?	Daylight distribution
Can you describe your feelings inside your working environment during daylight time?	Feelings
Do you have a shading device installed on the window of your working space?	Shading

4-4-3 Test Level of Association (Likelihood Ratio Tests)

In statistics, the likelihood ratio test assesses the goodness-of-fit of two competing statistical models based on the ratio of their likelihoods, specifically one found by maximisation over the entire parameter space and another found after imposing some constraint. If the constraint (i.e. the null hypothesis) is supported by the observed data, the two likelihoods should not differ by more than the sampling error. Thus, the likelihood ratio test tests whether the ratio is significantly different from one or whether its natural logarithm is significantly different from zero. As indicated in Table 4-5, the likelihood test ratio is significant at 0.005. Therefore, the variables daylight illuminance, daylight distribution, location and feelings should have strong associations to prove the hypothesis.

The research hypothesis in this study states:
The multifactor system that integrates daylight quality, view quality and shading system can improve people's comfort and well-being potential internally.
Therefore, the hypothesis assumed that the variables of daylight illuminance, daylight distribution, location, view type and feelings should have strong associations.
To statistically test the association level between these factors, there is a need to identify the dependent and independent variables. This research aims to define a new multifactor system to enhance occupant comfort and well-being inside the working environment by optimising shading systems and daylight quality and outside view quality. Therefore, daylight, shading, daylight illuminance, view type and location are the independent variables and occupants' feelings is the dependent variable. As indicated in Table 4-5, daylight distribution is the most significant variable with a significance (*P*-value) of <0.001 and shading systems have a significance score of 0.02; location, which is defined by overlit, daylit and underlit zones, is the second significant variable with a *P*-value of 0.004; daylight illuminance is the third significant variable with a significance of 0.008 and the last significant variable is view type with a *P*-value of 0.02. Model factors are explained in more detail as follows:

1. **Daylight Luminance**: The chi-square statistic for daylight luminance is 17.349, with 6 degrees of freedom (df) and a P-value of 0.008. This low P-value indicates a statistically significant

effect, suggesting that daylight luminance has a meaningful impact on the outcome variable in the model. The 6 degrees of freedom imply that several aspects or variations of daylight luminance (such as intensity levels, time of day, or direction) are tested to see if they contribute to explaining the outcome. Given the significant P-value, it appears that these factors in daylight luminance indeed play a role, meaning that changes in daylight luminance levels may affect the outcome significantly.

2. **Location**: For the variable "location," the chi-square value is 28.848 with 12 degrees of freedom and a P-value of 0.004. This P-value is also below the typical significance threshold of 0.05, indicating that location significantly influences the outcome. The 12 degrees of freedom suggest that multiple categories or variations of location (such as different floors, orientations, or building areas) are being tested to the outcome. This result implies that the particular location within the building or space has a significant impact, likely due to differences in exposure to natural elements like daylight or environmental conditions.

3. **View Type**: The chi-square statistic for view type is 55.510 with 36 degrees of freedom, resulting in a P-value of 0.020. This P-value is significant, though closer to the threshold, suggesting that view type has a relevant but perhaps less pronounced effect on the outcome compared to other variables. The 36 degrees of freedom reflect a high number of categories or possible view configurations (such as views of nature, urban scenes, or blank walls), each contributing to the assessment. The significant result implies that the type of view individuals have affects the outcome variable, potentially because different views provide varying levels of visual comfort or connection to the outside environment.

4. **Shading**: Shading has a chi-square value of 30.328, with 12 degrees of freedom and a P-value of 0.02. This significant result suggests that shading plays a meaningful role in predicting the outcome variable, likely by influencing daylight quality, glare, or heat. The 12 degrees of freedom indicate that various shading configurations or options (such as different types of shading devices, materials, or angles) are examined to understand their impact on the outcome. Since the P-value is significant, it appears that the presence and type of shading affect the outcome, potentially by enhancing comfort or visual quality in spaces.

5. **Distribution**: The chi-square statistic for distribution is 53.001, with 24 degrees of freedom and a P-value of less than 0.001. This very low P-value indicates a highly significant effect, suggesting that distribution is one of the most critical factors in the model. The 24 degrees of

freedom imply a broad range of categories or distributions (possibly of daylight, temperature, or airflow) that are tested for their impact. The strong significance here suggests that the way light or environmental conditions are distributed within the space has a substantial effect on the outcome, possibly because even distribution helps create a more comfortable or usable space.

In summary, each of these factors—daylight luminance, location, view type, shading, and distribution have a statistically significant impact on the outcome variable, with distribution showing the strongest effect due to its low P-value. This implies that to optimise the outcome, it is essential to consider not just the amount of daylight or shading but also how these factors are configured and distributed across spaces.

Table 4-5: Level of association test (likelihood test).

Effect	Likelihood ratio tests		
	Chi-square	df	*P*-value
Intercept	0.000	0	.
Daylight luminance	17.349	6	0.008
Location	28.848	12	0.004
View type	55.510	36	0.020
Shading	30.328	12	0.02
Distribution	53.001	24	<0.001

4-5 Visualisation of the Mental Map of Participants (Network Map Analysis)

Analysis of graph-based networks can help us understand their relationships to individual behaviour/attributes in the field of social network analysis. This Figure is based on a mathematical model connecting nodes to form a network structure. Network map analysis is a set of techniques used to understand these relationships and how they affect behaviour (Hevey, 2018).

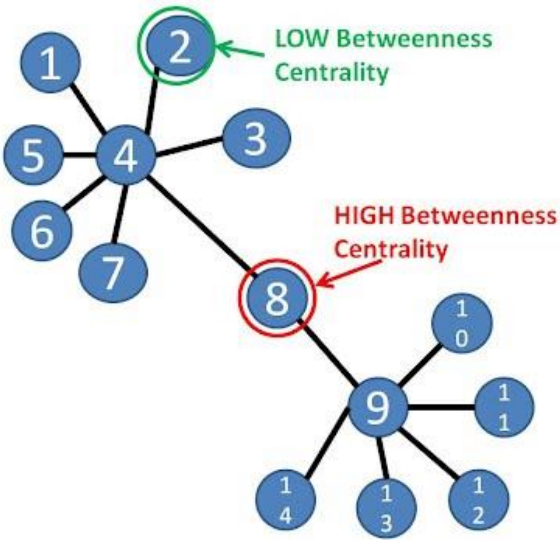


Figure 4-24: Betweenness centrality concept (Source: Bastian et al., 2009)

By representing these social structures as networks, researchers can apply various mathematical and graph-based methods to quantify structural characteristics and their relationship to behavioural attributes of a population (Amith et al., 2019). The present study uses Gephi, a powerful open-source software tool that is now widely used in network analysis (Bastian et al., 2009).

To illustrate the importance of each term, there is a need to measure betweenness centrality, which is considered a measure of centrality in a graph based on shortest paths. Betweenness centrality was devised as a general measure of centrality (Freeman, 1977) (Figure 4-24). A network analysis map is provided to show the terms that were selected more than once (Figure 4-25,26,27,28,29).

In Figure (4-25), there are three main nodes that drive the network related to daylight zones (overlit, daylit and underlit). Interpretation of the participant responses in relation to the three themes, as represented by their betweenness centrality values:

- *Theme 1: Overlit Zone*

In the "Overlit zone," participants identify strong associations with daylight quality, specifically "Enough light to see" (373.3), which is the most central response. This indicates that, for occupants experiencing an overlit environment, having adequate light is both a prevalent and pivotal factor in their responses. Related descriptors such as "Fair" (105.5) and "Bright" (92.2) suggest that while light levels are perceived as sufficient, there may also be issues with excessive brightness. In terms of feelings, "Comfortable" (99.8) and "Satisfactory" (80.5) suggest that some participants feel content in this environment, possibly appreciating the abundant daylight. For view quality, "Street view" (210.5) and "Greenery view" (135.8) emerge as important elements, indicating that exterior views, particularly natural or urban scenes, are valued even in brighter spaces. Regarding shading devices, "No shading device" (156) and "Vertical blind" (139.1) show moderate centrality, implying that while shading is sometimes desired, it may not be consistently used or considered necessary by all participants in overlit conditions.

- *Theme 2: Daylit Zone*

In the "Daylit zone," which likely represents a more moderate lighting environment, participants' *feelings* are more diverse, including "Active" (69.6), "Cozy" (32.3), "Gloomy" (25.6), "Happy" (25.6), and "Sleepy" (15.5). This mix of responses suggests that participants have varied emotional reactions to this zone, possibly influenced by individual preferences and specific lighting qualities. For *daylight* *quality*, "Exposure to sunlight" (50.1) is the most central response, indicating that participants in the daylit zone are aware of sunlight exposure, though it is generally lower than in the overlit zone. Responses like "Poor light" (42) and "Very good" (30.3) highlight a mix of satisfaction levels, with some participants perceiving light as insufficient or perfectly adequate. In terms of *view quality*, the limited response of "Don’t have any view" (22.3) suggests that a lack of view is a defining characteristic for some participants in this zone. *Shading device* usage is low, with only "Horizontal blind" (17.3) mentioned, implying minimal intervention with blinds in this setting.

- *Theme 3: Underlit Zone*

The "Underlit zone" has the lowest centrality, indicating limited participant engagement or fewer concerns expressed in this environment. In terms of *feelings*, only "Anxious" (4.4) is noted, suggesting a potential link between low light levels and discomfort or unease among participants. For *daylight quality*, responses like "Excellent" (7.47) and "Dark" (6.5) reflect some contrasting views, where some participants may appreciate the subdued lighting while others find it insufficient. The absence of *view quality* (0) suggests that views are either non-existent or unremarkable for participants in this zone. As for *shading devices*, "Mesh or tented glass" (7.3) and "Light shelf" (1.1) show very low centrality, implying these devices are uncommon or rarely impactful in underlit spaces.

Each theme reveals unique participant preferences and perceptions related to their lighting conditions. The "Overlit zone" shows the highest level of participant engagement, with strong associations with daylight and view quality. The "Daylit zone" reflects a balanced lighting condition, eliciting mixed feelings from participants, ranging from coziness and activity to occasional gloominess. In contrast, the "Underlit zone" is characterized by limited views and is linked to potential feelings of anxiety among participants.

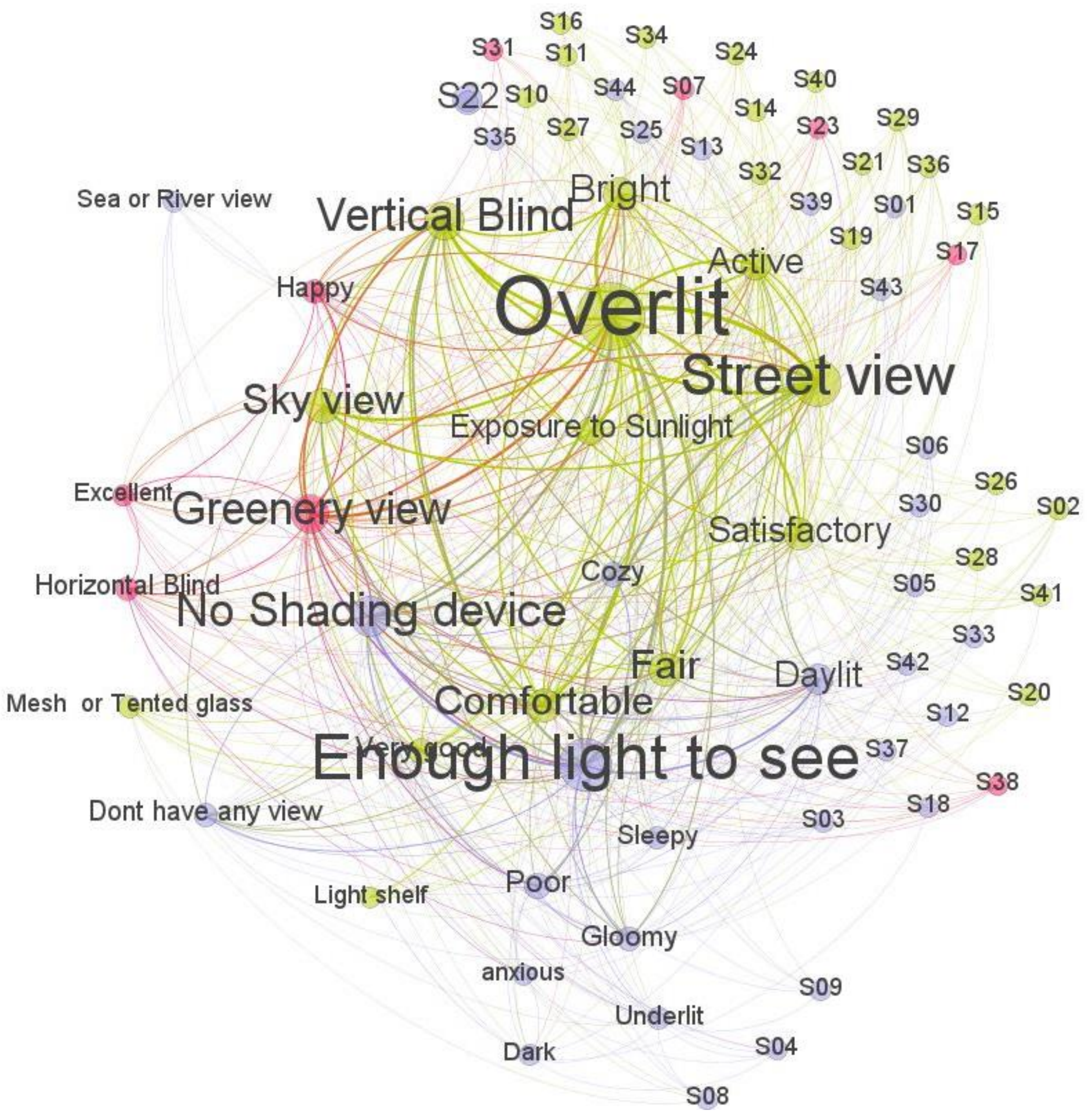


Figure 4-25: Network map analysis – visualisation of qualitative data using Gephi software (Source: Author)

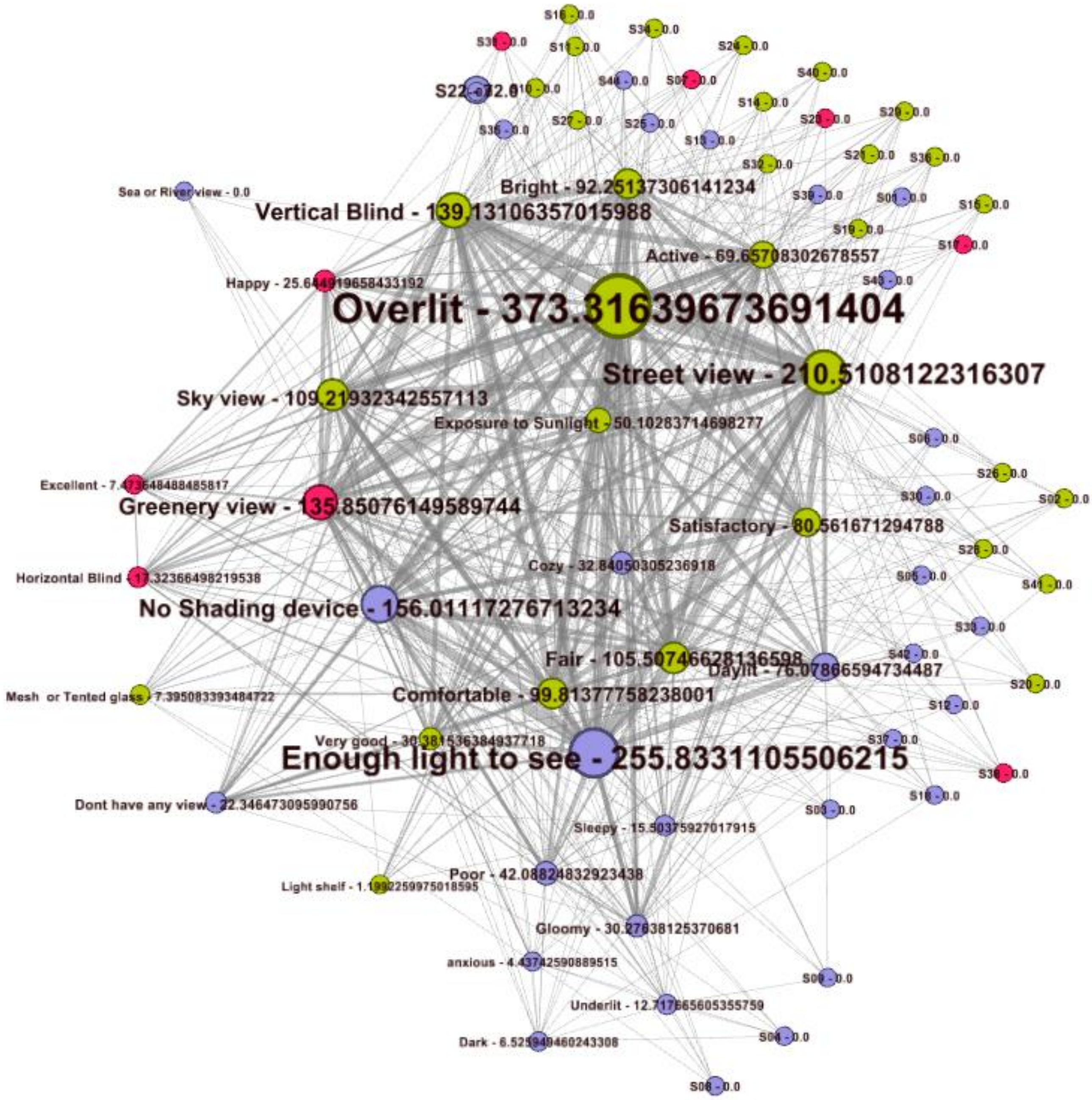
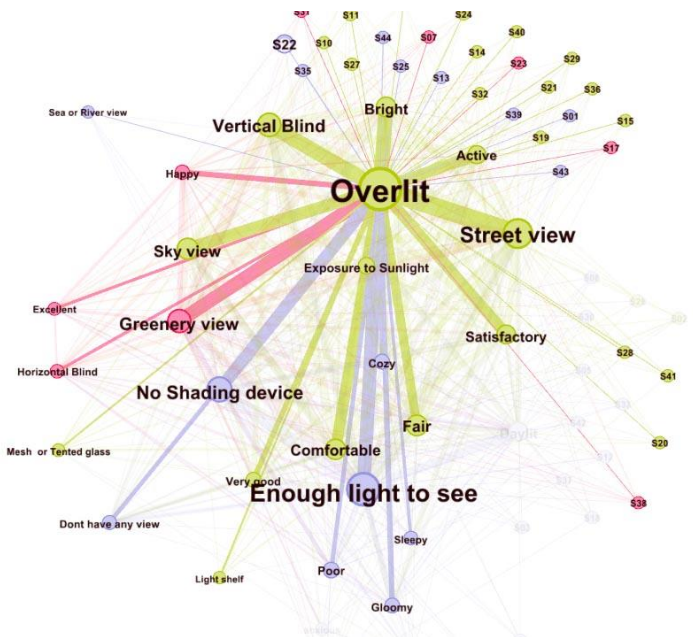


Figure 4-26: Variables betweenness centrality (Source: Author).

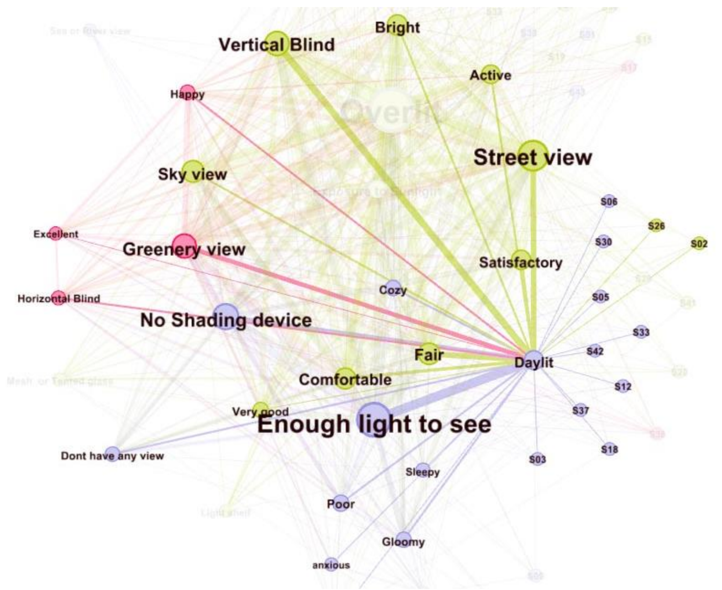
	Id	Label	Betweenness Centrality
Themes associated 01	1	Overlit	373.316397
	10	Enough light to see	255.833111
	20	Street view	210.510812
	28	No Shading device	156.011173
	24	Vertical Blind	139.131064
	19	Greenery view	135.850761
	21	Sky view	109.219323
	15	Fair	105.507466
	4	Comfortable	99.813778
	12	Bright	92.251373
	14	Satisfactory	80.561671
Themes associated 02	0	Daylit	76.078666
	3	Active	69.657083
	13	Exposure to Sunlight	50.102837
	16	Poor	42.088248
	5	Cozy	32.840503
	18	Very good	30.381536
	7	Gloomy	30.276381
	9	Happy	25.64492
	22	Dont have any view	22.346473
	25	Horizontal Blind	17.323665
	8	Sleepy	15.503759
Themes associated 03	2	Underlit	12.717666
	17	Excellent	7.473648
	26	Mesh or Tented glass	7.395083
	11	Dark	6.525949
	6	anxious	4.437426
	27	Light shelf	1.199226

Figure 4-27 Themes associated to daylight zones by Betweenness Centrality order



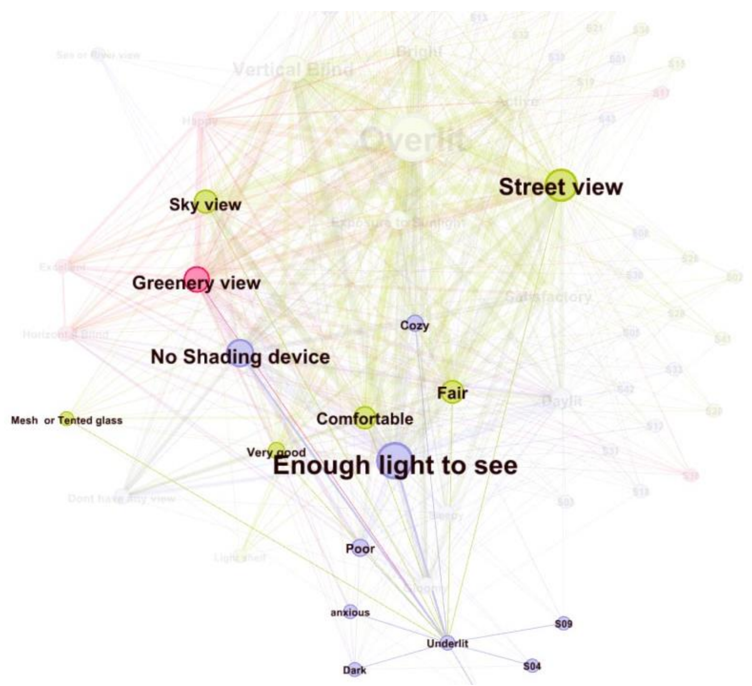
Comfort and well-being themes associated based on betweenness centrality factor				
	Feeling	**Daylight quality**	**View quality**	**Shading devices**
Overlit zone	Comfortable Satisfactory	Enough light to see Fair Bright	Street view Greenery view Sky view	No shading Vertical

Figure 4-28: Themes associated with the overlit zone (Source: Author).



Comfort and well-being themes associated based on betweenness centrality factor				
	Feeling	Daylight quality	View quality	Shading devices
Daylit zone	Active Cosy Gloomy Happy Sleepy	Enough light to see Poor Very good	Don’t have any view	Horizontal blind

Figure 4-29: Themes associated with the daylit zone (Source: Author).



Comfort and well-being themes associated based on the Betweenness centrality factor				
	Feeling	Daylight Quality	View Quality	Shading devices
Underlit zone	Anxious	Excellent Dark	Do not have any view	Mesh or tent glass Light shelf

Figure 4-30: Themes associated with the underlit zone (Source: Author).

4-6 Conclusion

The findings of this chapter evaluate participants' perception of daylight quality and outside view in their work environments. A spatial cognitive mapping (SC_{map}) methodology was used to obtain participants' hierarchical knowledge structure and mental model of daylight and outside view quality in a daylit zone. Overall, each theme shows distinct participant preferences and perceptions based on their lighting conditions, with the "Overlit zone" showing the highest participant engagement and connection to daylight and view quality, while the "Underlit zone" is associated with limited views and potential feelings of anxiety.

To test the research hypothesis and define the level of association between the correlated variables, there is a need to use likelihood ratio tests. These test results prove the variables of daylight illuminance, daylight distribution, location and feelings have strong associations with a Significance P-value of 0.005. The mental map of participants (network map analysis) was used to define the most significant factors that affect occupant satisfaction with daylight and view quality inside their workspace. The betweenness centrality metric was used as an indicator to define most terms used by participants in the overlit, daylit and underlit zones.

CHAPTER 5: Quantitative Assessment of Visible Outside View Quality as a New Indicator to Measure Well-Being Potential (Stage 2)

5-1 Introduction[1]

Viewing the natural environment from inside homes and workplaces has been recognised by several scholars as having an impact on improving health and well-being. Research has shown that a combination of outdoor elements – such as blue sky, sea view and greenery – is highly preferred as these elements are therapeutic for human well-being. However, installing shading systems is an important strategy for passive building cooling but it could affect our sense of connection to the outside environment. Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analysing the geometry outside using 2D and 3D software. The software needs the outdoor environment to be fully built accurately in the simulation, takes more time and may cause a system crash. This thesis presents a new facilitation tool to quantify the visible outside view (VOV) by analysing the outside view image by converting the view content into red, blue and green (RGB) pixels using an image processing technique. VOV measures the occupant's ray-tracking percentage to the visible outside view content taking into consideration the blind factor of shading. An indicator starting from 0% to 100% quantifies the outside view content including shading systems, which then measures the overall VOV related to the VOV quality as a factor of well-being potential (WP).

In current building standards, the introduction of the WELLv2™ standard is one of the most crucial aspects that aim to enhance occupant health and well-being (WELLv2, 2021) compared with sustainability rating systems (Schweizer et al., 2007). WELLv2 indicates that many factors could affect occupants' subjective well-being in a space, such as view quality, thermal comfort, noise impact and daylight (Farley & Veitch 2001). WELLv2 also recommends that the occupants' ability to interact with the outside view through windows has a psychological impact. This connection with the outside environment can contribute to the comfort and well-being of occupants because the interaction with direct sunlight and natural landscape elements can reduce stress and improve worker performance (Farley & Veitch 2001). View quality as a component of well-being factors in the building rating system is measured based on three metrics related to window design: (i) view access, (ii) view clarity

[1] The work presented in this chapter was originally published as,
Abdelrahman, M., Coates, P., & Poppelreuter, T. (2023b). Visible outside view as a facilitation tool to evaluate view quality and shading systems through building openings. *Journal of Building Engineering*, Volume 80. https://doi.org/10.1016/j.jobe.2023.108049

and (iii) view content (Ko et al., 2021). View access is defined as the sight angle to the outside environment; view clarity is defined as the visible transmittance for the window material (tent glaze or shading); and view content is related to how many layers are seen from the outside. Several studies evaluated the outside view quality based on subjective assessments using questionnaires that asked participants to rank photos to different outside views (Matusiak & Klöckner, 2016; ; Ko et al., 2021; Lin et al., 2022; Li & H. 2020); others evaluated view access by running a simulation process to measure sight line ratio to sky view through building opening (Bluyssen, 2009; Hellinga & Hordijk, 2014) and yet others assessed view content by ray-tracking occupant sight lines to outside view elements (Turan et al., 2021) or by rendering photorealistic views of the visible outside environment through windows opening with shades (Lee & Matusiak 2022).

This chapter examines the missing pieces by assessing the impact of view content and clarity in vertical and horizontal shading design. Interestingly, The literature review shows that, no method or metric has been found to measure the visible outside view (VOV) content ratio, which refers to the outside view content and clarity ratio (greenery, sky, context) that occupants can see through a window with a shading device installed at the same time. The proposed Multi-criteria approach takes into account the impact of shading systems on daylight quality and visual comfort.

The shading systems can affect view quality and are determinant aspects of passive building cooling strategies. Thus, a combined approach taking into account the obscuration of outdoor elements, building energy efficiency and occupants' thermal and visual comfort is needed. Although passive cooling shading is an important consideration, dealing with it is outside the current scope of the research undertaken. Several researchers focused only on assessing daylight and view access using computational methods (Pettersson, 1988) considering view access percentage (Turan et al., 2021), shading device parameters (Lee & Matusiak, 2022) and glare issues (Pettersson, 1988(. Although these approaches optimise daylight and view quality, only view access and view clarity have been considered. Moreover, existing tools are sometimes too complicated and need the outside environment to be fully built using three-dimensional (3D) modelling software (Lee & Matusiak, 2022), and some tools are not designed to simultaneously optimise between the optimal shading device and view quality.

WHO stated that the natural environment has a direct impact on our health and well-being and stated that most green spaces have positive effects on overall mental health, quality of life and subjective well-being (World Health Organization, 2021b). A study conducted by Mourato & MacKerron (2013) revealed that over 20,000 self-reported responses from the United Kingdom and overseas participants thought that the view quality to nature has a significant and direct impact on occupant well-being and happiness. According to WHO and LEED, three factors have been proposed for analysing view quality: view access, view clarity and view content. In the following sections, a critical overview of view quality measurements found in standards and building rating systems is provided for a deeper understanding of view quality assessment.

This chapter is structured into four main sections, following this introduction. Section 5-2 provides a general overview for those who are not deeply involved in the topic; this is through a critical review of the assessment criteria found in building rating systems and standards to measure view quality followed by a critical review of previous research to define the research gap. Section 5-3 is an explanation of the parametric algorithm method to assess outside view quality (i.e. VOV) by using the image sampler technique. Sections 5-4 provide an analysis of applying the algorithm to different outside view scenes and present the associated well-being potential. The algorithm is applied to a case study in Egypt, Cairo to test the system process. Outcomes and discussion are presented in Section 5-5.

5-2 Definition of Visible Outside View Quality Indicator (VOV)

As indicated in Chapter 2, most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analyzing the geometry outside using 2D and 3D software. In our perspective, there are drawbacks to each method; wellbeing is a subjective matter and the study needs to be objective to be more scientific; therefore, there is a need for both qualitative and quantitative data. In addition, using ray-tracking methods needs the outdoor environment to be fully built into the simulation software, which takes more time to complete the simulation and iteration process. Although prior research has identified a few methods that could be used in assessing view quality, such as Lee & Matusiak, 2022 and Turan et al., 2021, both methods have the same drawbacks related to the time consumed and the level of accuracy needed to build the outside view environment (trees, buildings, and other objects).

For view quality assessment, a new parametric algorithm is established to measure the connection with the outdoor environment using two metrics: (i) direct lines of sight (DLS) that present view access to the outside and (ii) view content by calculating the percentage of FOV of the visible outside view ratio content and clarity through any obscure physical element such as shading device.

To address the challenges mentioned, we introduce a new facilitation tool to quantify the view quality that combines view content (greenery, sky, context) and view clarity (shading system) in one indicator called VOV. This algorithm applying the Image Sampler plugin and Isovist Ray-Tracking technique found in Grasshopper, a cutting-edge parametric modelling tool that works with Rhino software to allow a new powerful and efficient way of designing the virtual environment (Rhino software, https://www.rhino3d.com/). This plugin will be used to create a complex series of parametric and mathematical relationships to quantify occupant sight lines through the shading device as a blind element to the outside view content. VOV at any test point is a percentage that present the view clarity and view content together taking in consideration the blind factor of shading devices installed as follows: VOV content + clarity (VOV sky, greenery, mass − blind ratio). A parametric analysis between the internal field of view (FOV) and outside view content was performed by importing the outside view image and converting the view content into red, blue, and green (RGB) pixels using the image sample modifier. These pixels were connected with the occupant's FOV and the shading device was defined as a blind element to the outside view clarity. This new tool quantifies the ray-tracking percentage, ranging from 0% to 100%, to enhance the evaluation of view content quality. It specifically assesses the blue ratio of the sky view and the green ratio of landscape elements as factors contributing to well-being potential (WP). The tool measures the overall percentage of View Out Value (VOV) content and clarity, including VOV sky, greenery, and mass, while accounting for the blind ratio, which is defined by the pixels obscured by the installed shading device. A two-dimensional (2D) map is provided showing the WP associated with the view quality credit recommended by LEED.

The first objective of using this method is to quantify VOV taking into consideration all barriers focusing on shading devices. The proposed facilitation tool (VOV) combines view access and view content to better evaluate the actual view quality received. The second objective is to create a 2D map showing the WP score by importing an image taken with a phone or camera from a specific position inside the workspace, which can be used to identify the view quality related to test points internally.

5-2-1 Import Image Sampler

The basic logic of the image sampler technique in the Grasshopper plugin Rhino software is that the user can load an image into Grasshopper, which then analyses the image in terms of colour, pixel brightness and saturation. The results of the image analysis can be used to perform operations on geometry in Grasshopper. In computer graphics, a sample is an intersection of a channel and a pixel

(W3C, 2022). Figure (5-1) depicts a 24-bit pixel, consisting of three samples for red, green and blue related to the outside view content sky, greenery and context.

This method starts with taking panoramic shots of the outside environment from different positions 7 metres away from the window, as recommended by LEED, WELLv2 and CIBSE to assess view quality. This panoramic view represents the picture frame of the visible outside environment. By utilizing the image sampler method in the Grasshopper plugin for Rhino software, the imported image is analysed and its content is converted into RGB pixels. (Fig. 5-1). A series of complex mathematical analyses occurred to split all pixels into RGB clusters to present the sky, greenery, and context ratio.

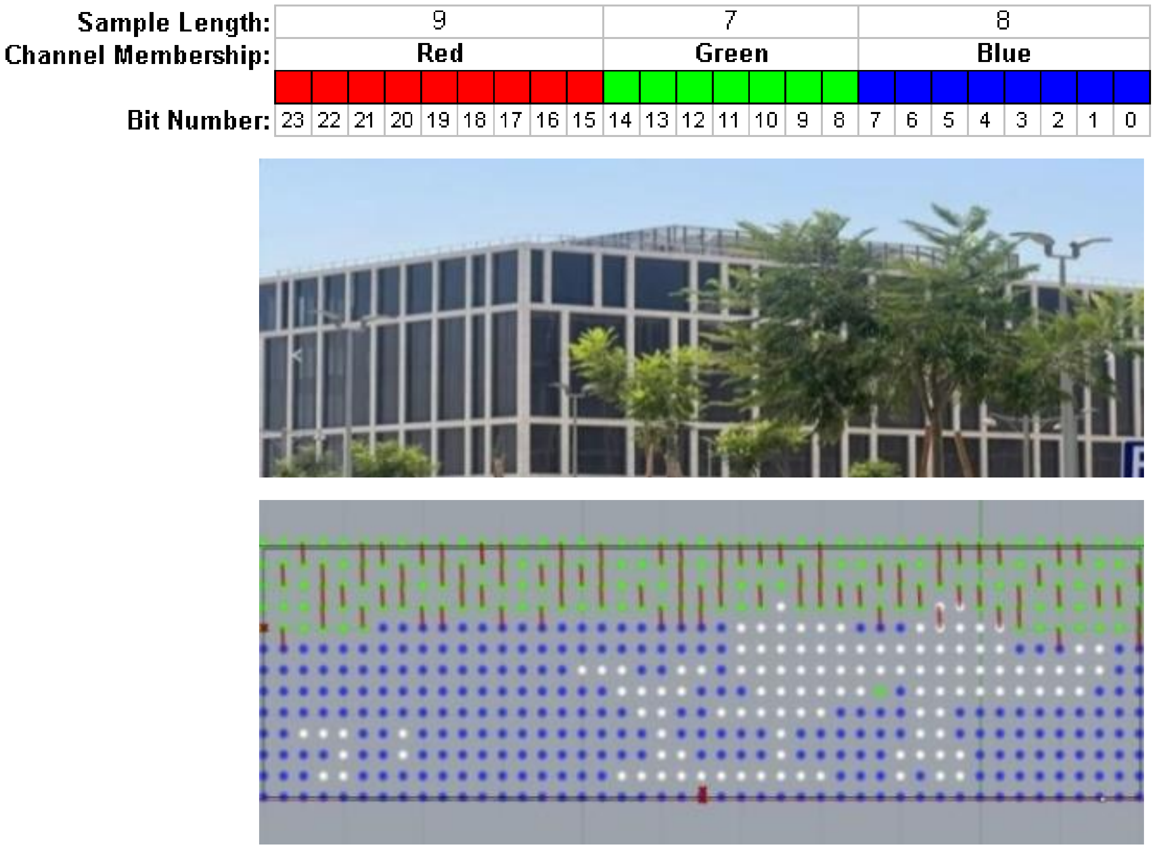


Figure 5-1: Image sampler to the outside view scene (commercial building in New Cairo, Egypt).

5-2-2 Visual Fields

This stage aims to determine the suitable test point location to establish the algorithm (Fig. 3). These test points were created in two levels related to the FOV limitation by EN, LEED, and WELLv2. As shown in Section 2.2.1, different rating systems have different requirements for testing view quality.

One of these requirements is the distance from the window, which affects the occupant's FOV. European daylighting standard EN 17037 and EN 14501 (CNE 2018; CE, 2021) state that the sight-seen angle should be at least 14 degrees and not more than 54 degrees, related to the minimum and maximum FOV. In addition, a clear view to the outside within at least 6 metres and a maximum of 50 metres is related to the standard visual acuity of 25 feet (7.62 meters). WELLv2 and LEED state that view Type 3 could be achieved if the unobstructed views are located within a distance of three times the head height of the vision glazing.

To comply with these recommendations, two test point edges are established, the first set of test points away from the window by 6 metres and the second set within three times the head height space of the floor space (Fig. 5-2).

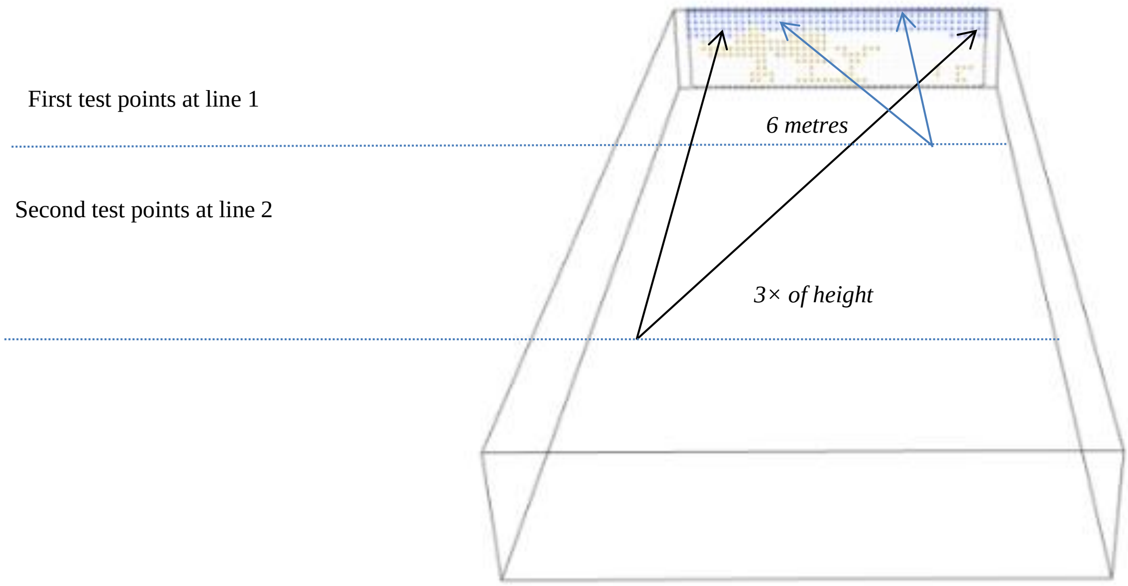


Figure 5-2: Demonstrate test-point location.

5-2-3 Quantifying Direct Line Sight (DLS)

DLS represents two indicators, the first one is related to VOV pixels (DLS_{greenery}, DLS_{sky} or DLS_{context}) and the second one represents the blinded pixels (DLS_{blind}) in case there is a shading device or anything obscure (Fig. 4). The process of computing the 2D viewing angles is established by using the Isovist ray component from Grasshopper (Fig 5-3). The VOV at the test point is defined by:

Equation 01

$$VOV = [DLS_{\text{greenery}}, DLS_{\text{sky}} \text{ or } DLS_{\text{context}}] - [DLS_{\text{blind}}]$$

The equation subtracts the obstructed sight lines (due to shading devices) from the available views, giving a net measure of Visible Outside View. In essence, the equation calculates VOV by accounting for all potential external views an occupant can see minus the areas obscured by blinds or other shading elements, where:

- *Visible Outside View (VOV):* This represents the amount or quality of the view that occupants have of the outside environment, such as greenery, the sky, or other contextual elements (e.g., buildings, streets).
- *Direct Sight Lines (DLS):* This term refers to the lines of sight available to occupants from within their indoor space. It is split into two parts:
- *[DLS greenery, DLS sky or DLS context]:* This part represents the unobstructed views that occupants can have, such as views of greenery, the sky, or other external elements. These views contribute positively to the VOV.
- *[DLS blind]:* This component represents any direct sight lines that are obstructed by shading devices (e.g., blinds) that block the view to the outside.

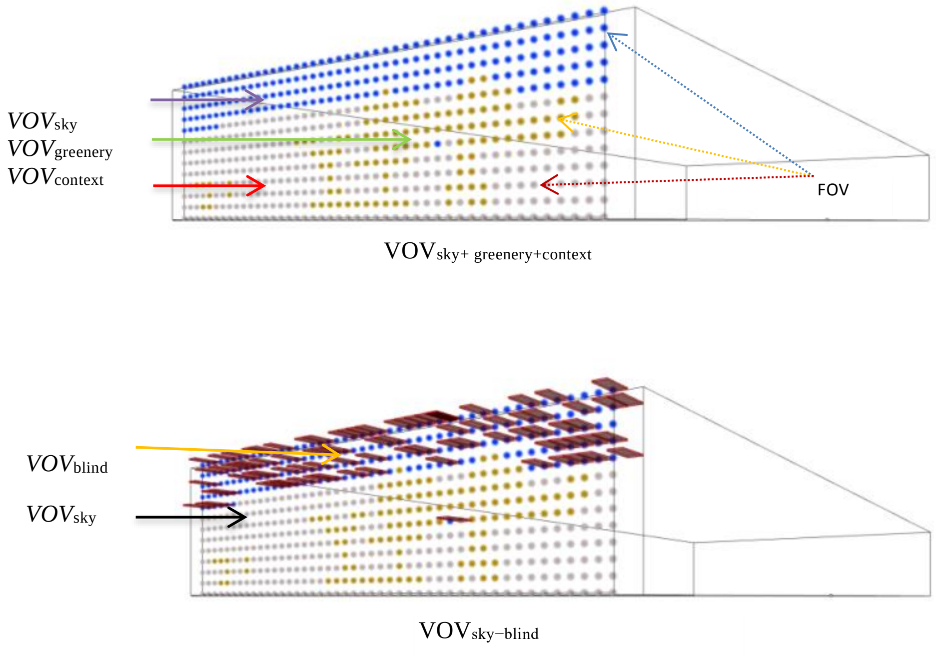


Figure 5-3: Defining shading location.

5-2-4 VOV Framework

A new parametric design approach was developed in Rhino/Grasshopper to quantify WP associated with the outside view quality. This algorithm consists of the following eight consecutive stages (Fig. 5-6):

Stage 1: Import the picture frame image to the algorithm.

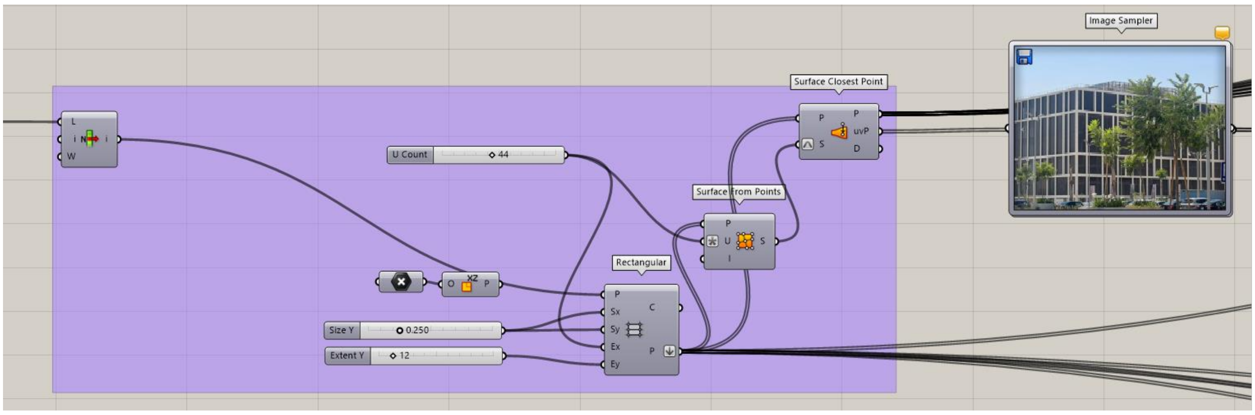


Figure 5-4: VOV assessing process.

Stage 2: Parametric modelling of the case study using Rhino/Grasshopper plugin.

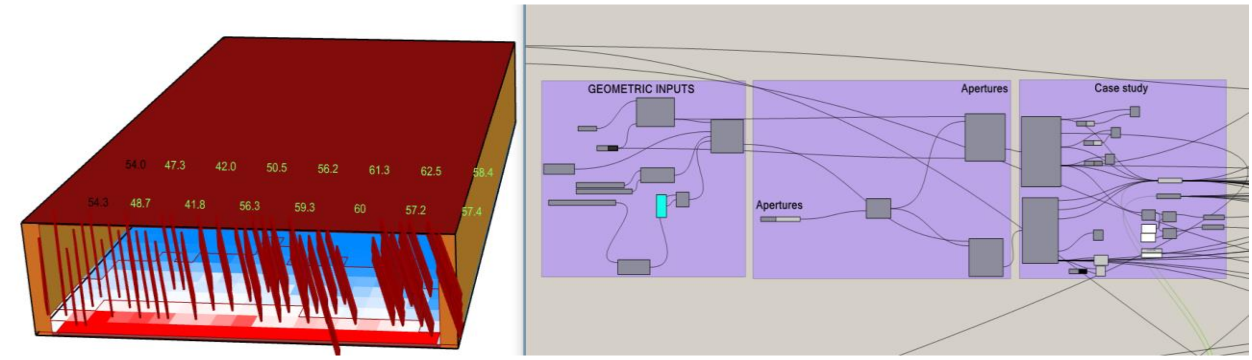


Figure 5-5: Case study modelling.

Stage 3: Carry out a parametric analysis of the outside view image by converting its colours to RGB pixels by using the image sampler and Isovist ray-tracking technique found in the Grasshopper plugin Rhino software to quantify occupant sight lines through the shading device as a blind element to the outside view content (Fig5-6,5-7,5-8).

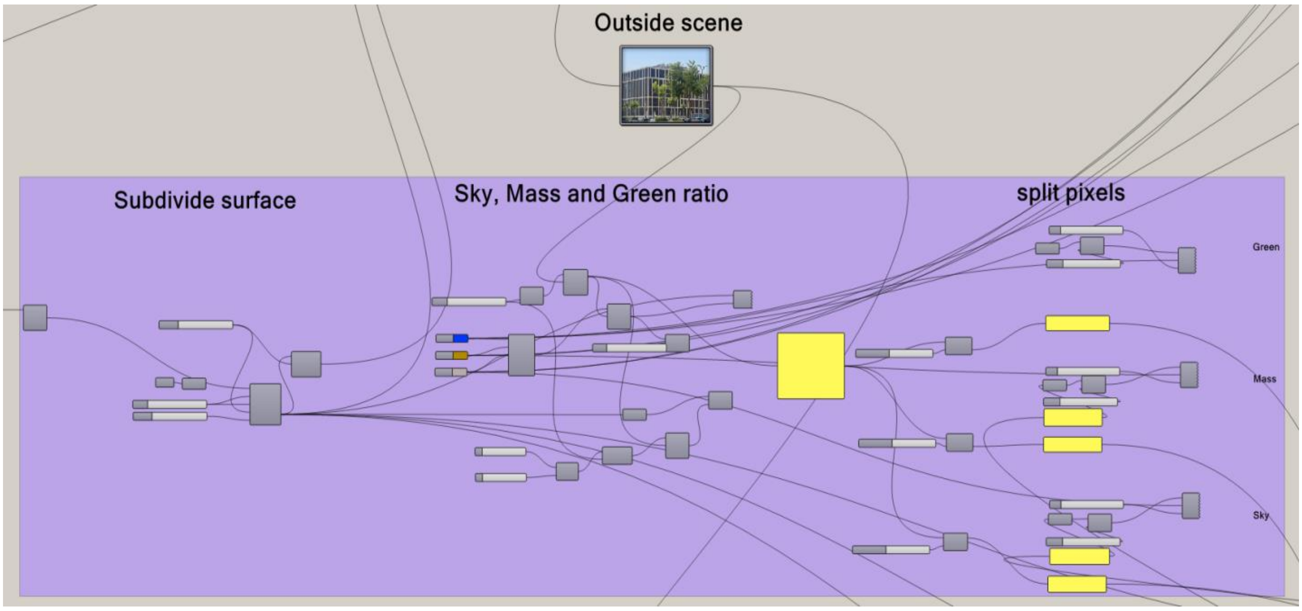


Figure 5-6: VOV image sampler to the outside scene.

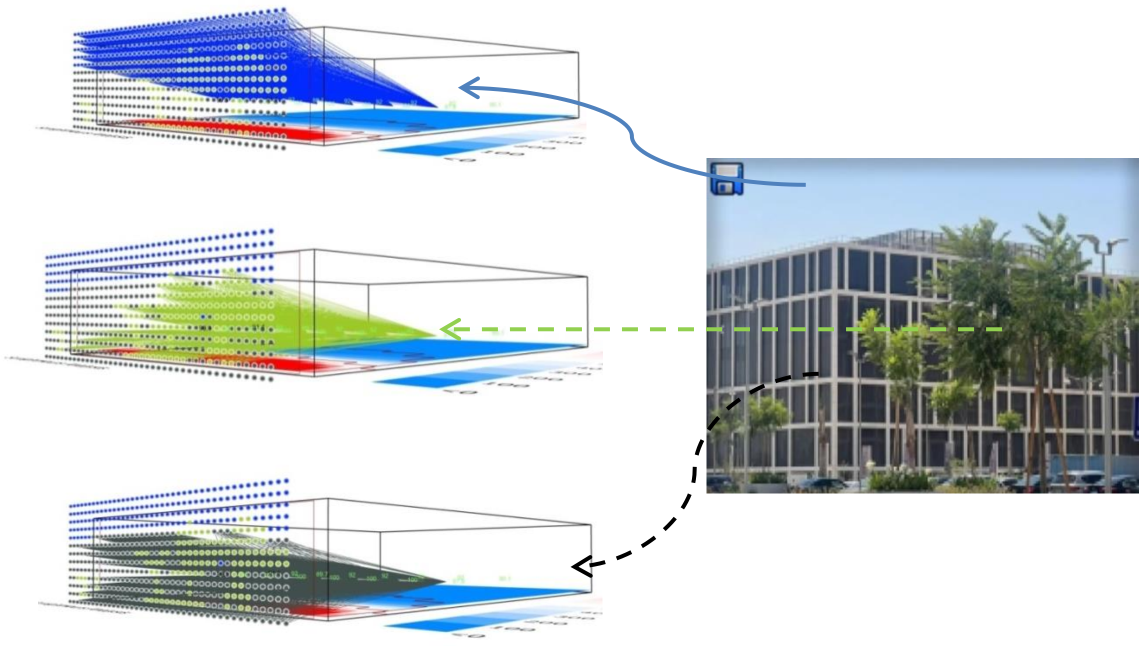


Figure 5-7: Picture to the outside scene to be analysed into sky, green and context pixels.

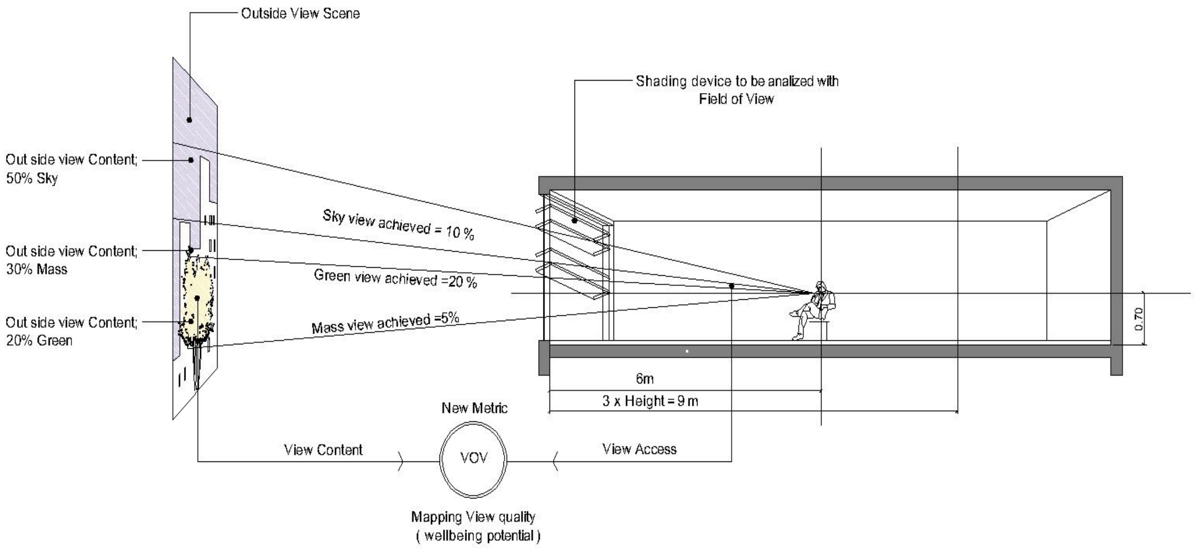


Figure 5-8: VOV assessing process.

Stage 4: Propose a percentage to measure the outside view quality based on the number of sight-seen rays from the test points located in Line 1 (6 metres away from the opening) internally (Fig 5-9).

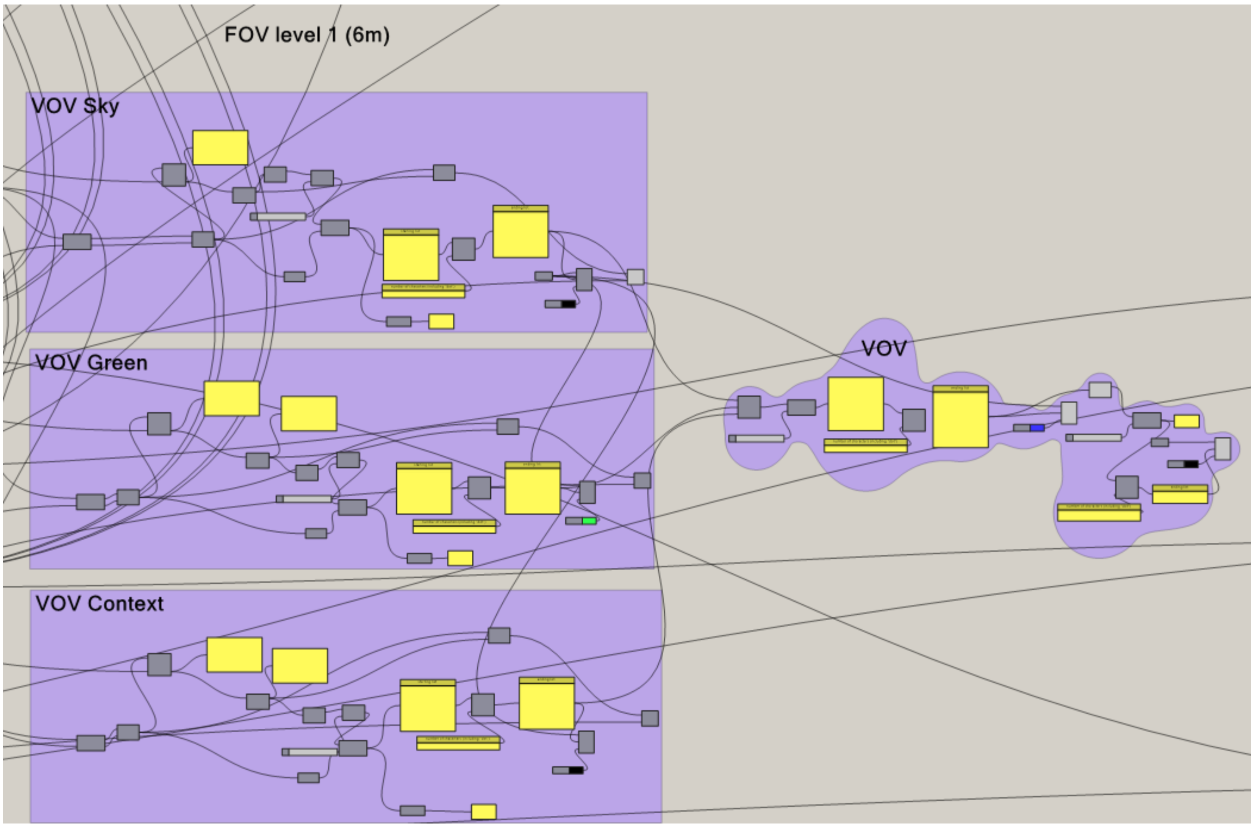


Figure 5-9: VOV process.

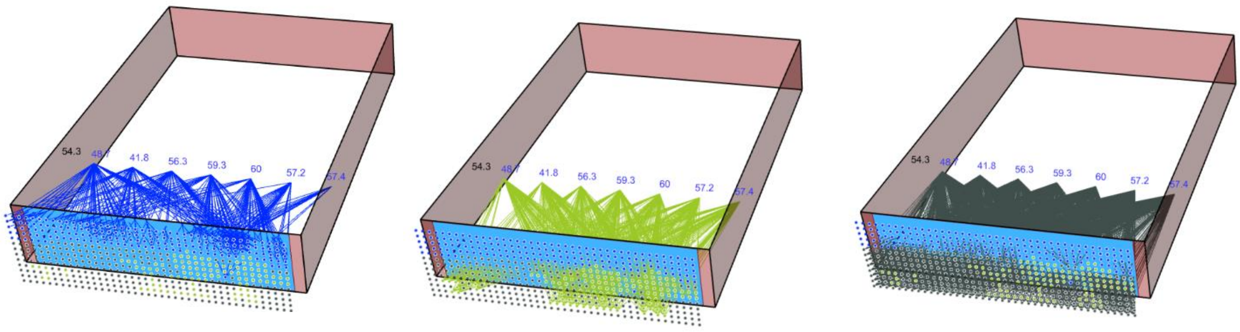


Figure 5-10: VOV values in line 1 away 6 metres away from the opening.

Stage 5: A proposed percentage to measure the outside view quality based on the number of sight-seen rays from the test points located in Line 2 (three times clear internal height away from the opening).

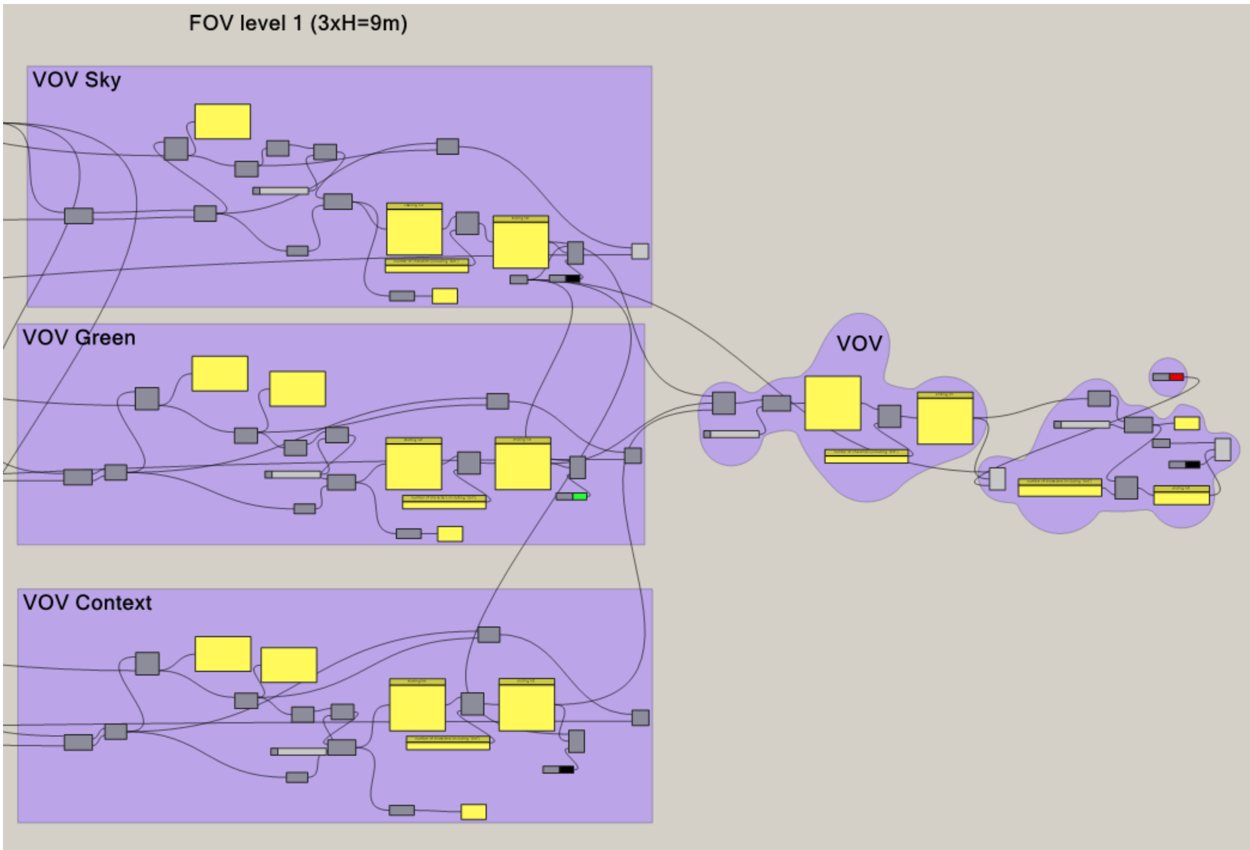


Figure 5-11: VOV process.

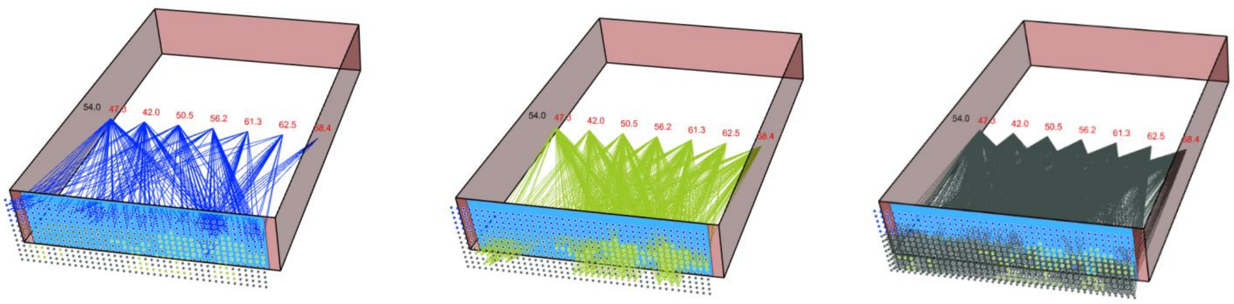
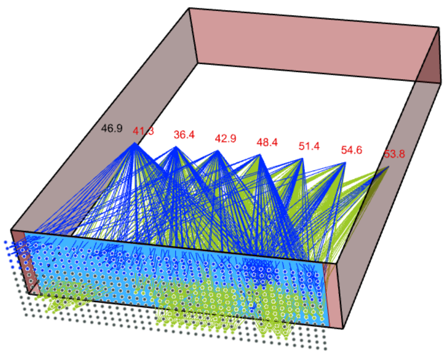


Figure 5-12: VOV values in line 2, 3 × height away from the opening.

Stages 6 and 7: Measure the wellbeing potential WP% by counting VOV to natural elements related to the picture content (green pixels for greenery, blue pixels for sky) for all test points indicated in the two lines shown in Fig (5-2) as follows:

Equation 02 $$WP\% = \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$



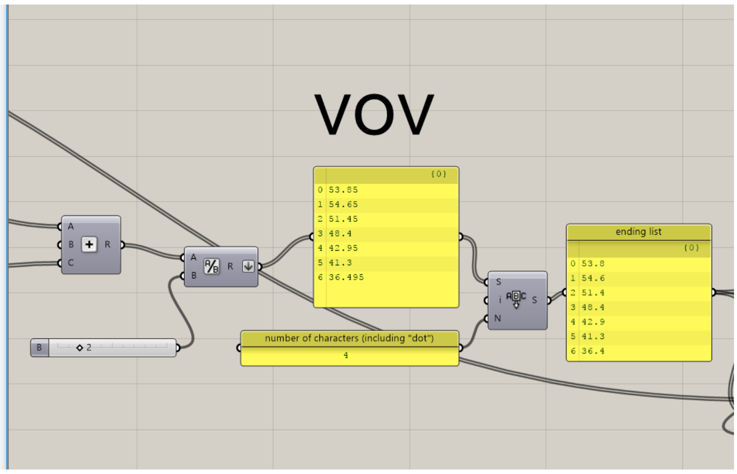


Figure 5-13: Visible outside view content (Green + Sky)

Figure 5-14: Total VOV.

Stage 8: Test how the proposed algorithm can be integrated with two types of shading systems (vertical and horizontal louvres) that are the most common shading devices used in Egypt (Fig 5-15). Finally, conduct a comparison between the three models to show the impact of using shading devices on visible view content and the view content quality as a factor of well-being potential (WP).

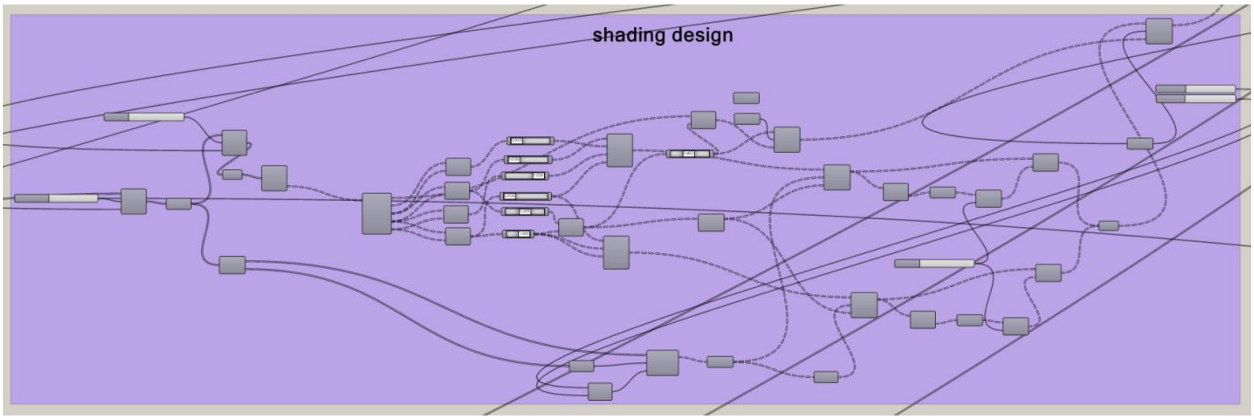


Figure 5-15: Automated shading design for testing the algorithm.

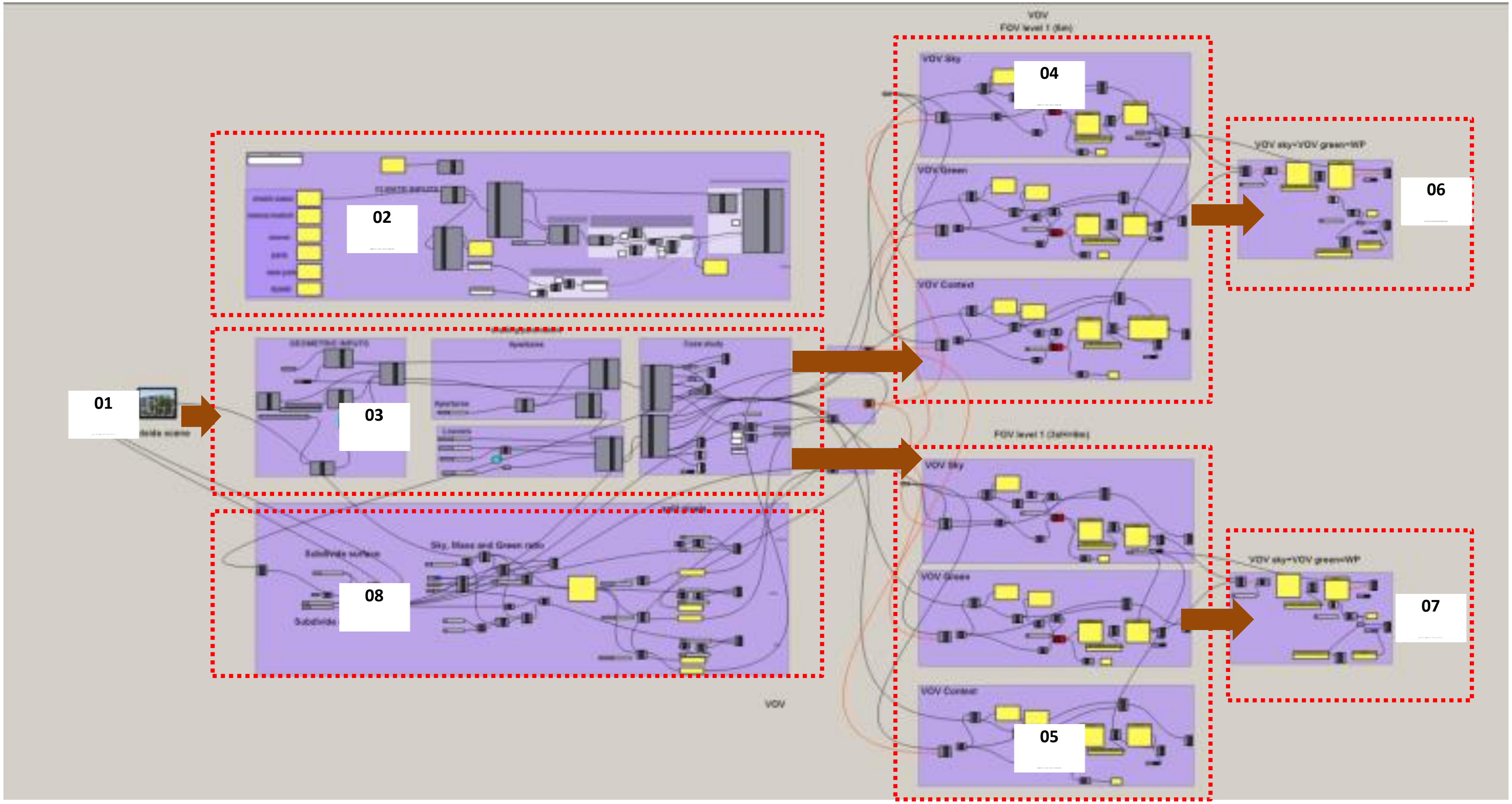


Figure 5-16: Algorithm stages.

5-3 Quantifying WP Index

5-3-1 VOV Algorithm

Previous studies have demonstrated that viewing natural elements from a residence or workplace is desirable and therapeutic for human health and well-being by reducing anxiety (CEN, 2021) and stress (Velarde et al., 2007; Ulrich, 1991) and increasing creativity (Ulrich, 1979). Studies have also shown that outside view content has a direct impact on occupant well-being (Moore 1981; Ulrich, 1979; Valdez & Mehrabian, 1994; Guilford& Smith, 1959; Jacobs & Suess, 1975; Ulrich 1991; West, 1985; Heschong 2003; Markus 1967; Domjan et al., 2023; Yao et al., 2024; Rizi et al., 2024) In the present study, to quantify WP, a parametric algorithm was established to calculate VOV content inside the space by tracing the occupant sight lines to the outside view content; three sets of lines were found related to sky view, greenery view, and context. These sight lines present the occupant’s FOV: green rays for the natural view, blue rays for sky view and black rays for the outside context as discussed in the previous section (Fig.5-7).

A parametric analysis was carried out by importing the outside view image and converting it into RGB pixels using an image sampler. After that, the algorithm connected these pixels with the test points that represent the occupant FOV internally, corresponding to 0.7 metres for seating position inside the working space as recommended by LEED (Altomonte & Allen, 2020). VOV was measured by deducting the pixels used to set the shading device to achieve daylight quality and reduce visual discomfort to be generated in the particular area determined as having a fitness value (sky zone, greenery zone, context zone).

5-3-2 Well-Being Potential (WP) Index

WP index will be identified by measuring the FOV to the outside content related to (blue ratio from sky view and green ratio from landscape elements) as a factor of well-being potential (WP). A set of test points recommended by LEED , WELLv2 and EN standards were located in two lines (Fig. 5-15): the first line presents the FOV away from the opening by 6 metres, and the second line is located within three times the space head height. A combination of elements in a coherent scene, such as blue from having a sky or sea view and green from the greenery elements that predominate nature scenes, is highly preferred as the elements are therapeutic interventions for human well-being (LEED v4 2019, ASHRAE, 2006, International Green Construction Code, 2021).

To measure the WP score, the mean value of all VOV to natural elements related to the picture content (green pixels for greenery, blue pixels for sky) set in two lines is calculated (Fig. 5-17). The area with a high VOV percentage and located in the visual comfort zone recommended by LEED, WELLv2 and EN standards will have the most WP.

The WP% equation is defined as follows:

Equation 02

$$WP\% = \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$

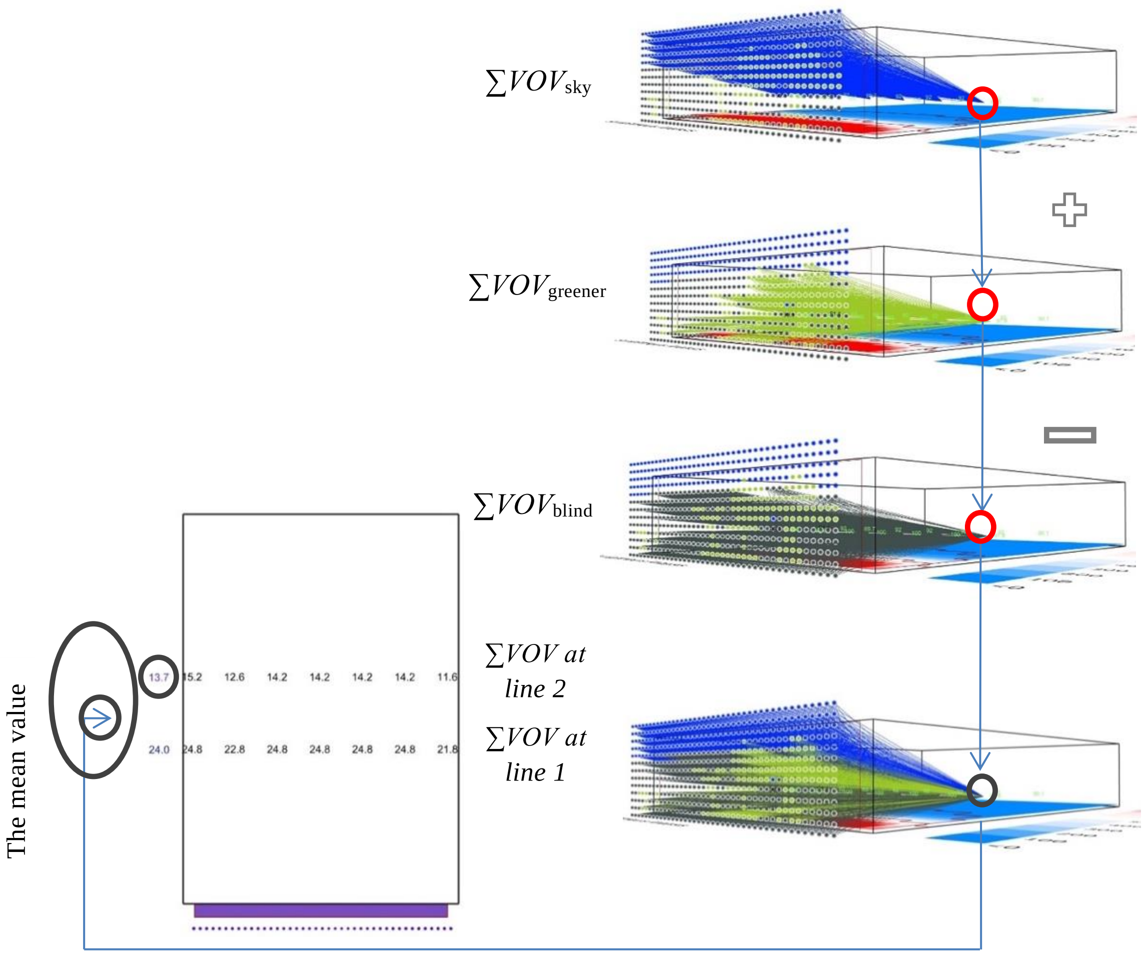


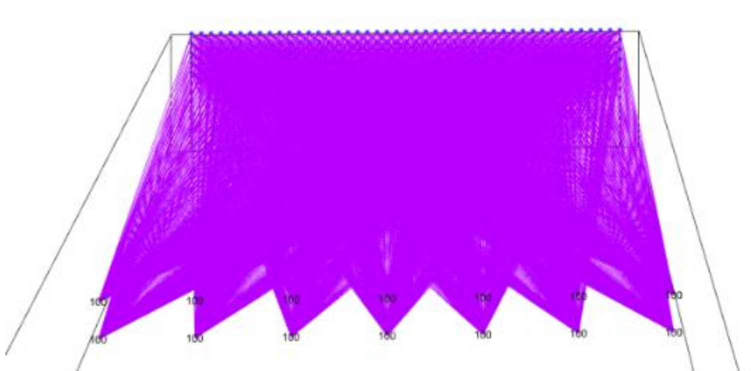
Figure 5-17: Defining visible outside view (VOV): blue pixels for sky, green pixels for greenery and black pixels for context.

This new algorithm evaluates the view quality by giving a percentage showing the WP of test points inside the workspace to measure the overall percentage of VOV according to equation 01 as shown in (Fig. 5-18).

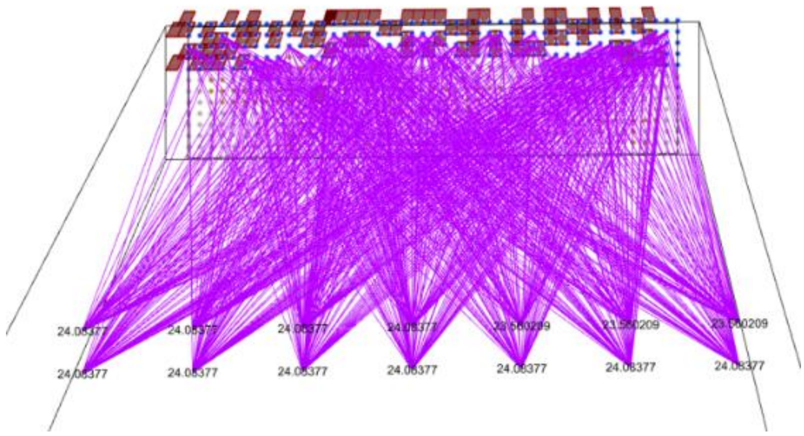
Applying the Equation 01 algorithm demonstrates the effect of shading devices on the quality of an occupant's view to the outside. In the initial scenario, with no shading device installed, the view to the sky achieves a score of 100%. This perfect score results from all available sight lines connecting to the designated blue pixels, representing an unobstructed view of the sky. Here, Equation 01 verifies that, without any obstructions, occupants enjoy a complete, uninterrupted view of the sky from inside the space.

In the second scenario, a shading device is added, which alters the quality of the visible outside view by blocking certain sight lines to the sky. The shading panels obscure a percentage of the previously available sky view, thereby reducing the connection to the blue pixels that represent sky visibility. This reduction in view is quantified as the blind factor, which measures the degree to which shading devices obstruct the view. Consequently, the Visible Outside View (VOV) score decreases by 20%, resulting in an adjusted VOV of 80%. This indicates that the shading device blocks approximately one-fifth of the sky view compared to the unshaded scenario.

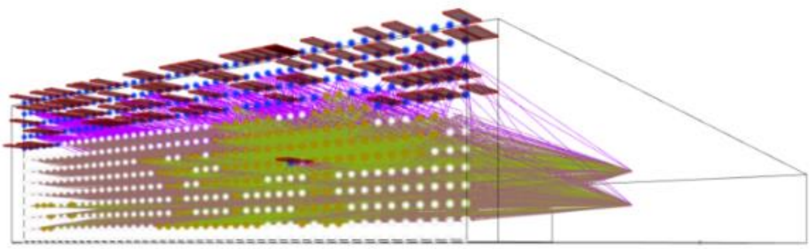
In the final scenario, Equation 02 is applied to provide a more comprehensive measure of the outside view quality, taking into account various types of visible content. This equation sums the VOV scores for both greenery and sky pixels, reflecting the quality of views of natural elements like trees, plants, or open sky. The combined score is then averaged by dividing by two, yielding the overall WP% (Window Performance Percentage) for the space. This final metric, WP%, serves as an indicator of the quality and diversity of the visible outside view content available to occupants, integrating the effects of both shading devices and diverse visual elements into a single percentage that represents the holistic outside view quality in the space.



*Scenario 01_* $VOV_{sky}=DLS_{sky}=100\%$



*Scenario 02_* $VOV_{sky}=DLS_{sky}-DLS_{blind}= 80\%$



*Scenario 03_* $WP\% = (VOV_{sky}+VOV_{greenery})/2$

Figure 5-18: Defining WP.

5-4 Case Study

The case study location was a multi-storey office building in New Cairo, Egypt, consisting of seven levels with dimensions of 12 metres × 8 metres × 3 metres (Fig. 8). A three-picture window for three levels was taken from inside the space at a distance of 6 metres from the façade, as recommended by building rating systems (Fig. 5-15). To comply with the view quality requirements in rating systems, the glaze is assumed to have visual transmittance of 0.7 to provide a clear image of the exterior, not obstructed by frits, fibres, patterned glazing or added tints that distort colour balance, as recommended by LEED and WELLv2 on view quality. A 3D modelling of the case study location was built in Rhino and then imported into the Grasshopper plugin. The study started by quantifying the VOV score to the base model (clear glass without a shading device). Three views were imported into the algorithm, the first view taken from the first floor, the second view from the third floor and the third view from the fifth floor (Figs. 5–19 to 5-26).

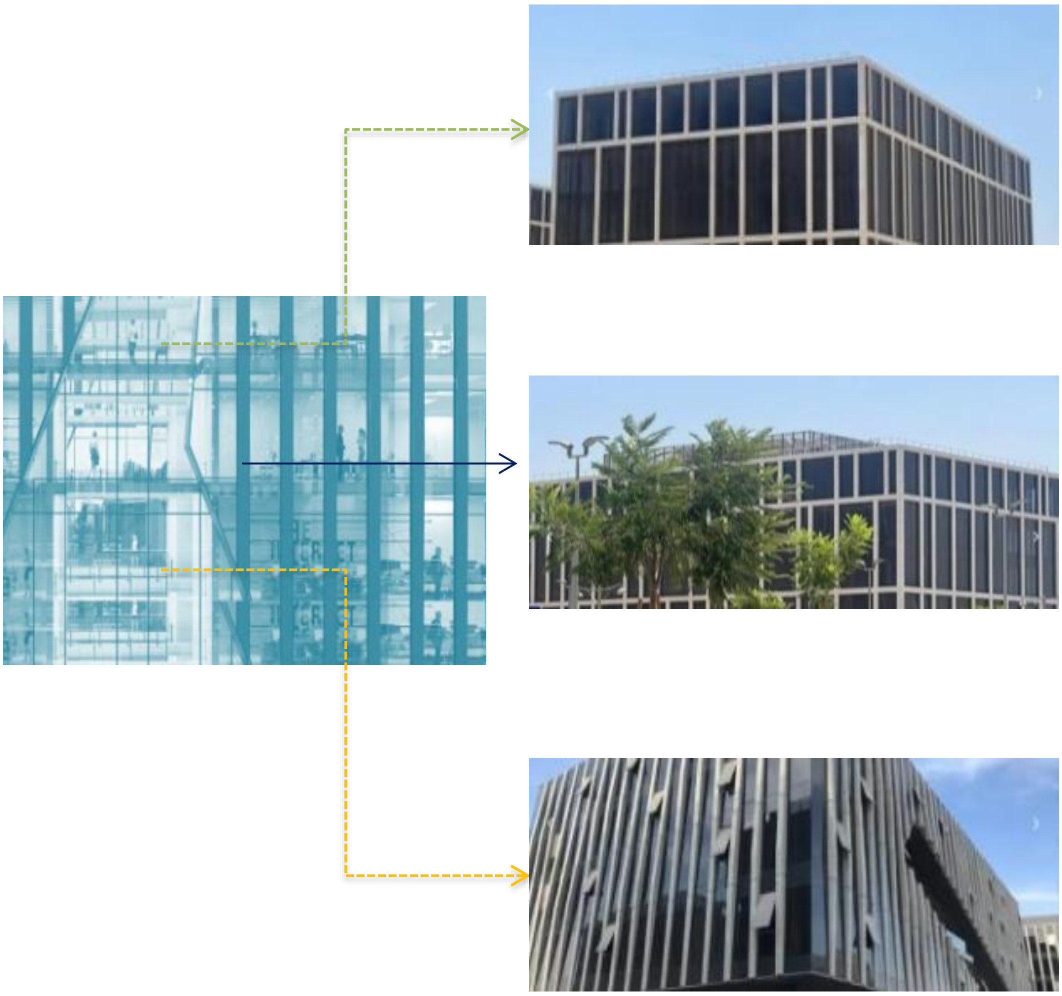


Figure 5-19: Outside view photos taken from the first floor, third floor and fifth floor.

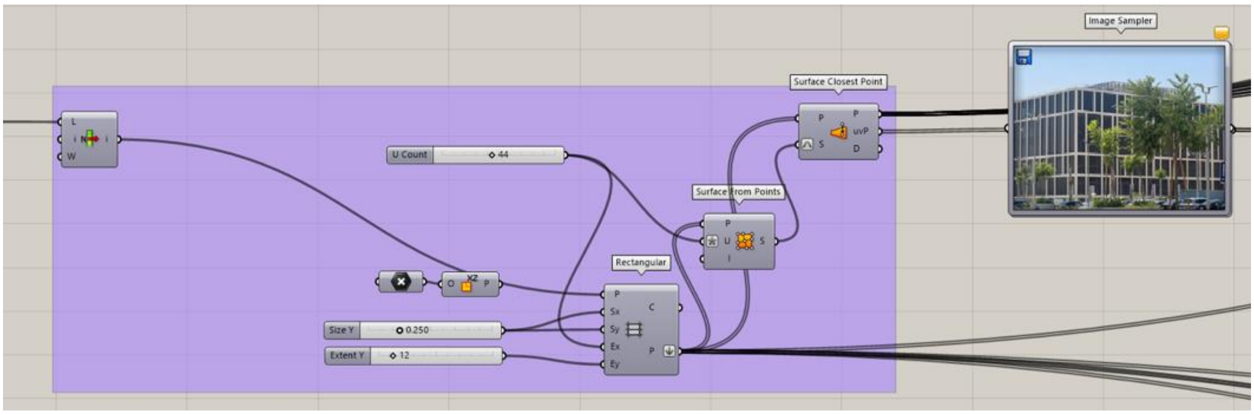


Figure 5-20: Insertion of the outside view image to be analysed.

- Vertical shading system

Figure 5-21:Outside view.

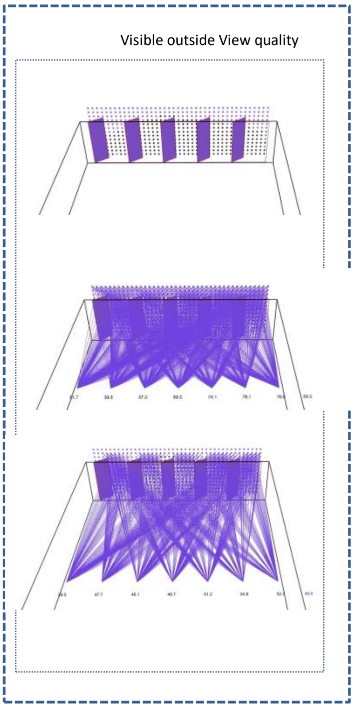


Figure 5-22: VOV algorithm.

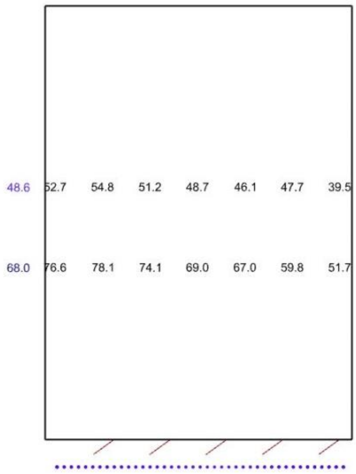


Figure 5-23: Test points

.

- Horizontal shading system

Figure 5-24: Outside view.

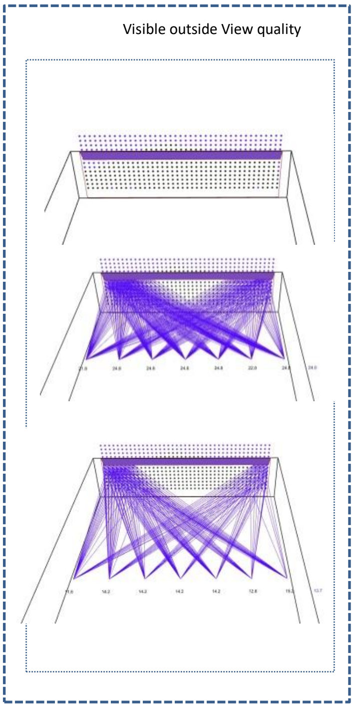


Figure 5-25: VOV algorithm.

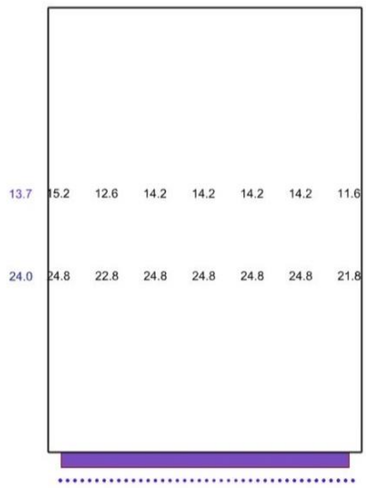


Figure 5-26: Test points

5-5 Results and Discussion

This section presents the results of applying two kind of shading systems in a case study in Egypt to assess view quality and WP. The algorithm proposed using two sets of test points recommended by LEED and WELLv2 to assess view quality; the first test point presented by Line 1 was away from the window by 6 metres and the second at a distance of three times the head height space of the floor space. Initially, three levels were assessed for comparison – first, third and fifth floors – by taking a panoramic photo of the outside view from the nearest point to the window to have a clear image without any obstructions (Fig. 5-19).

The VOV algorithm analysed the view content by splitting any photo content into three pixels (sky, green and context). By tracing FOV from all the test points to these pixels, the algorithm evaluated the view quality based on the VOV ratio taking into consideration the shading configuration that obscures some area to the outside. In our study, this is called ‘VOV blind’. WP is presented as the VOV ratio of sky and green pixels; the greater the ratio, the higher the WP. To investigate the impact of each shading device on view quality, visible view content ratio and WP ratio are introduced and discussed (Tables 5-1 and 5-2).

Table 5-1: VOV ratio using the horizontal shading system

Shading type		Horizontal shading								
Metrics		DLS for test points							Well-being potential	
Test points		T1	T2	T3	T4	T5	T6	T7	VOV	WP total
Picture frame 1	Test line 1 (6 m)	21.8	24.8	24.8	24.8	24.8	22.8	24.8	24.0	18.85%
At first floor	Test line 2 (3× height)	11.6	14.2	14.2	14.2	14.2	12.6	15.2	13.7	
Picture frame 2	Test line 1 (6 m)	51.2	51.5	51.5	51.5	51.5	51.3	51.5	51.2	47.5%
At third floor	Test line 2 (3× height)	43.9	43.9	43.9	43.9	43.9	43.0	44.5	43.8	
Picture frame 3	Test line 1 (6 m)	68.2	68.8	68.8	68.8	68.8	68.6	68.8	68.6	64.8%
At fifth floor	Test line 2 (3× height)	60.6	61	61	61	61	61	61.4	61	

Table 5-2: VOV ratio using the vertical shading system

Shading type		Vertical shading								
Metrics		DLS for test points							Well-being potential	
Test points		T1	T2	T3	T4	T5	T6	T7	VOV	WP total
Picture frame 1	Test line 1 (6 m)	51.7	59.8	67.0	69.0	74.1	78.1	76.6	68.0	58.3%
At first floor	Test line 2 (3× height)	39.5	47.7	46.1	48.7	51.2	54.8	52.7	48.6	
Picture frame 2	Test line 1 (6m)	42.3	51.9	62.1	67.0	73.5	78.2	75.6	64.3	61.15%
At third floor	Test line 2 (3× height)	42.6	51.3	56.2	56.7	60.4	64.0	63.3	56.3	
Picture frame 3	Test line 1 (6 m)	48.5	54.6	61.3	68.7	74.4	84.4	77.0	67	64%
At fifth floor	Test line 2 (3× height)	49.4	55.7	57.9	60.9	65.5	70.6	68.3	61.1	

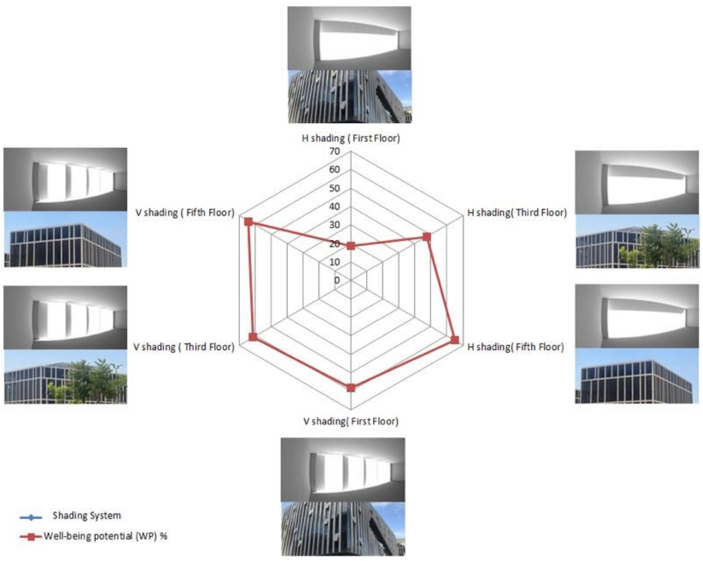


Figure 5-27: Impact of horizontal and vertical shading system on well-being potential.

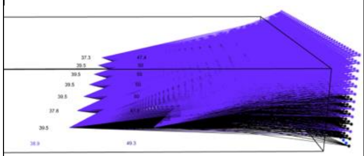
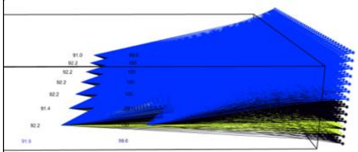
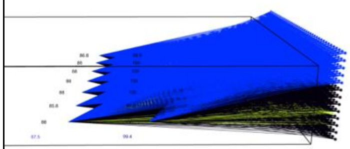
5-5-1 VOV

According to the ASHRAE 90.1 standard, in this case study the maximum WWR is achieved with the detail of input parameters of the case study dimensions. The ray-tracking to the outside view and the VOV from Grasshopper are generated to quantify the view content ratio. The large window size allows sufficient view to the outside but shading devices can obscure the view clarity. Two kinds of shading systems (horizontal and vertical) were tested for the first, third and fifth floors to evaluate the view content and clarity and the WP (Figs. 5-28, 5-29, 5-30). According to LEED and WELLv2, view content can be assessed if at least two of the following are achieved: (i) flora, fauna or sky; (ii) movement; and (iii) objects at least 25 feet (7.62 meters) from the exterior of the glazing, which is presented in our study by test points located in Line 1.

Regarding view clarity, LEED v4 and WELLv2 define it by the unobstructed view ratio located within a distance of three times the head height of the vision glazing. View performance in the case study satisfied the recommended value by LEED v4 and WELLv2, as all of the space has view access to the outside without shading devices. The view content analysis in the case study reveals that at the first floor (i) 90% of test points at Line 1 are located at a distance of three times the window head height; and (ii) 80% of multiple lines of sight to vision glazing have at least 90 degrees. Accordingly, 80% of the office room has satisfactory view quality without installing any type of shading system since the majority of test points have passed two out of three off view quality credits (Table. 5-3).

As recommended by WELLv2, the views of the natural elements that have blue and green colours such as sky and greenery landscape have a good potential to increase occupant well-being. The horizontal shading system used on the first floor obscures the view of the sky by 38.45% compared with the vertical shading system; therefore, the WP reaches the minimum level of 18.85% (Fig. 5-26). The lower levels do not have a clear view of the sky as the higher floors, also the view to the greenery landscape is greater on the ground floor than on the higher floors. These results demonstrate that the shading design strategy should not be the same at all levels. Although shading devices are a preferred strategy for achieving the recommended daylight levels internally, shading needs to be incorporated with the view quality in mind. The VOV algorithm proposed in this study can be used to evaluate the view content and clarity in parallel with a daylight simulation. The best shading devices will be the ones that allow building occupants a well-balanced VOV – lighting condition – energy saving potential in the extreme summer season. Thus, daylight simulation and the current algorithm need to be implemented with building energy simulation to consider this crucial aspect. This will be the only way to get efficient and sustainable buildings highly connected with the human dimension.

Table 5-3: Measure the total VOV for the base model without using a shading device.

Base model (VOV)					Image frame analysis	
Total VOV %	Test points L02		Test points L01		Image sampler	First floor level
	VOV G	VOV S	VOV G	VOV S		
L01= 49.3% L02= 39.9%	0%		0%			
						Third floor level
L01= 91.9% L02= 99.6%						
						Fourth floor level
L01= 84.5% L02= 99.4%						

5-5-2 Improvement in WP

In this section, WP results from quantifying the view content and clarity to the outside view are compared with the objective results of the three levels (first, third and fifth floors) to demonstrate improvement in WP related to the vertical and horizontal shading devices used. These three views were compared to test the best shading device that gives good view qualities. High values of 68.6% VOV and 64.8% WP were obtained for the fifth-floor score by using a horizontal shading device (Table 5-1), whereas the high 68% VOV score for the first floor was obtained by using a vertical shading device (Table 5-2). An improved WP of 39.45 % was noted by using the vertical shading device (58.3%) rather than a horizontal shading system (18.85%), because horizontal shading obscures the sky view more than vertical shading (Fig. 5-28).

Furthermore, implementing a vertical shading device on the third floor led to a notable enhancement in the window performance (WP), with an increase from 47.5% to 61.15%, representing an improvement of 13.68% (Fig. 5-29). This increase can be attributed to the clear, unobstructed views of both the sky and the surrounding greenery from all assessed test points. The vertical shading device optimises visual comfort by providing shade while still allowing extensive external visibility, which enhances the connection to the outdoor environment. Consequently, the improved WP indicates an effective balance between daylight access and visual quality, essential in sustainable architectural design. For the fifth floor, WP increased by only 0.8% when applying the vertical shading system because the sky view pixels ratio was nearly the same as the greenery pixels ratio (Fig. 5-30).

5-5-3-1 First Floor VOV Assessment

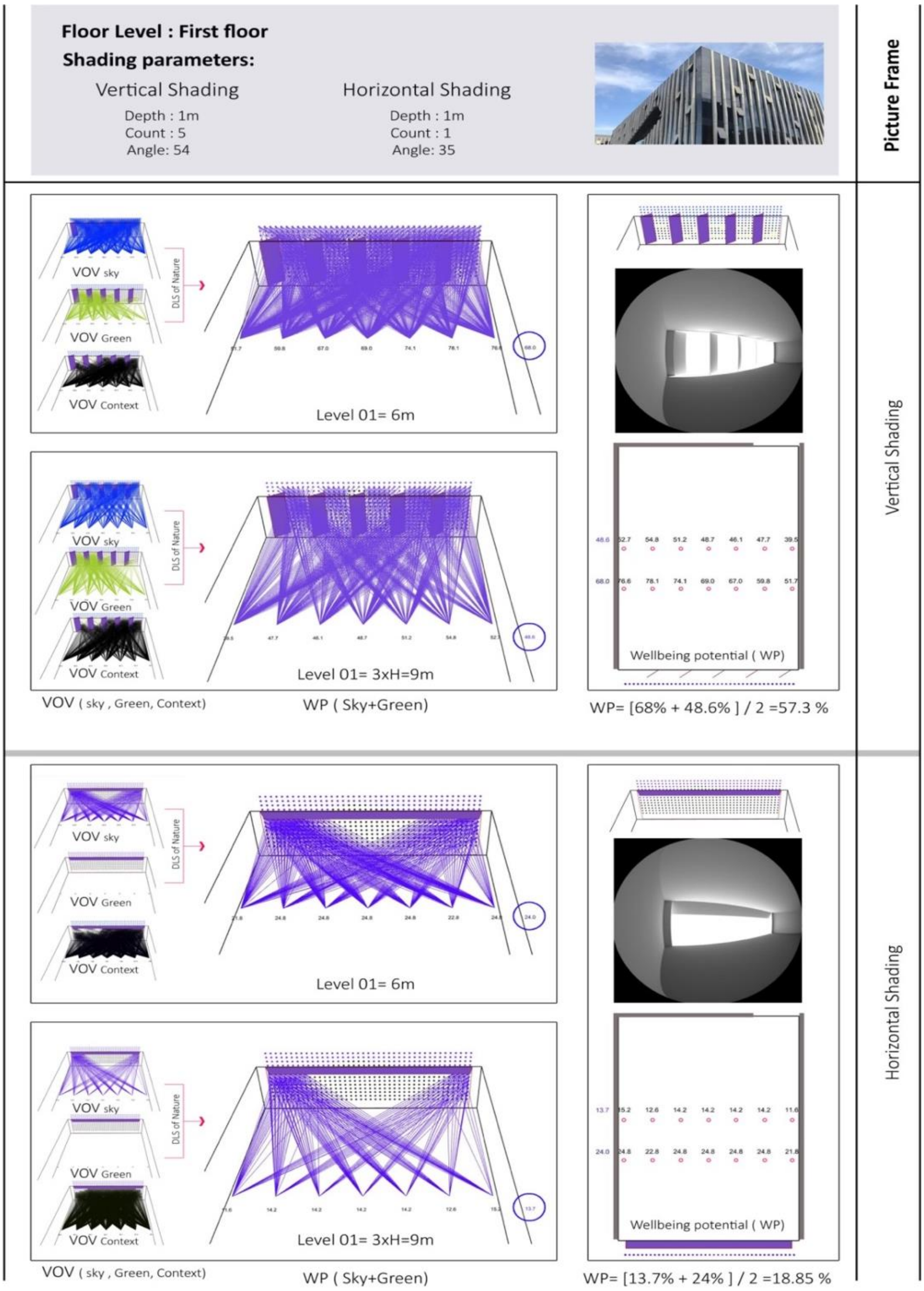


Figure 5-28: First floor outside view assessment.

5-5-3-2 Third Floor VOV Assessment

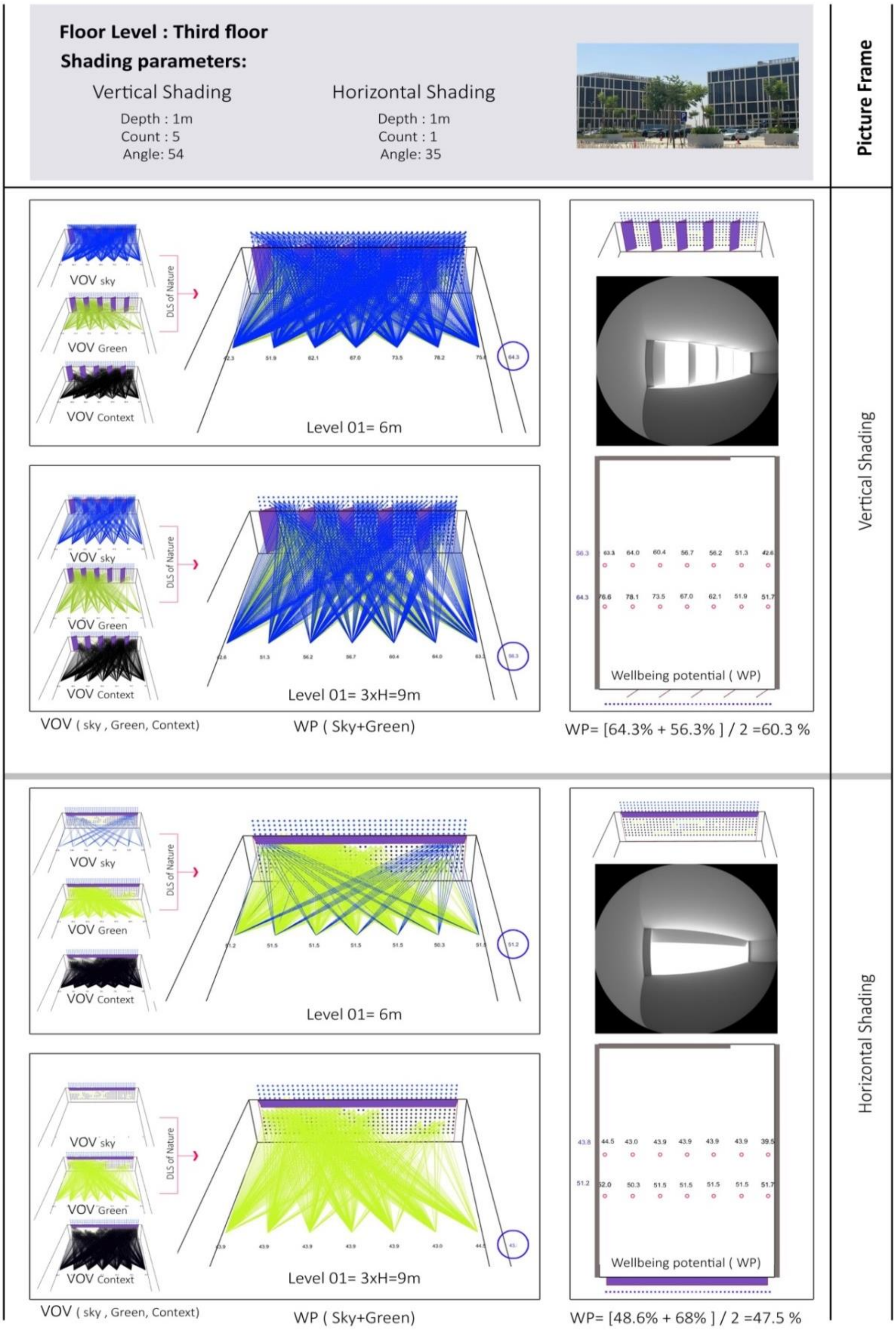


Figure 5-29: Third floor outside view assessment.

5-5-3-3 Fifth Floor VOV Assessment

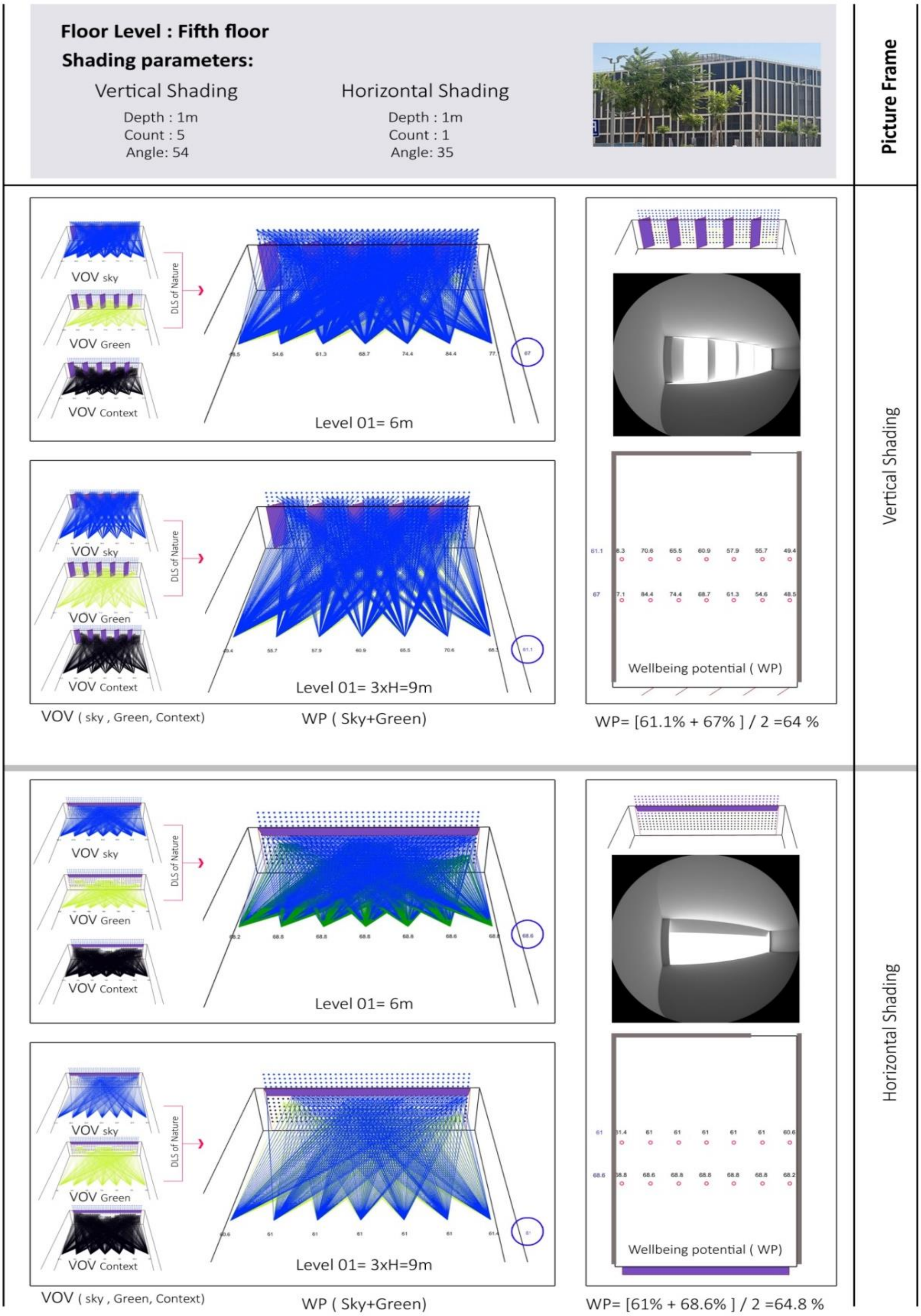


Figure 5-30: Fifth floor outside view assessment.

5-6 Conclusion

In this chapter, a new facilitation tool was defined using an image processing technique to evaluate both view content and clarity and the impact of installing two kinds of shading systems (horizontal and vertical) with indicated parameters for testing. The proposed facilitation tool presented in this thesis is considered the missing part for producing more multifactor systems that take into consideration different objectives such as energy, daylight and view quality. This is the first study to produce a quantitative tool to assess the visible outside view quality VOV using an image processing technique. Therefore, the well-being potential indicator WP needs to be validated and correlated with subjective assessment in a real experiment.

This study provides a new facilitation tool to evaluate the impact of installing vertical and horizontal shading systems on visible outside view content that could improve the well-being (WP) potential inside the working environment. Several studies indicate that sky and greenery view to the outside environment significantly affect occupants' health and well-being. Recent research on view quality has focused on quantifying the outside view content using questionnaires to rank some images to the outside view based on occupant preferences and feelings. Other techniques use the computational ray-tracing method, which needs the outside context to be fully built in three dimensions with a sufficient level of accuracy to match the real environment context in scale and position. Little attention has been given to the impact of shading devices on the view quality and how it can contribute to WP.

A new algorithm is proposed in the current study using an image processing technique to evaluate both view content and clarity and the impact of installing two kinds of shading systems (horizontal and vertical) with indicated parameters for testing. This study provides a new facilitation tool to evaluate WP by quantifying the overall ratio to VOV content (VOV_{sky}%, $VOV_{greenery}$%) to all test points shown, as recommended by LEED and WELLv2. These test points are located in two lines (Fig. 5-18). A new formula is produced to measure the mean value of WP for the space:

Equation 02

$$WP\% = \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$

The proposed algorithm was tested on a case study location in Egypt, Cairo. The results demonstrate that designing shading devices considering the view of natural elements (sky and greenery) positively affects WP. Therefore, building orientation is very important at the primary design stages as it has a significant impact on the ratio of natural elements and how many layers can be seen from windows. The proposed algorithm can be integrated into a multifactor system to achieve more sustainable shading devices. This multifactor system could investigate the possibilities of using different shading system parameters to compromise between different objectives such as daylight quality, energy consumption, view quality and air quality (Abdelrahman et al., 2023a).

CHAPTER 6: Quantitative Assessment of Daylight, Visible Outside View and Shading (DVS Multifactor System) (Stage 3)

6-1 Introduction

This research aims to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms as a means to enhance occupant comfort and well-being potential related to daylight quality and view quality. In Chapter 5, a new parametric algorithm was defined to quantify the visible outside view quality while installing a shading device called visible outside view (VOV). This new indicator is a percentage starting from 0% to 100% showing the well-being potential to test points inside the workspace to measure the overall percentage of the view quality. In addition, the literature review proves that there is no computational method found that can optimise between shading parameters, daylight and visible outside view quality in one system. Most researchers assess visible outside view quality separately using questionnaires or applying 2D tracing methods to analyse the outside view content (Chapter 2).

The goal of this system is to show how daylight, view quality and shading systems can be integrated into one system. It investigates the possibilities of using different shading system parameters to compromise between daylight quality and view quality. Shading configuration is categorized by a series of parameters to provide the appropriate visual comfort and well-being potential inside the workspace. This chapter introduces a novel method to design shading systems by using multi-objective evolutionary algorithms (MOEAs) by connecting daylight quality and outside view quality to improve comfort and well-being potential inside the working space. This multifactor system consists of two levels of optimization. The first level occurs by using MOEA techniques to achieve optimal daylight quality inside a working space. This optimisation defines the best shading device solutions related to five selected objectives: (1) to minimise annual sun exposure (ASE), (2) maximise spatial daylight autonomy (sDA), (3) maximise useful daylight illuminance (UDI), (4) maximise view percentage, and (5) minimise daylight glare probability (DGP). The second level of optimisation incorporates the visible outside view (VOV) algorithm (defined in Chapter 5) with the optimum solutions resulting from the first level of optimisation related to daylight simulation.

The first objective of using the DVS system is to find the optimum solution for designing shading systems that can improve daylight quality and view quality values recommended by WELL standards and the LEED rating system (resulting from Chapter 2, Literature review). The second objective is to provide architects and non-expert people with a dashboard to evaluate different shading solutions (vertical blinds, horizontal blinds and parametric panels). This dashboard visualises all optimisation results regarding daylight and views to a 2D map showing comfort and well-being potential zones that can be used to make better seat arrangements for users.

This chapter is structured into the following four sections. Section 6-2 discusses the DVS system methodology, showing input and output parameters for each process using multi-objective evolutionary algorithms (MOEAs). In Section 6-3, the system is applied to a commercial building case study in Cairo to test the system process and outcome. Sections 6-4 discuss the results from the application of the DVS system in the case study, followed by a discussion of the selection criteria of the best solution to create the comfort and well-being potential map. The final section, Sections 6-5, provides a summary of the chapter, highlights the main knowledge contributions and provides future research recommendations.

6-2 DVS System Methodology

The DVS system is based on the ability to integrate an algorithmic approach to optimise between different solutions of shading configuration and the parametric-based design approach to quantify the outside view quality (VOV). All case studies were developed with Rhino and Grasshopper in the context of this study. Rhinoceros (commonly, Rhino or Rhino3D) is a commercial 3D computer graphics and computer-aided design application software based on the NURBS mathematical model developed by TLM, Inc., dba Robert McNeel & Associates (McNeel 2014). Grasshopper is a visual programming language and environment that runs as an extended plugin for Rhino. Through the definition of form-generating components in Grasshopper, users can easily modify the dimensions of models using sliders and mathematical expressions to optimise the process. By directly connecting the Grasshopper interface to Rhino, changes in the algorithm are visible directly in the Rhino window.

Ladybug and Honeybee plugins for Grasshopper are used to run a series of daylight simulations related to the assessment criteria. As a result of the usage of these plugins in this study, a series of performance evaluations were conducted by applying validated tools, such as RADIANCE, Daysim, Evalglare and EnergyPlus plugins which are all included in the study. Rhino and Grasshopper were used for all modelling and daylight simulations. The simulation results were dependent on the sun and sky conditions obtained from standard meteorological data of the case study as well as building location, orientation and shading system configuration.

Wallacei (Showkatbakhsh & Makki, 2022) is a multi-objective evolutionary algorithm (MOEA) embedded in Grasshopper through Rhino as an interface. Wallacei is used in this study to solve and optimise multi-conflicted objectives together in one system. These conflicted targets in this research are related to daylight quality, outside view quality and shading parameters. The Grasshopper parametric definition is used to bridge the gap between the early design stage and the performance of the building with regard to daylight (Mahmoud & Elghazi, 2016). Moreover, it is used to identify the input parameters of the building skin and set the evaluation criteria for daylight assessment. These parameters and criteria are passed to the daylight simulation tools, Ladybug and Honeybee, to simulate the process of daylight and send the results back to Wallacei for evaluation until an optimal solution is reached.

Tools were selected based on their ability to be integrated to provide real-time feedback. Understanding the algorithmic logic and the input and output needed for each component are the most important factors in making this integration. The models for the case study were defined first where weather file, location and material were defined as dependent variables. The 3D models for each shading device were also defined where shading angle width, shading count and direction work as independent variables. The performance for visual comfort associated with daylight based on the assessment criteria (discussed in Chapter 2) simulated using Ladybug and Honeybee tools. After that, the genetic algorithmic tool Wallacei changes the independent variables of shading devices to create search space for all possible solutions according to the fitness value formula sorted by the designer and based on the simulation assessment criteria.

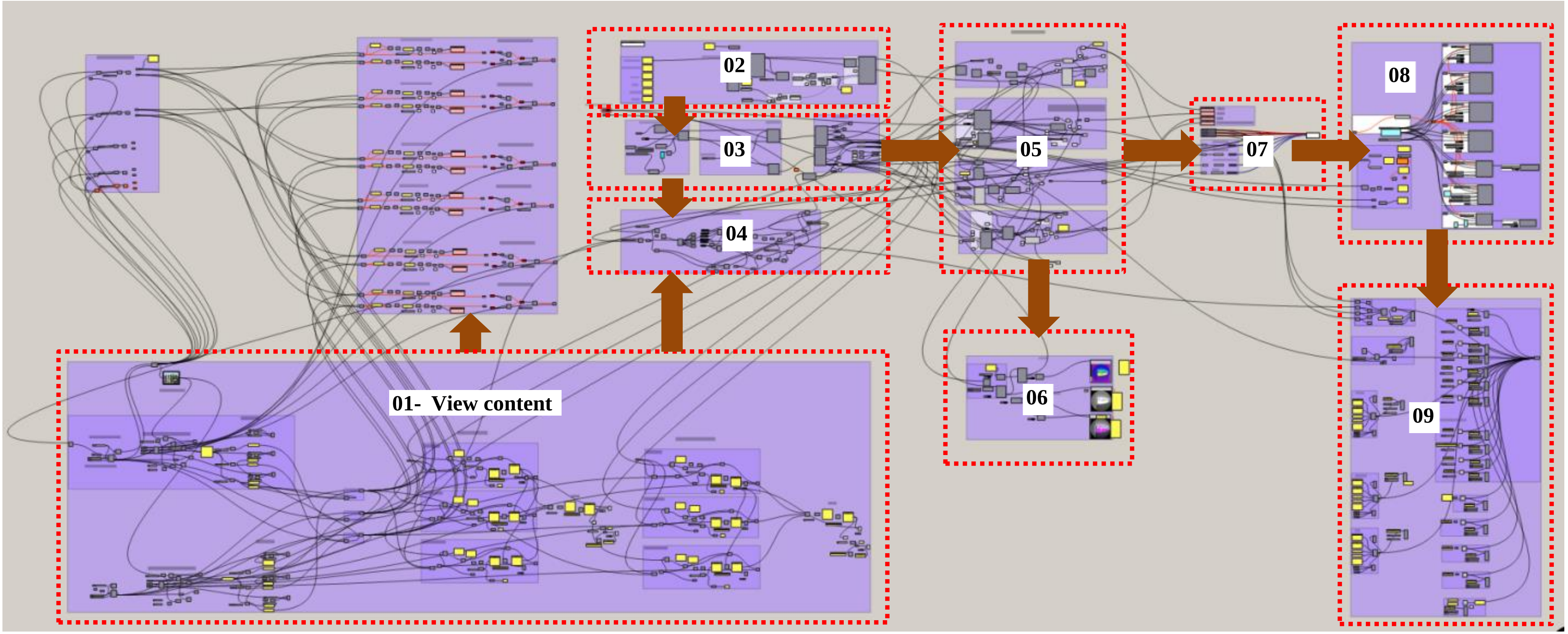


Figure 6-1: Holistic systems algorithm.

6-2-1 The Multifactor System Algorithm

There are six main steps in the multifactor system algorithm. The first step is to identify design parameters and build a parametric design model. The second step is the development of a daylight model for the optimisation of a shading system. The third step is to connect the visible outside view (VOV) algorithm with the shading parameters to work at the same time as the daylight simulation. The fourth step is multi-objective optimisation processes run by Wallacei to optimise between the possible solutions that achieve the fitness value. The fifth step is to analyse the solution. The sixth step involves analysing and evaluating simulation data and optimising the shading design parameters. The optimal designs are compared using different criteria such as standard deviation and parallel coordinate plot for all possible solutions (discussed in detail later in this chapter). All these steps run two times individually: the first run aims to evaluate the base model without a shading system and the second run aims to evaluate the model with shading; the reason to evaluate the base model without shading is to fully investigate the shading impact on daylight and view quality by comparing the performance difference. The DVS algorithm consists of ten stages as indicated in Figure 6-1. Stage 1 aims to quantify the visible outside view (VOV), as discussed in Chapter 5. Stage 2 to Stage 10 comprise the algorithm workflow.

Stage 1: Define VOV (discussed in Chapter 5)

This stage involves defining the sight line percentage for each outside view content (sky, greenery) while installing the shading device. A new formula is produced to measure the mean value of WP for the space by quantifying the overall ratio to VOV content ($VOV_{\text{sky}}\%$, $VOV_{\text{greenery}}\%$) to all test points shown. These test points are located in two lines. Equation 02 is applied to measure the mean value of WP for the space:

$$WP\% = \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$

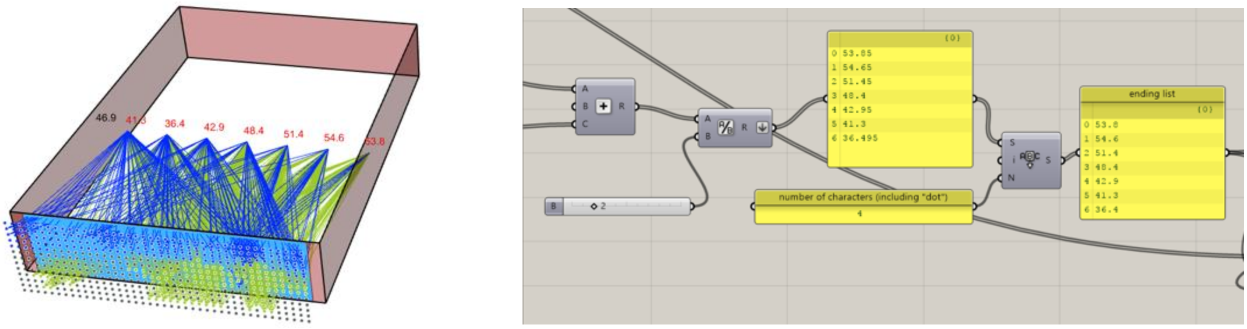


Figure 6-2: Defining the sight line percentage for each outside view content (sky, greenery and context).

Stage 2: Define the weather file input and extract the sun vectors

At this stage, the sun vectors are extracted for hours above the threshold recommended values to use as an input parameter to calculate annual sun exposure (ASE), resulting from Chapter 2.

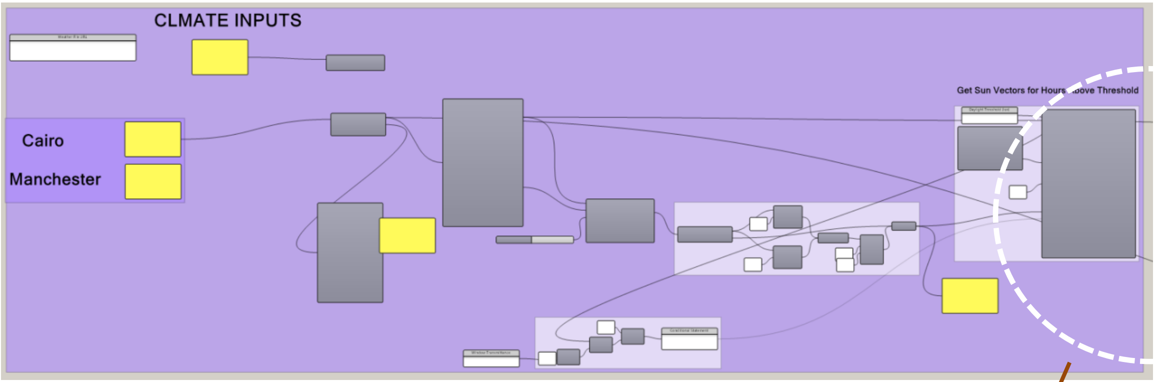


Figure 6-3: Climate parameters input panel.

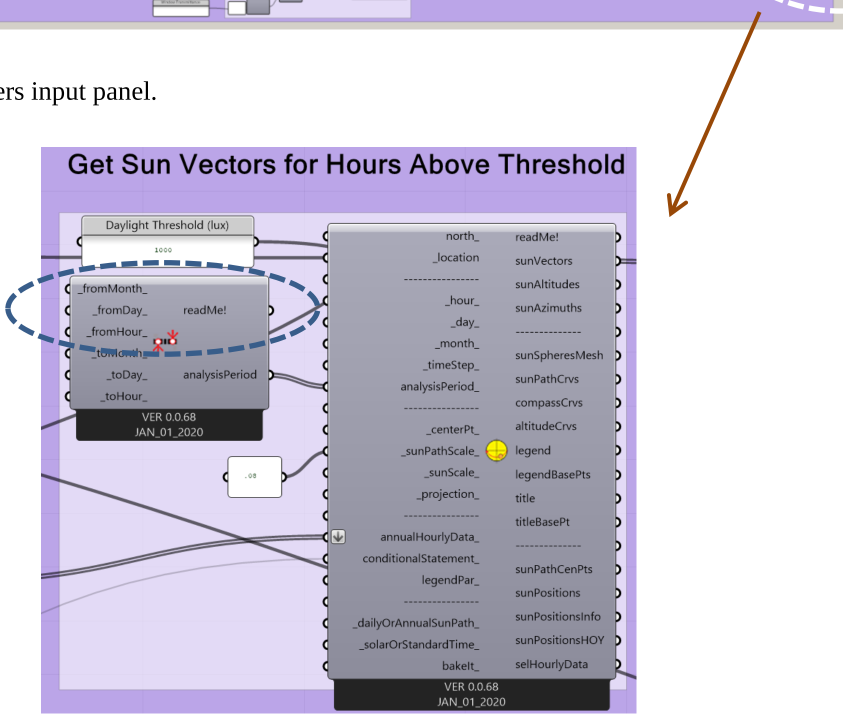


Figure 6-4: Defining sun vector for house above 1000 lux.

Stage 3: Define geometric parameters, window-to-wall ratio and materials used

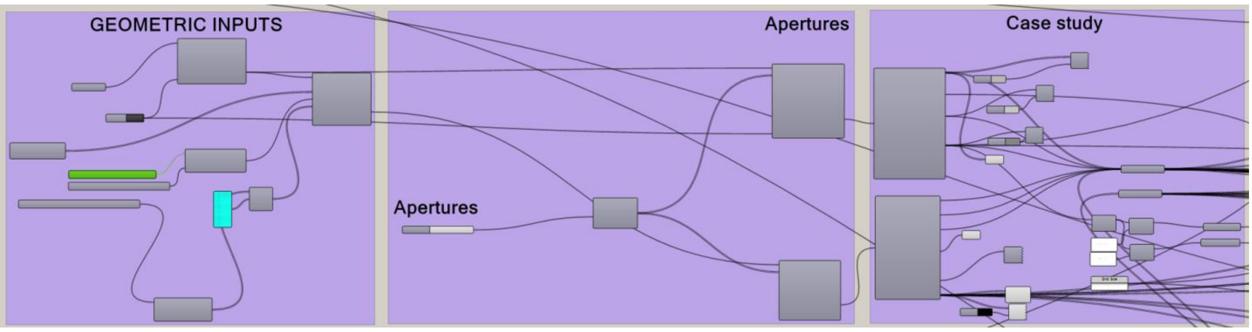


Figure 6-5: Case study modelling.

Stage 4: Define a parametric shading device

At this stage, a parametric shading device is defined consisting of rectangle panels and can rotate on the X, Y and Z axes. These panels are used as an example of the automated shading façade that can rotate on the X-axis to become vertical shadings or the Y-axis to become horizontal shadings. The ability to rotate in the Z-axis will give an automated shading system pattern as shown in Figures 6-6 to 6-9.

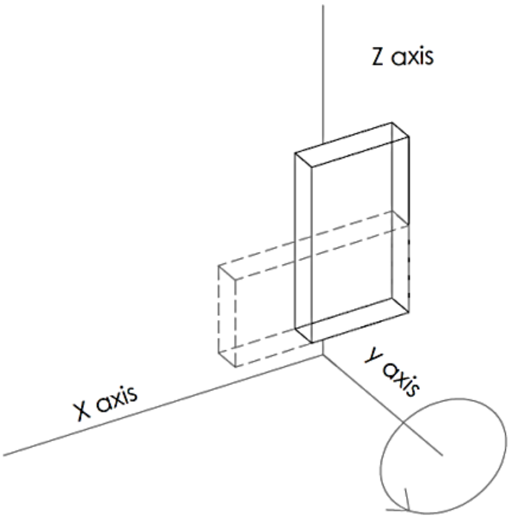


Figure 6-6: Automated panel rotation on Y-axis.

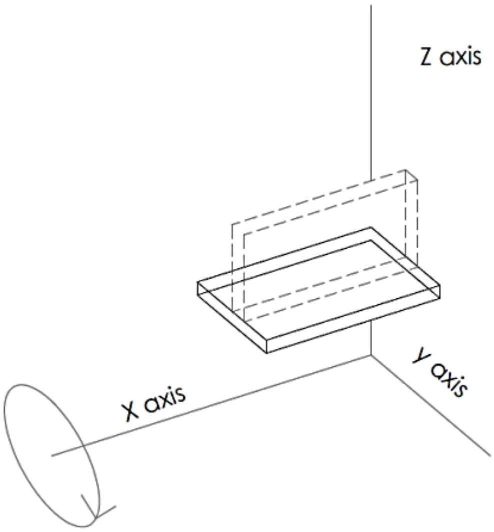


Figure 6-7: Automated panel rotation on X-axis.

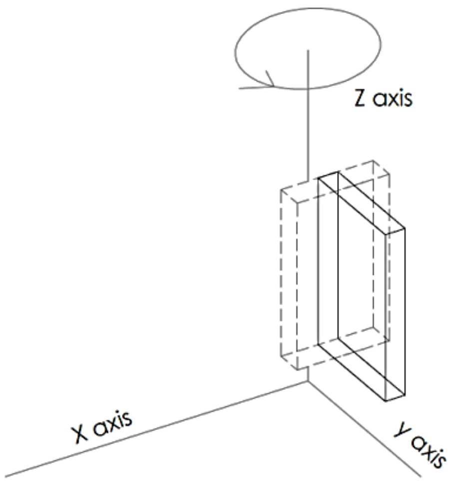


Figure 6-8: Automated panel rotation on Z-axis.

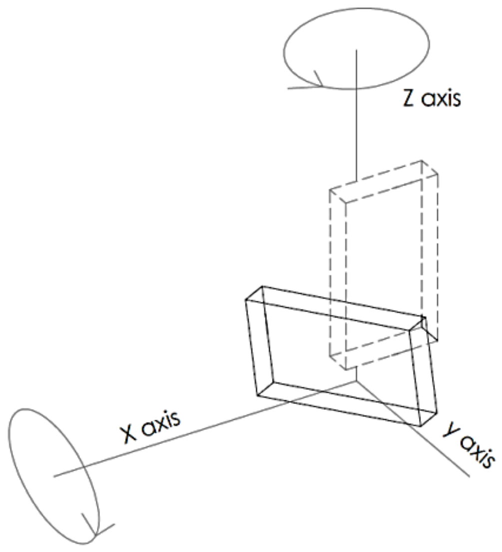


Figure 6-9: Automated panel free rotation.

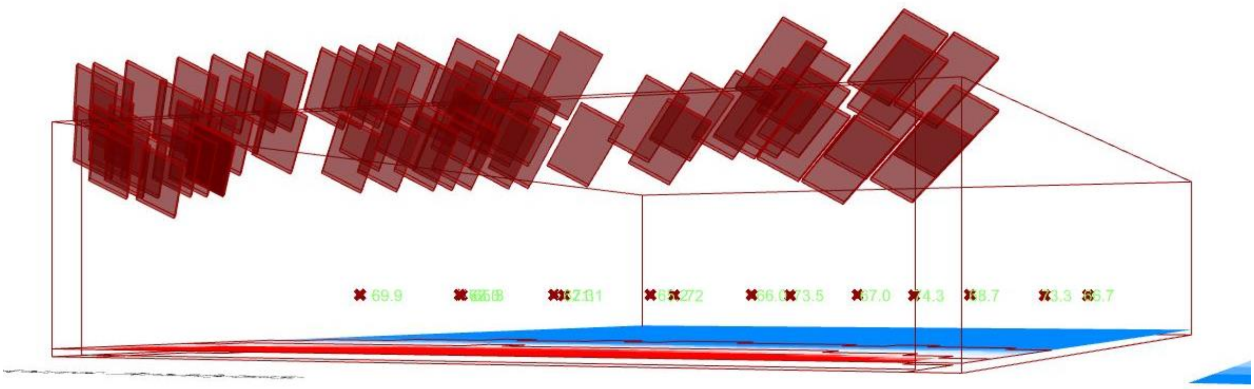


Figure 6-10: Optimised prototype panels generated using Rhino and Grasshopper.

Stage 5: Define surface material of objects

The next step, after applying Honeybee Objects with assigned glazing, is to define the material of each surface of these objects as they have different material properties that will influence daylight simulation of the whole model. The properties for each surface of the chosen model are selected using the Honeybee plugin to define the reflectance and the colour for each material component. It is assumed that the reflectance of the interior wall is 50%, of the ceiling 80% and of the floor 80%. The visual transmittance used for the glazing was 0.7 VT as recommended by LEED and WELL in their view quality credit.

Stage 6: Apply daylight assessment criteria

At this stage, the daylight assessment criteria (discussed in Chapter 2) are applied using a series of daylight simulations by Honeybee and Ladybug plugins, as follows:

1. ASE: 50% of the floor plan exceeds the threshold of 1,000 lux with more than 250 occupied hours per year. This complies with WELL v2 and LEED v4.01 criteria.

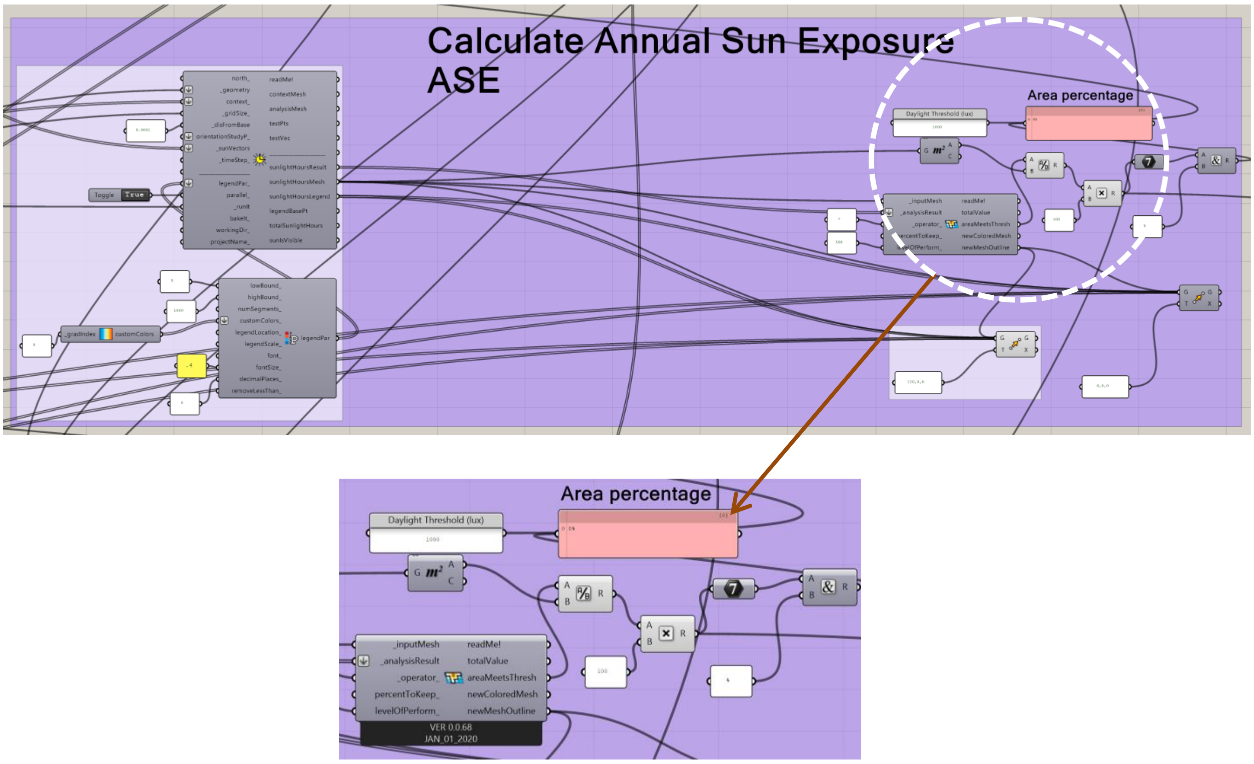


Figure 6-11: Annual sun exposure parameters.

2. UDI: the percentage between the periods that received adequate daylight levels per year to occupied hours in the same year between 100 lux and 2,000 lux. This complies with LEED v4.01 criteria.

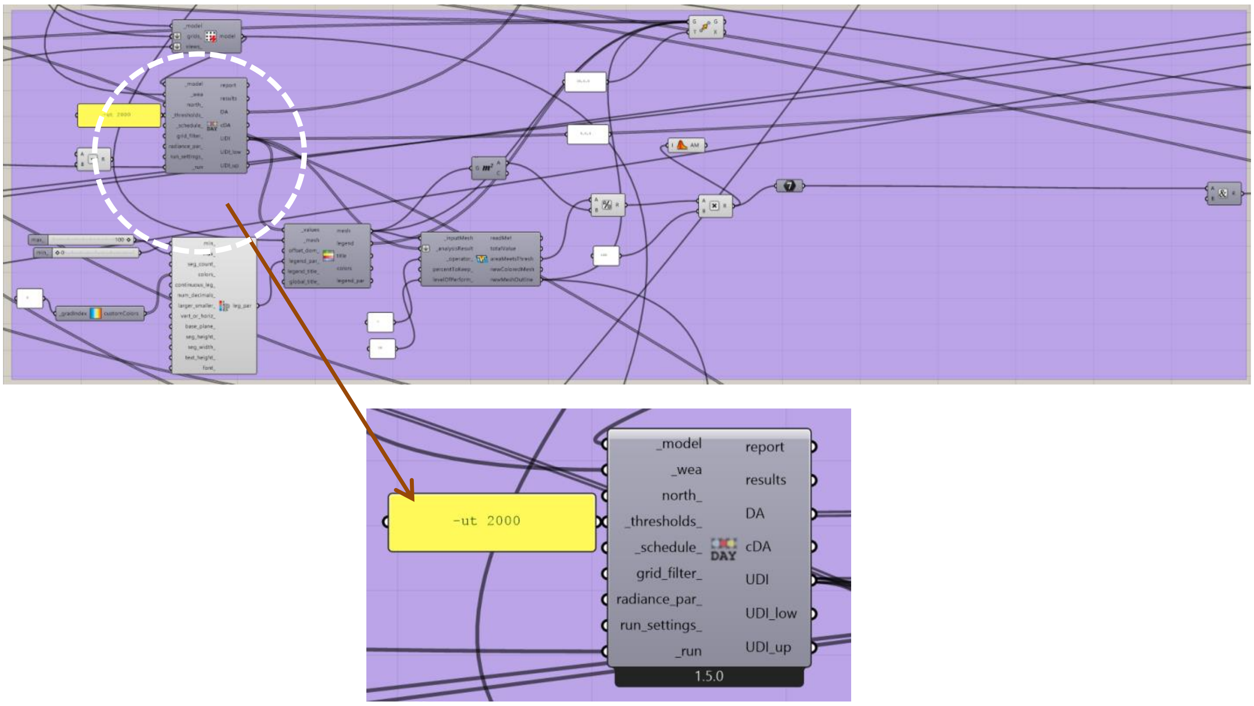


Figure 6-12: Useful daylight illuminance parameters.

3. View percentage: the maximum value that can be achieved.

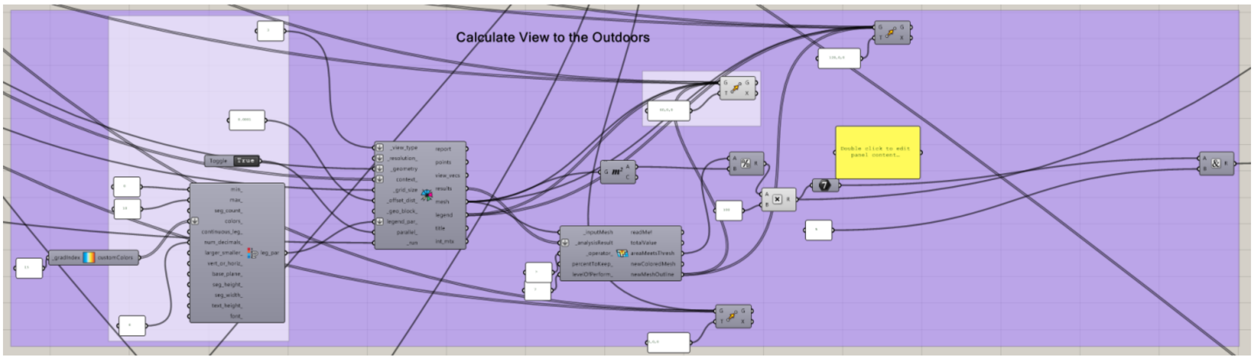


Figure 6-13: View percentage parameters.

Stage 7: Quantify daylight distribution and glare issues

This stage is related to quantifying the daylight distribution and glare issues.

- Daylight glare probability (DGP): it ranges from 0 to 1 and indicates whether a glare situation will be imperceptible (DGP ≤ 0.35), perceptible (0.35 < DGP ≤ 0.40), disturbing (0.40 < DGP ≤ 0.45) or intolerable (DGP > 0.45) to a majority of occupants. This complies with LEED v4.01 criteria.

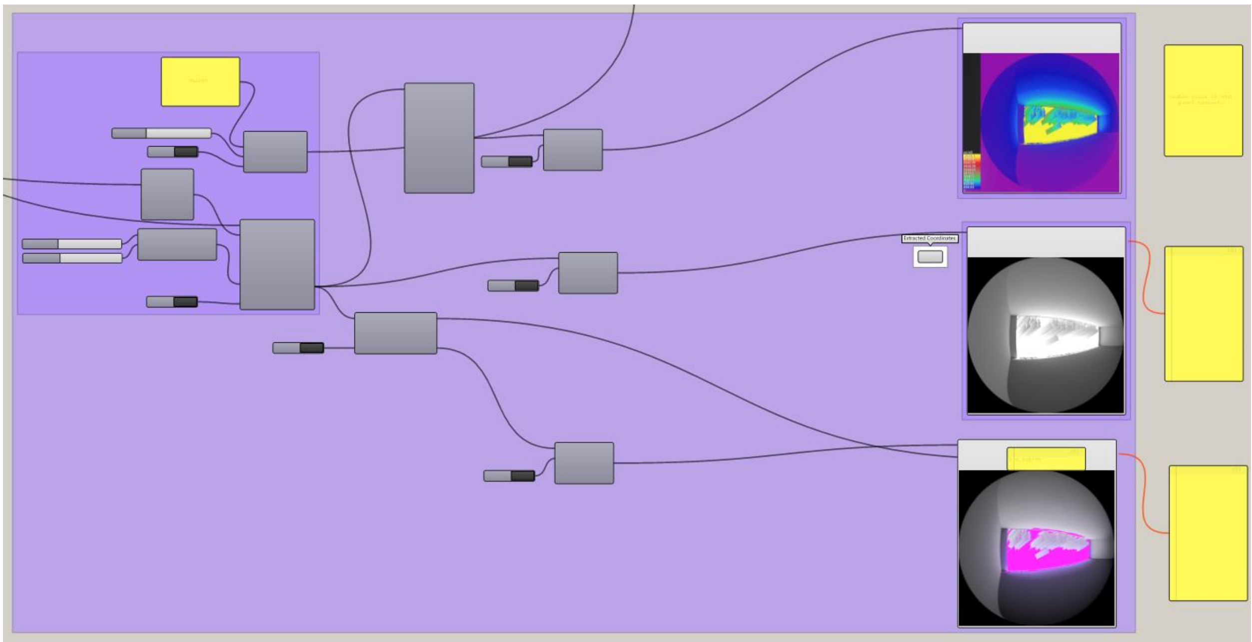


Figure 6-14: Visual comfort factors.

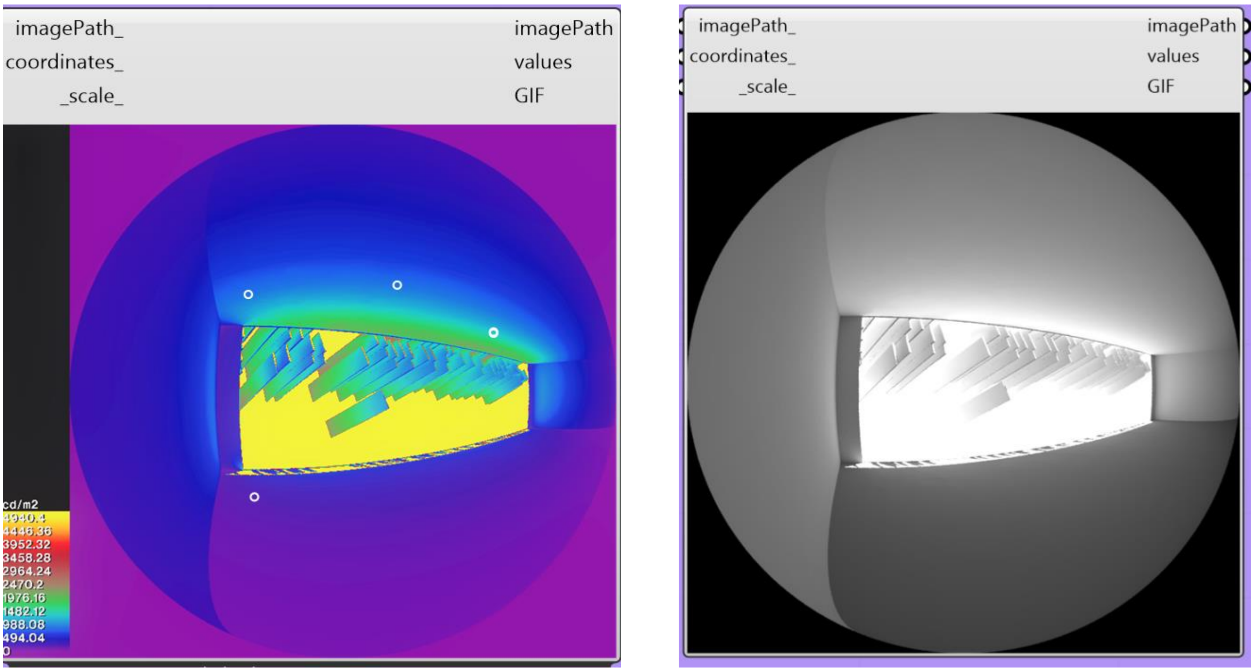


Figure 6-15: Daylight distribution values.

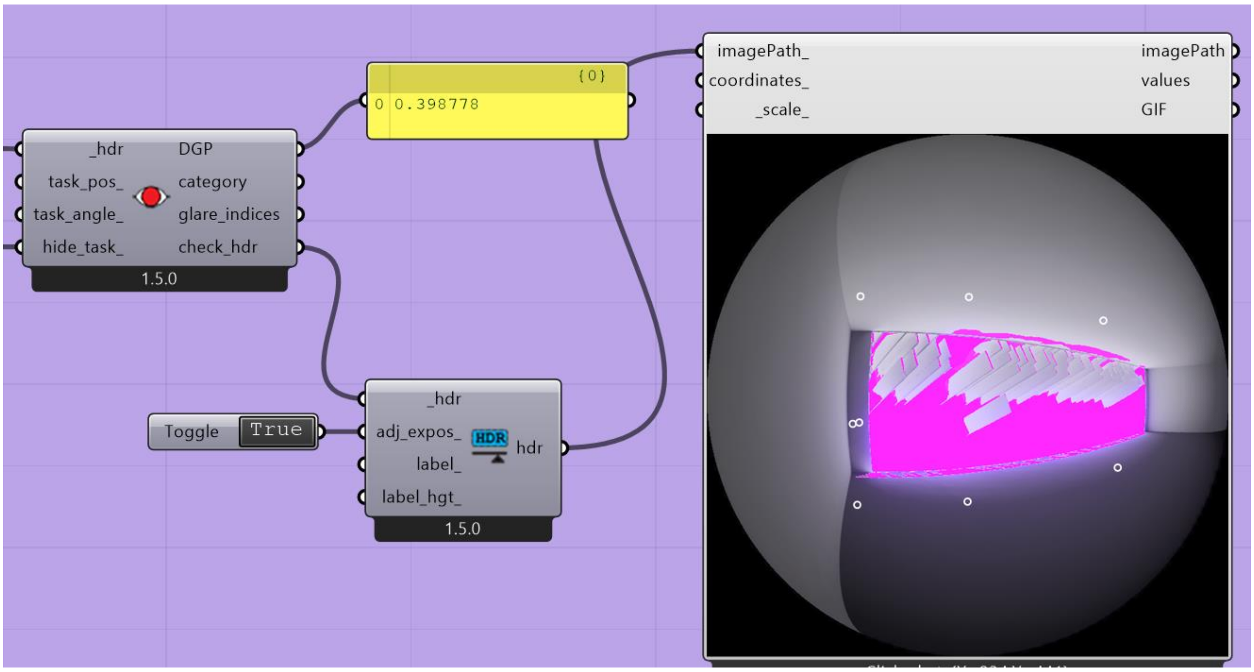


Figure 6-16: Daylight glare probability values.

Stage 8: Fitness Values

Because there is more than one objective and many solutions, the multifactor system applies a multi-objective evolutionary algorithm (MOEA) method to help decision-makers choose the best solution to the design problem. A multi-objective optimisation plugin called Wallacei is used to generate all possible optimisation solutions based on the input parameters. The system runs a series of simulations related to daylight quality and view quality assessment criteria. The design variables are re-evaluated, if necessary, to achieve the fitness goal in the final phase. The simulation works to achieve the following objectives:

1. to minimise ASE: 10% of the space achieving 1000 lux for 250 hours in the year;
2. to maximise sDA;
3. to maximise UDI: illuminance on the work surface between 300 and 3,000 lux at 9 a.m. and 3 p.m. on a sunny day at equinox for >75% or 90% of occupied spaces.
4. to maximise outside view percentage to the maximum value that can be achieved; and
5. to minimise DGP to $0.35 < DGP \leq 0.40$.

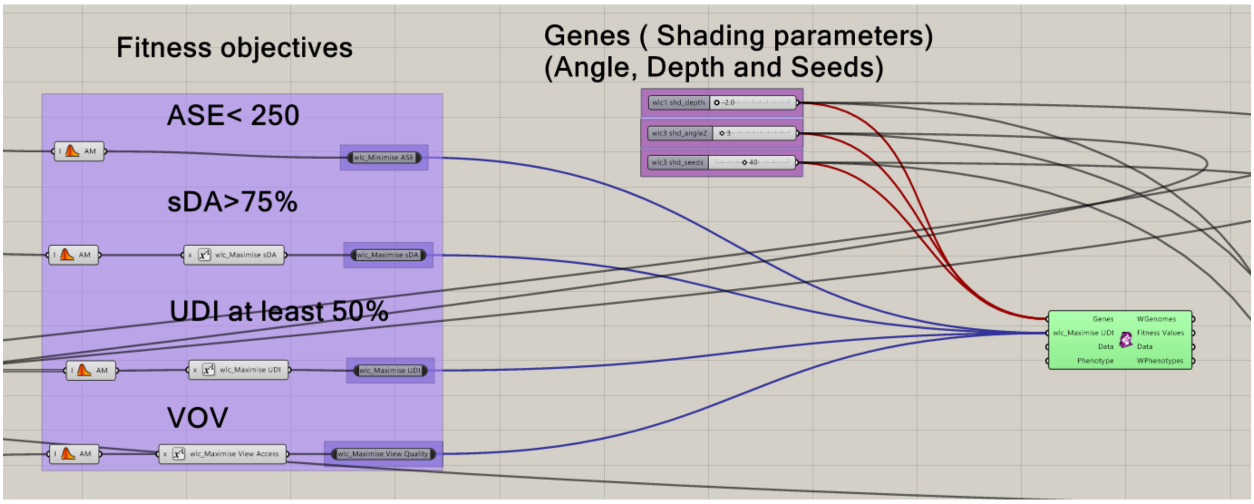


Figure 6-17: Genes and fitness values.

Stage 9: Data visualisation for the optimisation output

At this stage, a series of data analyses are provided by Wallacei to select the best solution, such as standard deviation, diamond fitness chart, parallel coordinate plot and mean values. This stage will be discussed in detail for a case study in Section 6-4-2.

Stage 10: DVS multifactor system dashboard

A dashboard is provided at the final stage to simplify the system input and output using the Human User Interface (UI) plugin. Human UI is a new interface paradigm for Grasshopper to create professional-looking Grasshopper apps with custom user interfaces. An example of this result is provided in the next section.

6-2-2 Quantifying Comfort and Well-Being Potential (CW_{map}) as Indicators for the Best Seat Arrangement

Daylight has a direct impact on visual comfort. Daylight quality for visual efficiency is determined by how it is delivered and how it is integrated with other conflicting issues such as illuminance and glare. Therefore, the visual comfort zone should avoid glare, which will help the zone achieve the illuminance required. This zone is a combination of the area that complies with the daylight quality assessment criteria recommended by LEED, WELL and EN standards that define the visual comfort potential.

Based on the daylight assessment criteria in Chapter 2, this study evaluates the daylight quality based on four types of measurements:

1. Spatial daylight autonomy (sDA): to be achieved if at least 75% of the regularly occupied floor area received 300 lux for 55% of the annual occupation hour; sDA 300/50% of at least 55%, 75% or 90% is achieved.
2. Annual sunlight exposure (ASE): LEED and WELL recommend ASE to be 1000 lux/250 hours for no more than 10% of the regularly occupied space.
3. Useful daylight illuminance (UDI): to achieve 300 lux of daylight for at least 4 hours according to WELL at a time between 9 a.m. and 1 p.m. for 75% of the floor area.
4. DGP: ranges from 0 to 1 and indicates whether a glare situation will be imperceptible (DGP $\leq$ 0.35), perceptible (0.35 < DGP $\leq$ 0.40), disturbing (0.40 < DGP $\leq$ 0.45) or intolerable (DGP > 0.45) to a majority of occupants.

A 2D perimeter is defined to identify the threshold area that complies with the assessment criteria (Fig. 6-18). This area represents the comfort potential inside the working environment. Along with the well-being potential measurement results from Section 3-4, the final comfort and well-being potential map shows two measurements: the first is an overall ratio to the greenery and sky visible outside view content (VOV_{Green}%, VOV_{Sky}% or $VOV_{Context}$%) to all test points shown in two line positions as discussed in Section 5-5-2. The first line represents the field of view away from the opening by 6 metres, and the second line is within three times the space head height of the floor space ended. Therefore, the area that receives the highest VOV percentage and is located in the visual comfort zone will have the most comfort and well-being potential (Fig. 6-19). The second measurements are related to the simulation threshold for sDA, ASE, UDI and the view access.

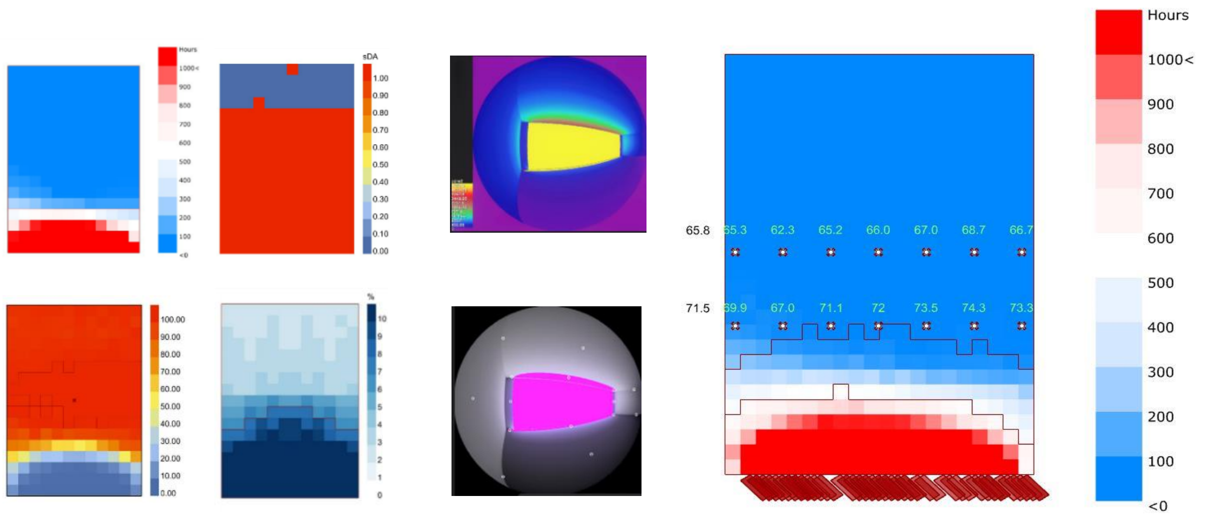


Figure 6-18: Comfort and well-being potential map simulations.

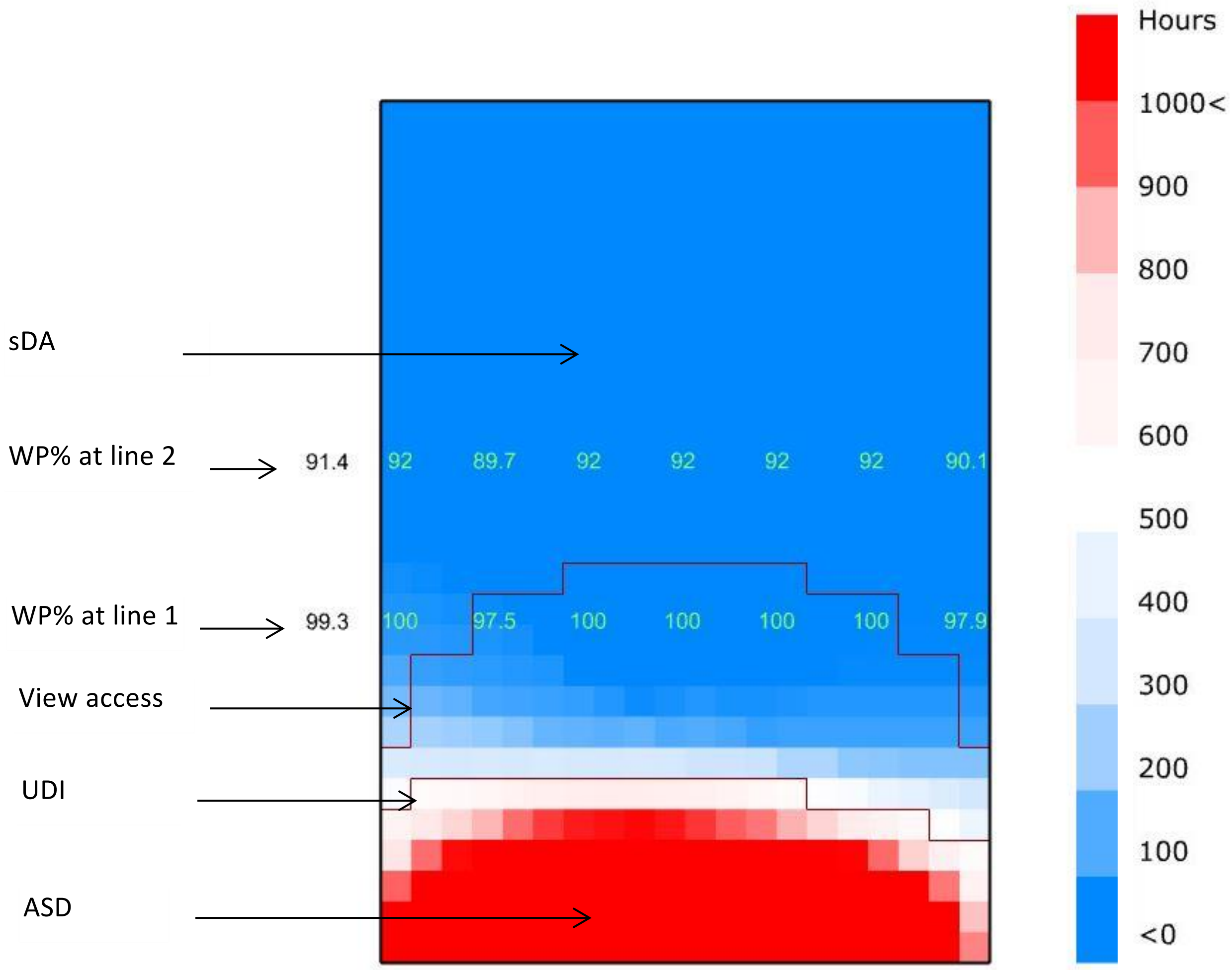


Figure 6-19: Comfort and well-being map (CW_{map}).

6-3 Application to a Case Study

As a case study, south-facing single office space in Egypt was used as a model to explore the possibilities and limitations of the multifactor system within algorithms in three consecutive phases.

1. Model parameters
2. Multi-objective evolutionary optimization
   a. Objectives and simulation tools
   b. Criteria
   c. Procedure
   d. Deviation
3. Parametric method to measure the new view quality metric (VOV_{SKY}, VOV_{Green}, $VOV_{Mass+Blind\ ratio}$)

6-3-1 Model Parameters

An office building located in New Cairo, Egypt with dimensions of 12 × 8.5 × 3 m^3 was used for the case study (Fig. 6-20). The study aims to test the multifactor system on the second floor. A picture window was taken inside the space from a point far from the façade by 6 metres, as recommended by the new European daylight standard EN17,037, to evaluate view quality. Egypt is considered to have hot-arid-desert climate with minor parts (along the north coast of Egypt) being hot-arid-steppe climate (Peel et al., 2007). The weather files used in the present study are available to download from Energy Plus. The window in the building was located on the south façade with a window-to-wall ratio of 0.85 (Figs. 8a and 8b). The walls were finished in white plaster, the floor was covered with grey tiles and the ceilings were white. The reflectance of the interior wall was 50%, of the ceiling 80% and of the floor 80%. Glazing consisted of double clear glass with air in the middle based on ASHRAE standard (2006) for cities in climate zone 3B. This glazing had a visual transmittance of 0.7 VT as recommended by LEED and WELL in their view quality credit. For daylight performance simulation, the sky should be clear with a minimum of 500 lux on the work plane at a height of 0.75 from the floor. As recommended by LEED, a 0.6 × 0.6 m^2 grid of sensors and artificial light were used during the simulation process.

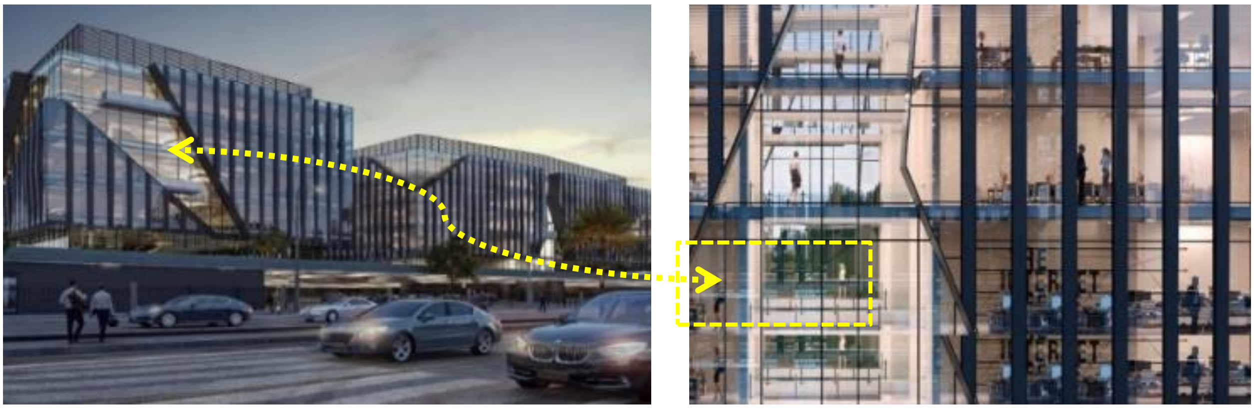


Figure 6-20: Case study office building in Egypt.

Figure 6-21: Different levels of outside view.

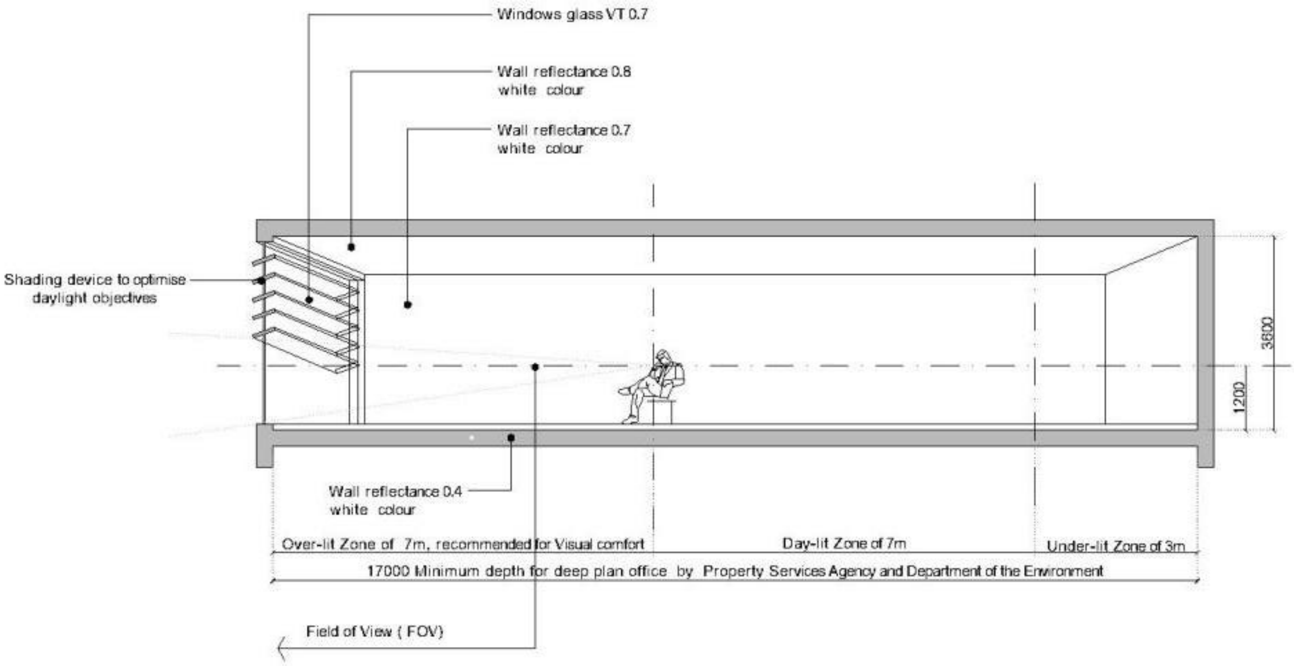


Figure 6-22: Case study material and parameters.

6-3-2 Optimisation Criteria

This section aims to optimise different kinds of shading device parameters that have the most comfort and well-being potential inside the workspace. The proposed shading device in this study was installed on sky pixels of the picture frame image imported to the algorithm to maximise the greenery and context of view content. In addition, the window-to-wall ratio (WWR) for the base model was 90% according to ASHRAE standard (2006). The visible outside view content optimised according to the shading device parameters to achieve optimisation objectives. Based on the input parameters of the optimisation shown in Figure 6-23, 5,000 solutions were tested. Two models were simulated: a base model without a shading system and a second model with shading. A comparison between the two cases shows the impact of using the shading device in daylight and view quality.

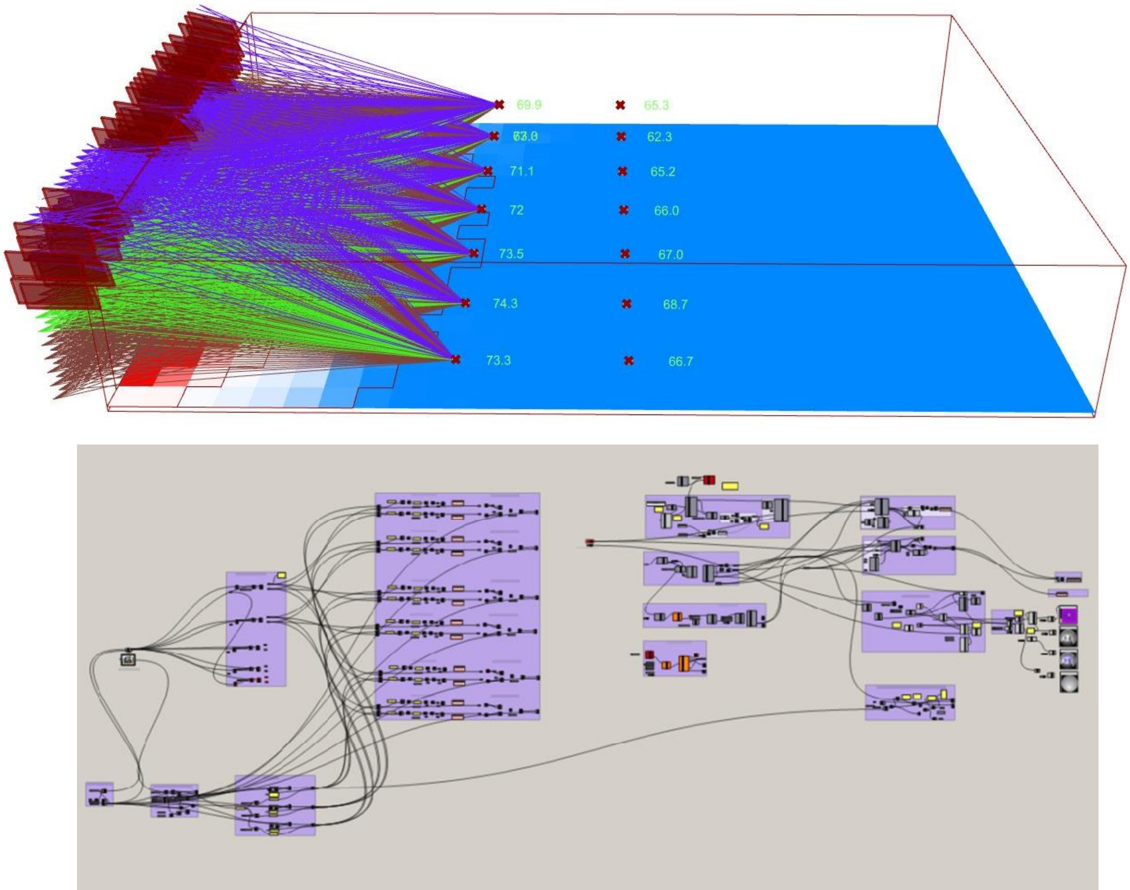


Figure 6-23: DVS algorithm.

This simulation and optimisation process was run on a desktop computer with Intel(R) Core(TM)i7 8700 CPU @3.20 GHz processor and 64.00 GB RAM. This system ran more than 2,500 simulation processes to daylight and views together and generated 5000 generations of genomes. The entire simulation and optimisation process took approximately two days to complete. The best result is discussed later in Section 6-4-2-3.

6-3-3 Fitness Functions

A multitude of metrics has been identified to optimise the developed phenotype. Four fitness values were selected to achieve daylight quality and view quality recommended by building rating systems such as LEED as follows:

1. Daylight quality
    1. ASE: more than 50% of the floor plan exceeds the threshold of 1,000 lux with more than 250 occupied hours per year. The results failed to meet LEED v4.01 criteria.
    2. UDI: the percentage between the periods that received adequate daylight levels per year to occupied hours in the same year between 100 lux and 2,000 lux.
    3. DGP: it ranges from 0 to 1 and indicates whether a glare situation will be imperceptible (DGP ≤ 0.35), perceptible (0.35 < DGP ≤ 0.40), disturbing (0.40 <DGP ≤0.45) or intolerable (DGP > 0.45) to a majority of occupants.
2. View quality
    1. View Type 2: at least 75% of the regularly occupied building floor area design should achieve at least one of the following: nature, art, urban landmarks or objects at least 25 feet (7.62 meters) from glazing
    2. View Type 3: unobstructed lines of sight view location with a line of sight to vision glazing from within three times its head height and view.
    3. Visible outside view (VOV): VOV_{Sky}=40%, VOV_{Green}=20%, $VOV_{Context}$=40%.

Table 6-1: Optimisation values

Optimisation control	Value
Population	
Generation size	10
Generation count	30
Population size	300
Algorithm parameters	
Crossover probability	0.9
Mutation probability	1/n
Crossover distribution index	20
Mutation distribution index	20
Random seed	1
Algorithm parameters	
No. of genes (slider)	3
No. of values (slider value)	211
No. of fitness objectives	4

Where:

1. Population Size: 300 individuals are present in each generation.
2. Generation Count: 30 generations total.
3. No. of Genes: 3 genes (sliders), each representing an independent decision variable.
4. No. of Values per Gene: Each gene has 211 possible values, so each gene can independently assume any of 211 states.
5. Fitness Objectives: 4 objectives to evaluate the fitness of each solution, though they don't impact the count of possible solutions.

6-4 Simulation of Daylight Performance

6-4-1 Base Model Simulation

In this case, four types of daylight simulation occurred: (1) annual sunlight exposure (ASE), (2) spatial daylight autonomy (sDA), (3) useful daylight illuminance (UDI) and (4) daylight glare probability (DGP). For view quality, one simulation was done to measure the view percentage of the outside sky view. After that, a parametric analysis of visible view content VOV (green, context and sky) was compared with the optimised solution that has a shading device. The results of the base model simulations were as follows:

3. Daylight quality
    1. ASE: The results failed to meet LEED v4.01 criteria.
    2. UDI: The results failed to meet LEED v4.01 criteria.
    3. DGP: The results failed to meet LEED v4.01 criteria.
4. View quality
    1. View Type 2: The results meet LEED v4.01 criteria.
    2. View Type 3: The results meet LEED v4.01 criteria.
    3. Visible outside view (VOV): VOV_{Sky}=40%, VOV_{Green}=20%, $VOV_{Context}$=40%.

Table 6-2: Assessment criteria for the base model

Objective	Base model (without shading system)			
	Daylight quality	Status	View quality	Status
Assessment criteria	ASE	Fail	View Type 2	Pass
	UDI	Fail	View Type 3	Pass
	DGP	Fail	VOV	Pass

6-4-2 Optimised Model Simulation

6-4-2-1 Analysis Criteria

In this study, different methods have been used to Visualise all data results by simulation from different fitness objectives and extract specific solutions from the population. The first method is based on an analysis of standard deviation charts. The second one evaluates the fitness value charts that show the solution from generation, with each line in a generation having a colour index of red to blue. The red index represents the last generation that is considered to achieve the fitness values. The third one is the standard deviation trendline which shows the standard deviation factor per generation. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, whereas a high standard deviation indicates that the values are spread out over a wider range. The fourth method is the mean value trendline which shows the average fitness value per generation. By selecting a solution and generation, the diamond fitness chart compares the different fitness objectives for this specific solution. If the selected solutions are closer to the centre, then these are more likely to achieve fitness. This graph gives us information about the fitness objective for the solution in the entire population.

6-4-2-2 Selection Criteria

To select the best solution, all the solutions are compared with each other through the entire population and ranked within the population. When using an extensive set of analytical methods, one of the challenges of running any evolutionary simulation is creating a population of many solutions and then extracting the last generation as the best solution. But even within the last generation, there may be 100 or 200 solutions and you still need to select a single solution from that last generation. The Wallacei plugin provides multiple analytical methods that will help to filter all solutions and to extract a specific solution with the optimal fitness value.

There are two types of selection criteria found in Wallacei to select the optimum solution. The first one is to choose by rank using the standard deviation charts and the second one is to select by the average fittest values using parallel coordinate charts. As this study aims to find the optimum solution to all fitness values, the fittest solution generation is the most recent generation and the parallel coordinate method is the most suitable technique. Parallel coordinate visualisation is used to represent high-dimensional data in two-dimensional space.

Therefore, the first step is to draw the parallel coordinate plot of all populations. The general trend of the graphs in Wallacei shows red indicating the first solution and blue indicating the latest solution. The graph below the simulation shows progressing solutions are getting closer to the x-axis, which essentially represents the fitness solutions values. Using three primary analytical methods that rely on parallel coordinate plot settings and one parallel coordinate plot, there are four primary analytical methods. The first method is repeated fitness, which highlights the most repeated fitness value across the population. The small circle indicates that this fitness value has been repeated the least and the large circle indicates that this fitness value has been repeated the most number of times (Fig. 6-25). The second analytical solution shows the most repeated fitness value to extract the associated solutions with the entire fitness value. For example, Objective 1 has 50 associated solutions with the most repeated fitness value and then extracts these solutions and constructs the phenotype to be exported. In the visualisation, all the data dimensions are represented as equidistant vertical axes that are arranged parallel to each other. The optimum solution at the parallel coordinate is defined as a balance of daylight and view quality. The best fitness value is achieved for model 2264 (Table 6-3), by 96.47%.

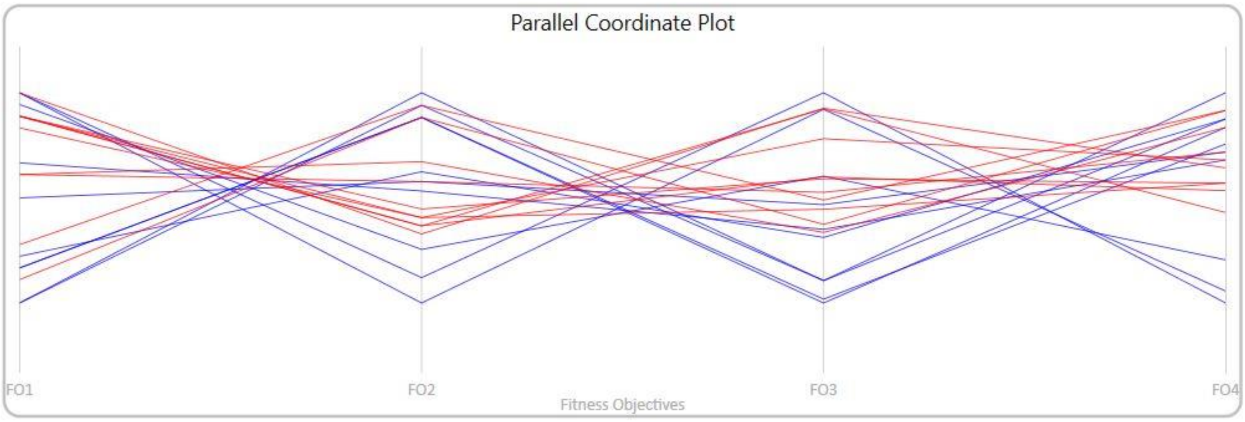


Figure 6-24: Parallel coordinate plot.

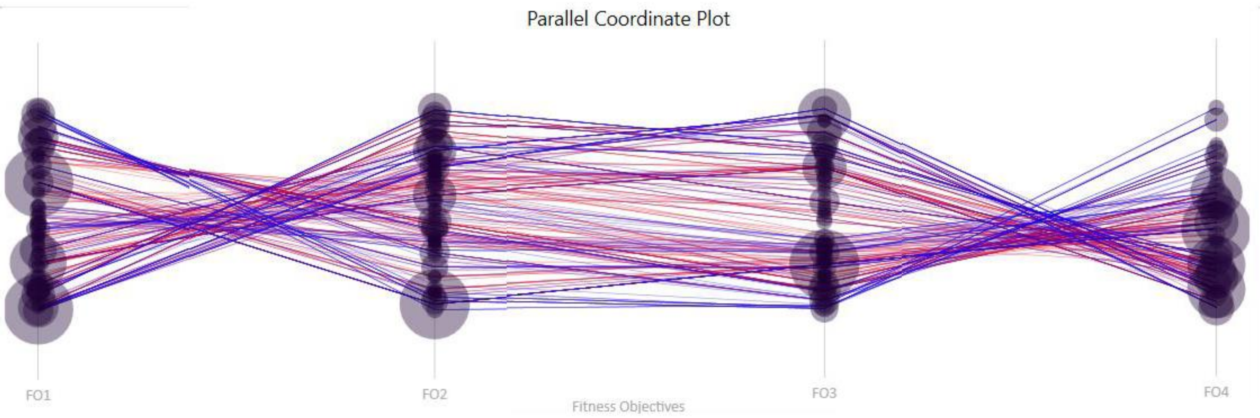


Figure 6-25: Selection of the most fitted solutions.

6-4-2-3 Selection of the Best Solution

Table 6-3: Genes and fitness values, red colour shows the base model results, green colour shows the optimised value after using shading device.

Gene	Shading parameters				Objectives				CW		Total CW
	Width (m)	Depth (m)	Angle	Max sDA%	Min ASE%	Max UDI%	Max view%	Min DGP%	CW1%	CW2%	Mean %
BASE model	—	—	—	24	20	25	41	49	0.993	0.914	0.95
Gen10. S 00	0.50	0.10	0	74.2	18	82	29	47	0.810	0.910	0.86
Gen14. S 02	0.50	0.10	0	74.28	18	82	38	47	0.798	0.914	0.85
Gen22. S 01	0.50	0.20	8	61.25	8	89	39	39	0.811	0.914	0.86
Gen29. S 00	0.50	1.90	3	62.8	9	89	25	40	0.572	0.566	0.56
Gen29. S 01	0.50	0.10	6	73.5	18	82	38	47	0.792	0.888	0.84
Gen29. S 02	0.50	0.10	0	74.1	18	82	25	47	0.553	0.546	0.82
Gen29. S 03	0.50	0.20	3	62.1	8	25	25	39	0.543	0.540	0.54
Gen29. S 04	0.50	1.9	1	59.9	8	90	24	40	0.535	0.531	0.53
Gen29. S 05	0.50	0.2	3	69.8	16	84	33	45	0.788	0.824	0.80
Gen29. S 06	0.50	0.5	3	64.4	12	85	30	42	0.709	0.661	0.68
Gen29. S 07	0.50	1.8	3	61.25	10	88	25	40	0.574	0.557	0.56
Gen29. S 08	0.50	0.6	3	64.6	13	86	29	42	0.676	0.636	0.65
Gen29. S 09	0.50	1.9	3	62.1	9	89	25	40	0.572	0.566	0.56

In this study, the best solution was found in the first solution at the 22nd generation and its fitness function value represents the highest in this study (shown in green in Table 6-3), equal to 86 %. It maximised the sDA value with a percentage of 37.25% from 24 % for the base model to be 61.25 % and minimise ASE value with a fitness rank of 35 by the percentage of 12% (from 20 % to 8). Also, it maximised the UDI and the DGP by 64% and 10% respectively (Fig. 6-26). The optimised model scored the accepted percentage of sDA and ASE by 61.25 % and 8% respectively.

In later generations, no better genome was found, and the density of solutions increased in the range of origin of the coordinates. The generation numbers in which each of the top 13 solutions is produced are given in Table 6-3 in numbers and shown in Appendix 2. Finding genomes with better fitness functions continued until the 29th generation, and no better genomes were found in later generations. As such, although the optimisation for a further six generations continued, results of only solutions that achieve the fittest values, last genes are reported in this research (Table 6-3).

To illustrate the relationship between the four optimisation objectives on the parallel coordinate chart, the latest generation was evaluated by inputting the last generation number and checking the fitness value on the chart. The big red spheres represent the most fitted solutions in the optimisation process. As demonstrated in Figure 6-26, while the small red spheres have the highest QV and sDA and the least UDI, their value of ASE is undesirably high. Although the optimisation was set to reduce the value of ASE, the analysis found other solutions (showed in blue in Table 6-3) that score the same ASE percentage of 8% (Gen29. S 03 and Gen29. S 04) but with decreased of UDI, View access values and WP%.

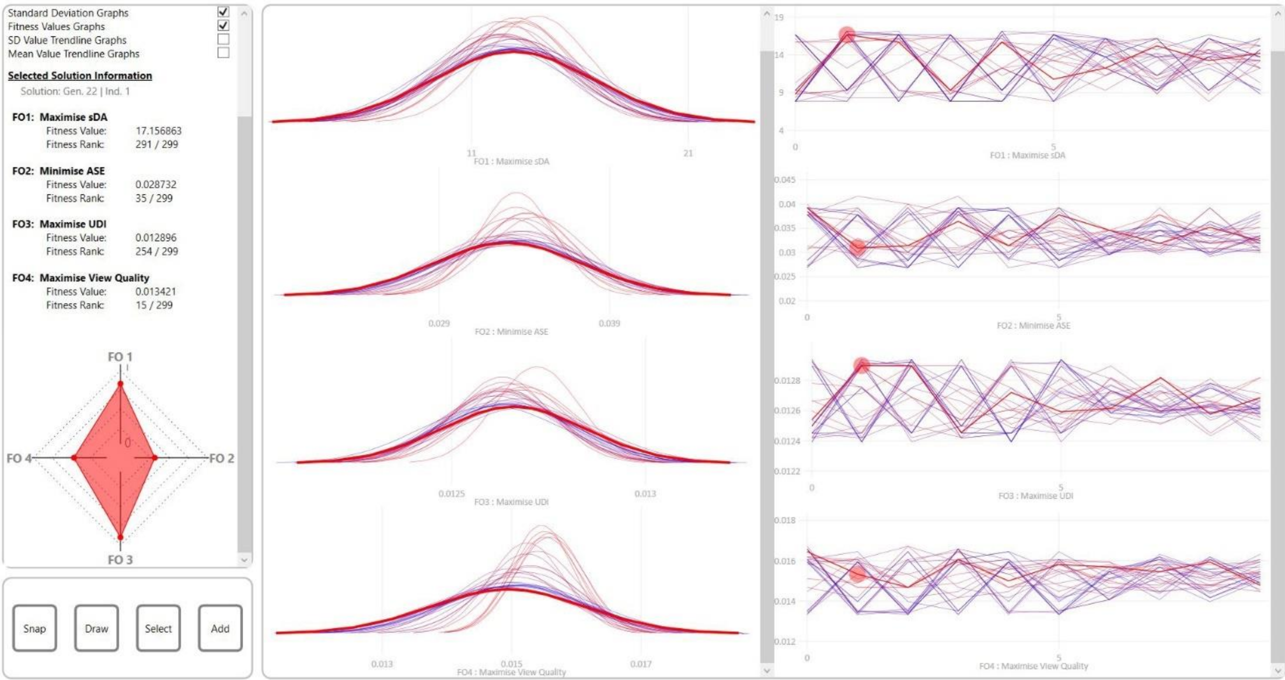


Figure 6-26: Selection of the best solution using standard deviation analysis of Gen22. S 01.

6-4-3 Comfort and Well-Being Map (CW_{map})

A comparison between the base model (without the shading device) related to the optimised model (with the shading device) was conducted at this stage to evaluate the differences between the assessment criteria. In the first model, only simulation was implemented for daylight and view analysis. The optimisation process only occurred for shading device parameters (angle, depth and count). The parallel coordinate analysis method was used with the optimised model to show how different parameters affect daylight and view quality. A parametric analysis regarding visible outside view content was conducted for each model to evaluate the well-being potential inside the working environment.

6-4-3-1Comfort Potential for Daylight Quality

Regarding daylight quality, the ASE of the optimised model is 79.52 kWh/m^2 with a 2% increase compared with the base model. Therefore, the optimised model will pass the daylight quality criteria of LEED v4.01 requiring more than 50% of the floor plan to exceed the threshold of 1,000 lux and more than 250 occupied hours per year. The UDI of the first model scores 340 lux; as a result of using a shading device in the optimised model, this illuminance value decreased but is still within the recommended value from 100 lux to 2,000 lux. The optimised model also passes the glare index value DGP from 0.35 to 0.5. LEED recommends that the DGP values be perceptible ($0.35 < DGP \leq 0.40$), disturbing ($0.40 < DGP \leq 0.45$) or intolerable ($DGP > 0.45$) to a majority of occupants.

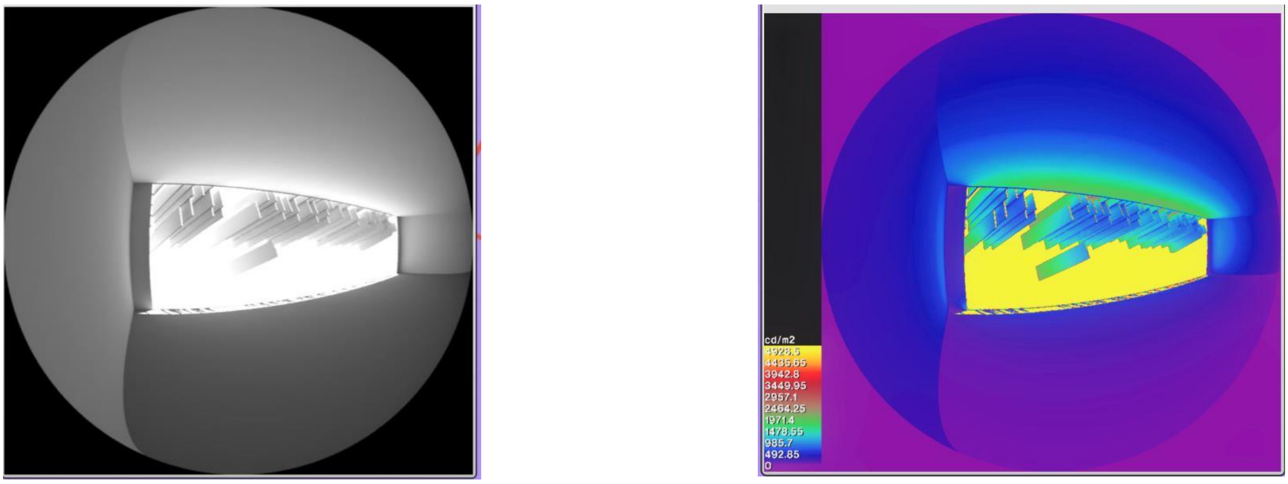


Figure 6-27: Daylight distribution and glare index *of Gen22. S 01*.

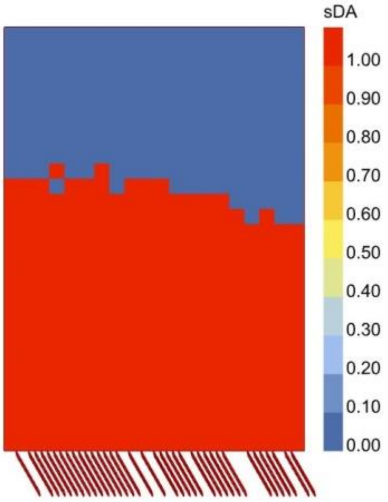


Figure 6-28: sDA simulation output *of Gen22. S 01*.

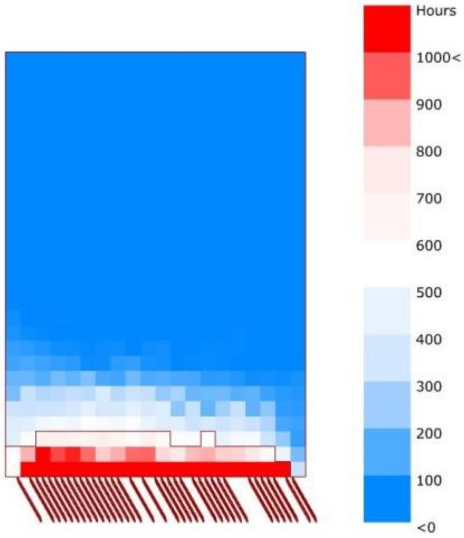


Figure 6-29: ASE simulation output *of Gen22. S 01*.

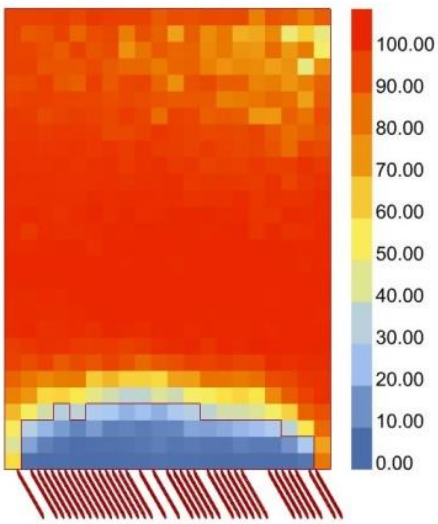


Figure 6-30: UDI simulation output *of Gen22. S 01*.

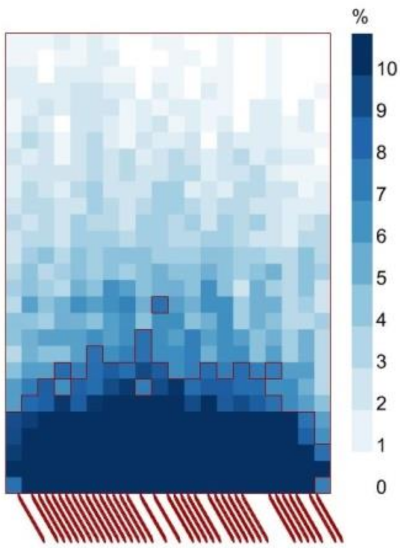


Figure 6-31: View access *of Gen22. S 01*.

6-4-3-2Well-Being Potential for View Quality

To quantify the well-being potential, a parametric algorithm was established to calculate the visible outside view content inside the space. Three sets of points were found related to sky view, context and greenery. A new metric – visible outside view (VOV) – was used to measure the view clarity and content together. The view quality was affected by using a shading device in the optimised model, although the multifactor system maximised the view content and clarity by choosing the sky area for installation of the shading device. A parametric algorithm was established and connected to the optimisation output to measure the visible outside view content (VOV). The base model scored a high value of VOV but it failed to comply with the daylight quality requirements. Both the optimised and base model scores for $VOV_{greenery}$ and $VOV_{context}$ were 30% and 20% but the optimised model score for VOV_{sky} was less than the base mode by 5% because of a shading device.

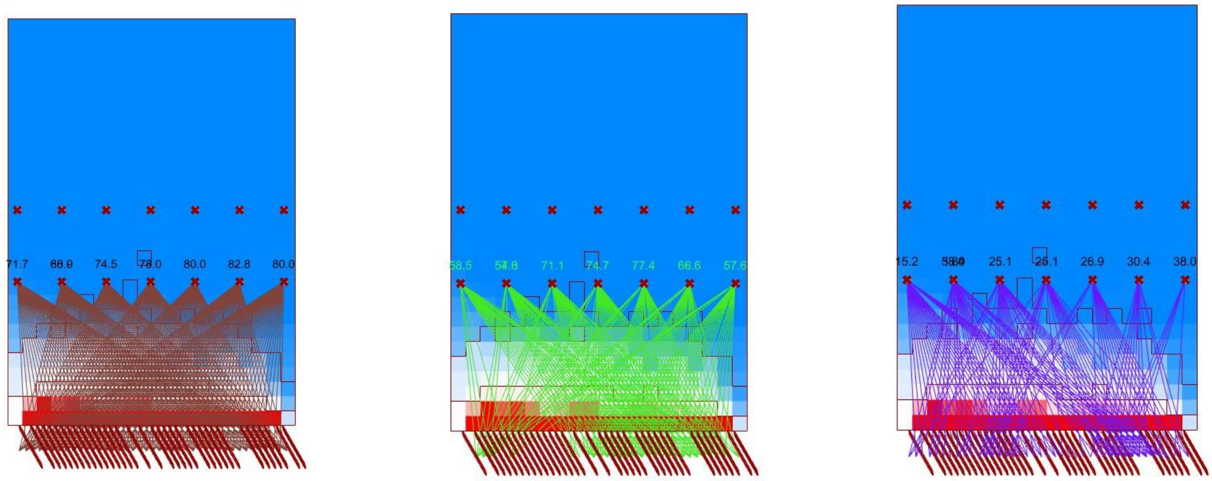


Figure 6-32: Visible outside view (VOV) context, greenery and sky (from left to right) at test point 1 *of Gen22. S 01*.

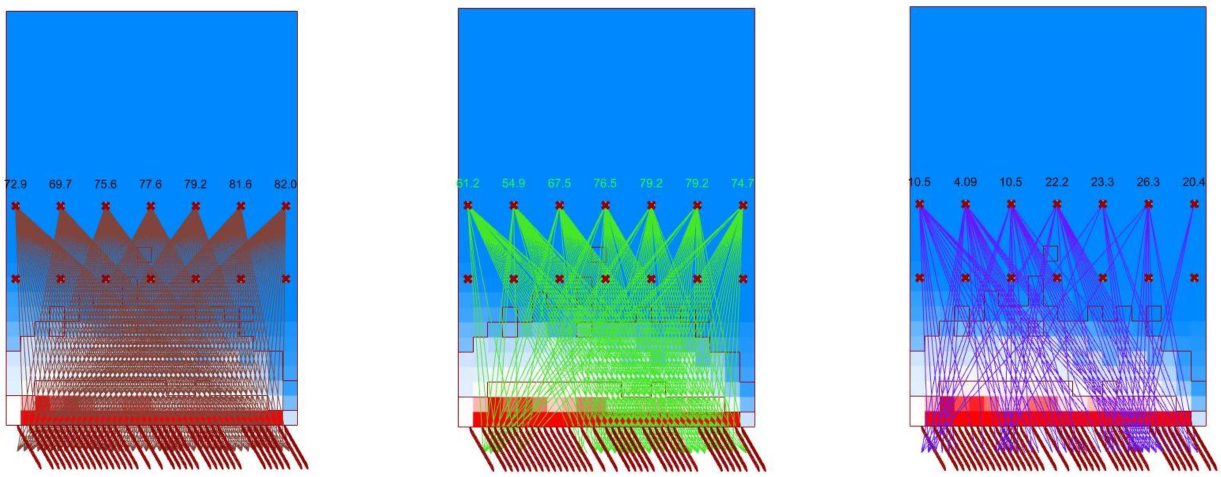


Figure 6-33: Visible outside view (VOV) context, greenery and sky (from left to right) at test point 2 *of Gen22. S 01*.

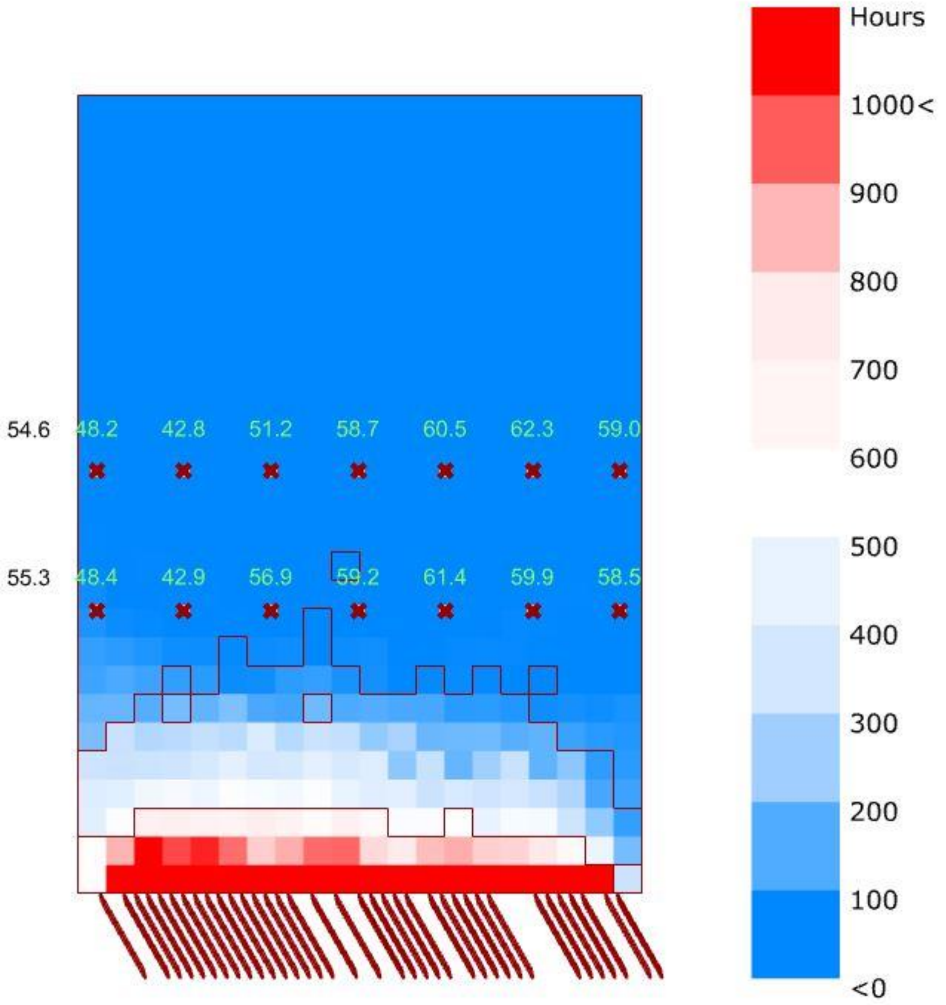


Figure 6-34: Comfort and well-being map (CW_{map}).

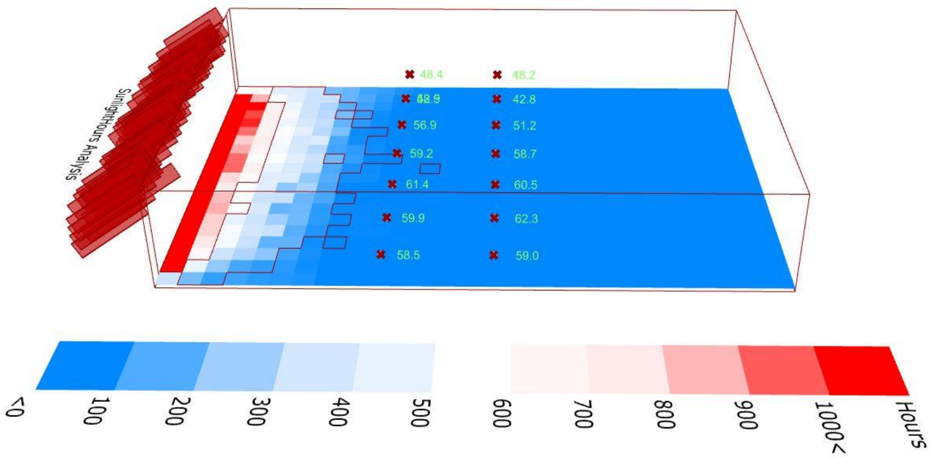


Figure 6-35: Comfort and well-being map (CW_{map}).

Daylight quality affects occupant visual comfort; therefore, the test points inside the working space that have the most comfort potential should fall within the recommended criteria of daylight quality. These areas are defined during the simulation process and a combination of three areas related to ASD, UDI and DGP is needed.

To quantify the comfort and well-being potential, a parametric algorithm was established (in Chapter 5) to calculate the visible outside view content inside the space. Three sets of points were found related to sky view, context and green view. A new metric – called visible outside view (VOV) – measured the view clarity and content together. As discussed in Chapter 6, the new parametric algorithm was integrated into a multifactor system (DVS system) to optimise between three aspects of daylight quality and view quality at the same time by optimising shading system parameters. The final simulation results were interpreted into the contouring map to show the zones that have good daylight and view quality. Table 6-37 shows the area that has the most comfort potential. The annual sun exposure (ASE) was decreased from 20 % to 8 % compared to the base model, also the Daylight Glare Probability (DGP) decreased from 49% to 39%. That means the base model visual comfort improved by 11% due to the decrease of DGP and ASE.

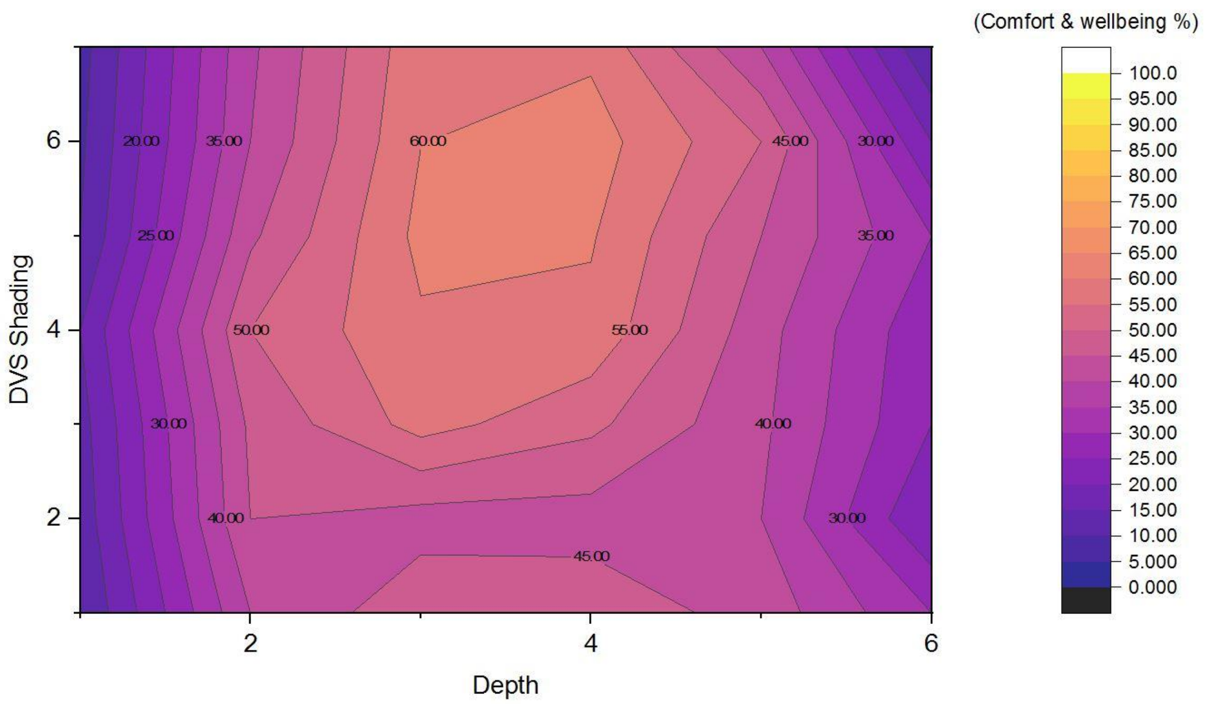


Figure 6-36: Comfort and well-being map (CW_{map}).

As shown in Figure 6-36, the space was divided into three zones: overlit, daylit and underlit zones. The overlit zone was located near the window at a distance of not more than 2 metres and a maximum of 2.5 metres, the daylit zone was located between 2.5 and 4.5 metres and the underlit zone was located at 4.5 to 6 metres. The very bright zone that achieves the assessment criteria was found in the zone between 60% and 56%. This percentage is the average weight of all VOV percentages. However, the CW_{map} shows that the best area with high well-being and comfort

6-4-3-3 DVS Dashboard Application

The Human User Interface plugin for Grasshopper was applied as a user interface for a new multifactor system algorithm based on the multi-evolutionary optimisation (MEO) method embedded with a dashboard to be improved in the future and be made available in the market as a standalone application. This dashboard aims to combine daylight quality and view quality in one track with reefing to the optimum shading device parameters to achieve this goal. It can be used to assess view quality and give a different solution to the optimal shading device. The measurements and metrics used in this system comply with the most up-to-date assessment criteria provided by LEED v04.01 (resulting from Chapter 2, sections 2-6). Also, this application can be used as a benchmark to evaluate an apartment's view quality, which will help to increase the rent percentage for offices and the residential sector. The outside view image can be imported using a camera phone or drone taking pictures from a specific point to comply with the view quality assessment criteria recommended by the building rating system. Also, it can be applied to the building to measure the best orientation and opening size for better view quality.

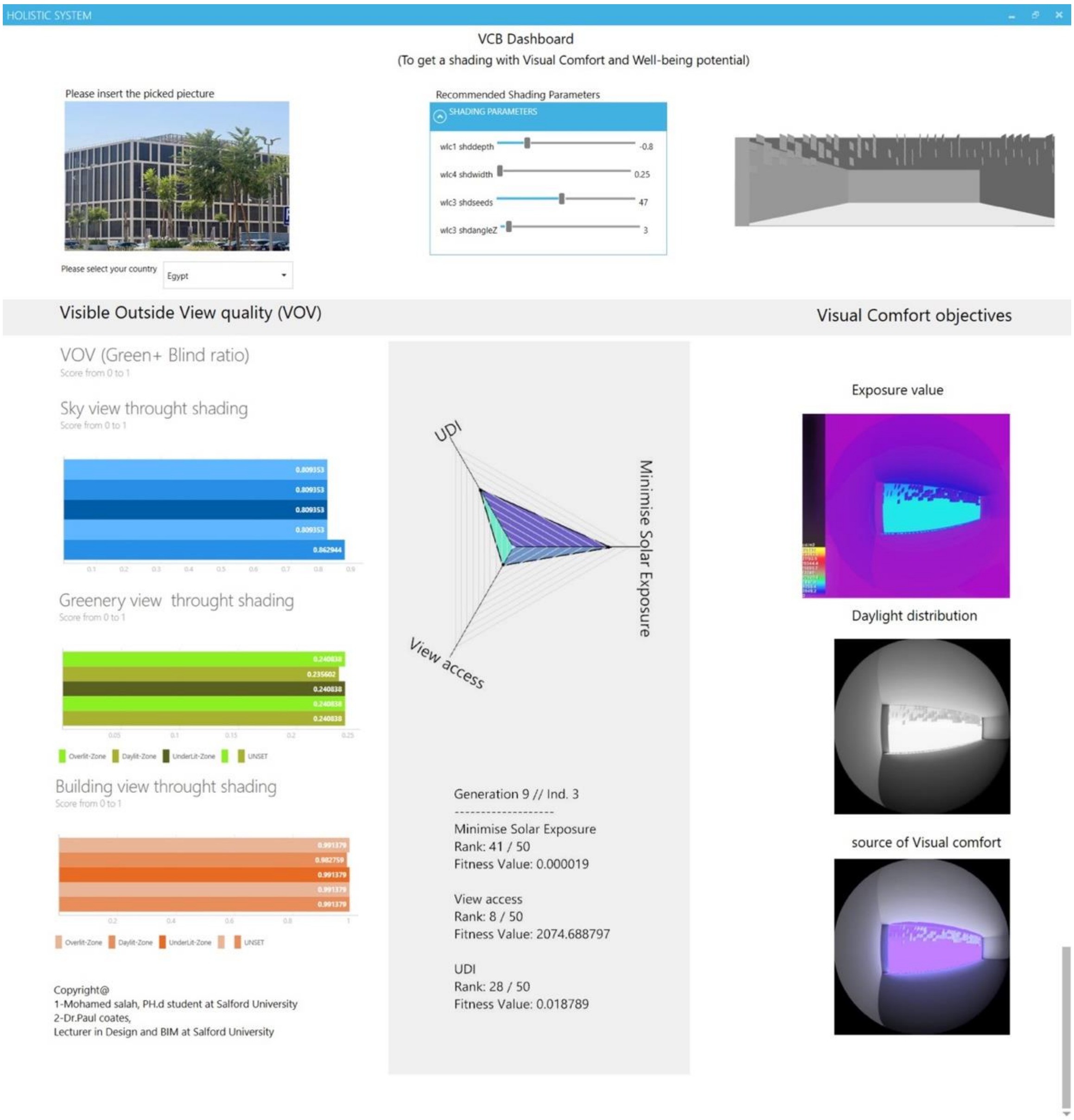


Figure 6-37: DVS dashboard application.

6-5 Conclusion

This chapter introduces a novel method to design multifactor shading systems by using multi-objective evolutionary algorithms (MOEAs) connecting daylight quality and outside view quality and aiming to improve comfort and well-being potential inside the working space. Previously, in Chapter 5, a new indicator – called visible outside view (VOV) – was found to measure the view clarity and content together. This new metric is a percentage starting from 0% to 100% showing the well-being potential to test points inside the workspace to measure the overall percentage of sight lines that have a clear view of landscape elements and sky view.

The goal of this system is to show how daylight, view quality and shading systems can be integrated into a multifactor system. This study investigates the possibilities of using different shading system parameters to compromise between daylight quality and view quality. Shading configuration is categorized by a series of parameters to provide the appropriate visual comfort and well-being potential inside the workspace. This study provides a new multifactor system for designing shading devices by using two approaches: multi-objective evolutionary algorithms (MOEAs) and parametric-based design. MOEAs aim to quantify daylight quality and the associated visual comfort potential. This multifactor system used an algorithmic and parametric-based design approach developed in Rhino/Grasshopper to quantify the well-being potential associated with the outside view quality (resulting from Chapter 5). Ladybug and Honeybee plugins for Grasshopper were used to run a series of daylight simulations related to the assessment criteria by measuring (1) daylight quality UDI, (2) spatial daylight autonomy sDA, (3) annual sunlight exposure (ASE) and (4) daylight glare probability (DGP).

Next, the validation of this system will be implemented in Chapter 7 by conducting a virtual reality experiment to measure daylight's subjective characteristics and produce an immersive environment.

CHAPTER 7: DVS System Validation – Virtual Reality Experiment

7-1 Introduction

In this chapter, the simulation outcomes are examined by a range of participant choices related to daylight quality, visible outside view quality and shading device parameters resulting from applying the DVS system. This study aims to validate the shading device configuration resulting from applying the DVS system. To validate the system, a virtual reality experiment was conducted to measure the subjective characteristics of daylight and view. An immersive environment was produced where participants can express their feelings and indicate their level of satisfaction with daylight quality and view quality. As discussed in Chapter 1, this research aims to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms to enhance occupant comfort and well-being potential for recommended values and standards of daylight quality and view quality. A comfort and well-being map (CW_{map}) was defined in Chapter 6 as a result of applying the DVS system to indicate the predictive VOV percentage in a space.

This experiment took place over one week at an office space in the Maxwell building at Salford University, UK. A total of 45 participants (25 male and 20 female) took part in the study (Fig. 7-1). All participants were unpaid volunteers recruited by email and over 18 years of age. The main aim was to test participants' feelings and satisfaction with daylight and view quality that improved by using the shading device resulting from applying the DVS system. In addition, to validate the DVS system, the comfort and well-being map (CW_{map}) created by applying DVS simulation was compared with participants' choices in an immersive environment using VR. In Chapter 6, it is assumed that the CW_{map} can predict the level of comfort and well-being of a shading device at a certain point in space by measuring the view and daylight quality together. By importing the shading device into virtual reality, participants can walk through the same space used in the simulation and express their feelings and satisfaction with the daylight and view quality received; then, they are asked to choose the best location. These locations chosen by the participants are compared with the CW_{map} resulting from the simulation to investigate the level of accuracy of the DVS system.

The choice to conduct the VR experiment in a separate virtual space, rather than directly in the Egyptian case study, was purposeful for several reasons. First, the VR experiment included a preliminary questionnaire, which participants completed before entering the VR simulation. This setup enabled us to gather initial subjective impressions, ensuring that participants were unbiased by any prior contextual details specific to the Egyptian case.

Additionally, incorporating both the Egyptian and Salford Maxwell Building cases allowed us to validate and test the (DVS) across two distinct regional contexts. This approach enhances the robustness of the DVS system by confirming its effectiveness across varying geographic and climatic contexts, supporting its adaptability and relevance in diverse environments.

Figure 7-1: Maxwell building at Salford University, UK.

7-2 Validation

Validation of simulation results is required in the current research area that needs further in-depth investigation (Tahmasebi & Mahdavi, 2017). To minimise discrepancies between simulations and experiments, sensitivity analyses can facilitate the calibration of simulation models, while two kinds of shading devices – vertical and 3D panelling – are tested for simulation in this research. In addition, it is imperative to develop well-established measures to determine whether simulations and experimental results are generally in agreement. Due to time and cost limitations, many researchers utilise simulations and modelling to investigate and explore complex phenomena through computer simulations (Tahmasebi & Mahdavi, 2017). As discussed in Chapter 6, simulations can be used to improve the design outcome by investigating design decisions during the design process, but these approaches have some drawbacks (Aksamija, 2018). These drawbacks are to check the accuracy, uncertainty and validity of software used in the simulation process to reflect real-world situations.

System validation can generally be conducted using one of three comparison methods, that is, analytical solutions, empirical evidence or peer models (Ryan & Sanquist, 2012).

To improve the accuracy of the validation process, it is necessary to compare the simulation model output with the virtual reality experiment output (Neymark et al. 2002). In this experiment, the accuracy of the DVS system was examined from three aspects: (1) virtual environment creation, (2) shading device import and export process from the simulation output to the VR platform (i.e. shading device integration, and (3) daylight and outside view parameters to match the real-world situation (i.e. daylight validation).

7-2-1 Virtual Environment Creation

This stage aims to develop a virtual environment that accurately represents the real-world context where the shading device will be installed. This includes modelling the building, its surroundings and the specific location where the shading device will be placed. To achieve this, a high-quality HDR image of the outside environment was taken and used in the view quality simulation discussed in Chapter 5 and imported to the VR platform as a background. Both backgrounds are found to be the same in simulation and VR (Figs. 7-2 and 7-3).

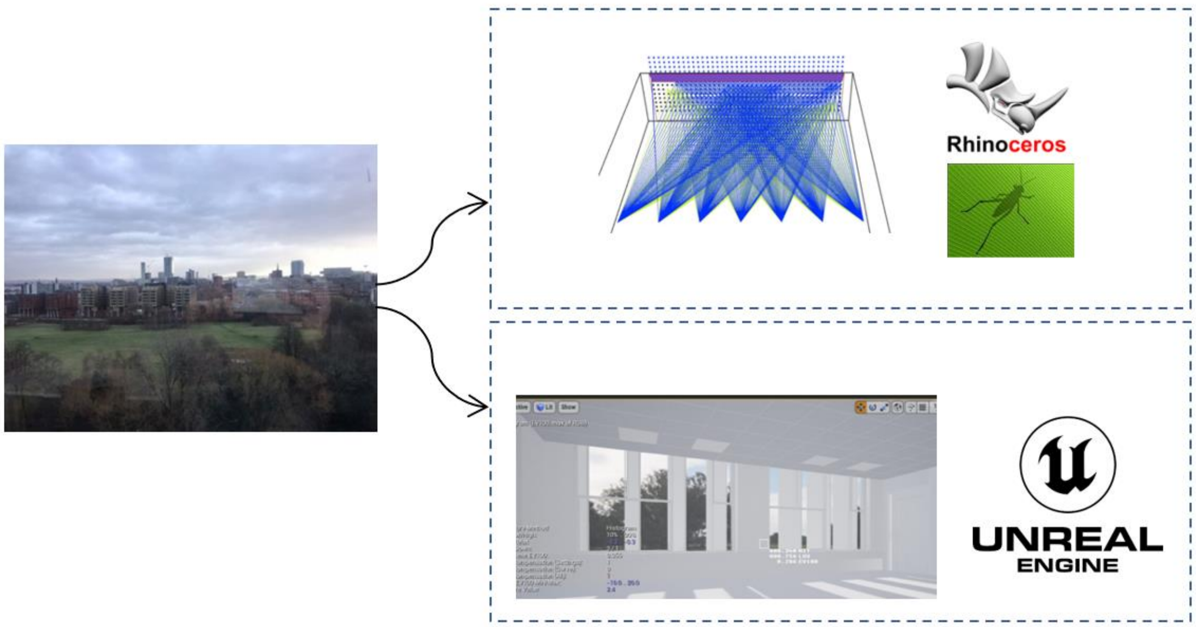


Figure 7-2: Outside view image used in simulation and Unreal software.

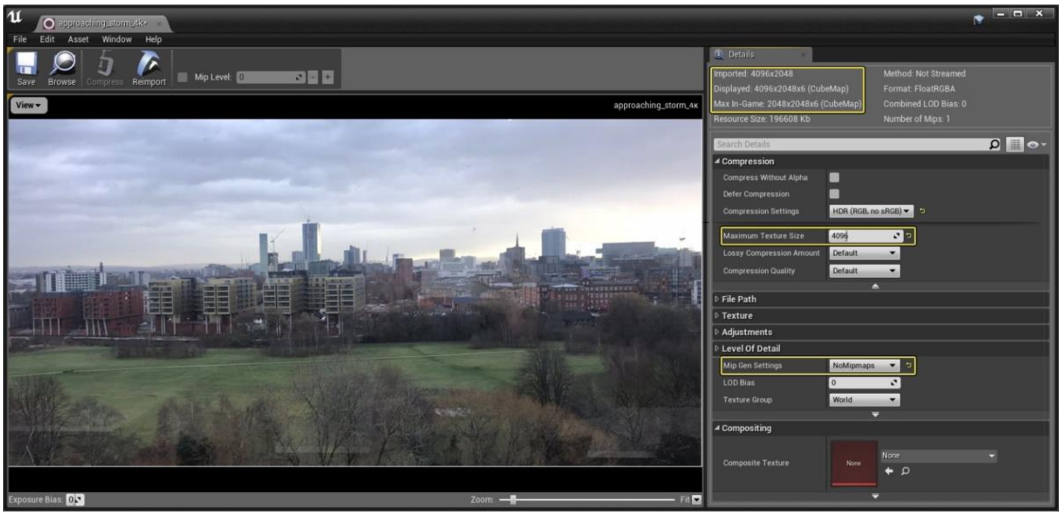


Figure 7-3: Creating a new HDR map using the outside view photo.

7-2-2 Shading Device Integration

This stage aims to incorporate the shading device model into the virtual environment to ensure that the virtual representation of the shading device accurately reflects its physical properties and dimensions. To achieve this target, the optimal shading device was selected according to the multi-objective optimisation process and imported as a mesh to 3D Studio Max. After that, the space was textured with the same material used in the simulation and discussed in Chapter 4. The textured model including the shading device was exported to the VR platform Unreal software using the Datasmith plugin to make sure the same model and material used in the simulation are used in the VR (Fig. 7-4).

Figure 7-4: Datamish plugin connections.

7-2-3 Daylight Validation between Unreal and Simulation

Modern game engines have made significant advancements in rendering technology, allowing them to achieve impressive levels of photorealism in real-time. These game engines utilise various techniques and algorithms to simulate lighting, shadows, textures and other visual effects, resulting in highly realistic graphics (Sheng et al., 2015). Unreal Engine 5 (UE5), developed by Epic Games, was used in this experiment and the daylight simulation was verified through different aspects of daylight and view quality. The lighting algorithms in Unreal Engine work to replicate the physical interaction between light and surfaces as accurately as possible, taking into account properties such as reflectance, roughness and the inverse square law (Walker, 2014). In addition, lighting in Unreal can be measured using lux and candle per metre square (cd/m^2) and the sky model's accuracy can be validated in real-time simulation. The accuracy of daylight simulation in Unreal has been validated in many studies against physical sensor measurements (Natephra et al., 2017) and daylight simulation done using the Radiance simulation package (Larson & Shakespeare, 1998).

7-2-3-1Validating Illuminance between Unreal and Radiance Simulation

Validating daylight simulation between reality and simulation involves comparing the simulated lighting conditions with the actual measured lighting conditions in the real world. Fisher (1992) recommended that the absolute error between reality and simulation should not exceed 10% for average illuminance and 20% for each test point. In an experiment conducted by Natephra et al., (2017), the maximum absolute error for daylight simulation in Unreal did not exceed 11.08%.. In the present study, to simulate the sun in Unreal, the Sun Position plugin was used to detect the position of the sun according to the geographical database in Unreal. A set of parameters was adjusted manually to match the daylight simulation parameters set in Honeybee, such as sun intensity of 100 Klux and temperature of 6000 K. to reflect the daylight with a clear sky.

A test was conducted to verify the accuracy of luminosity between Unreal and Radiance simulation outputs. First, in Unreal software, the geographical coordinates were set to 55.3781°N and 3.4360°W (Manchester, UK). The date was set to test the shading device on the summer equinox in the UK on 21 June and the time was 2.57 p.m. A point-in-time simulation was carried out by the Radiance engine used in the DVS system to get the optimal shading device that has high comfort and well-being potential at the indicated time. After that, six test points were set on the True False colour image produced by Radiance and compared with the lumen produced on Unreal (Fig. 7-5).

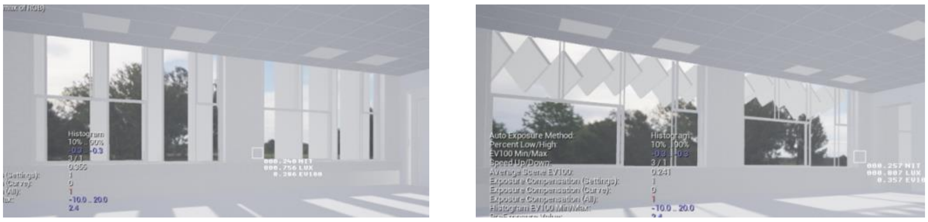


Figure 7-5: The experiment space in Unreal software.

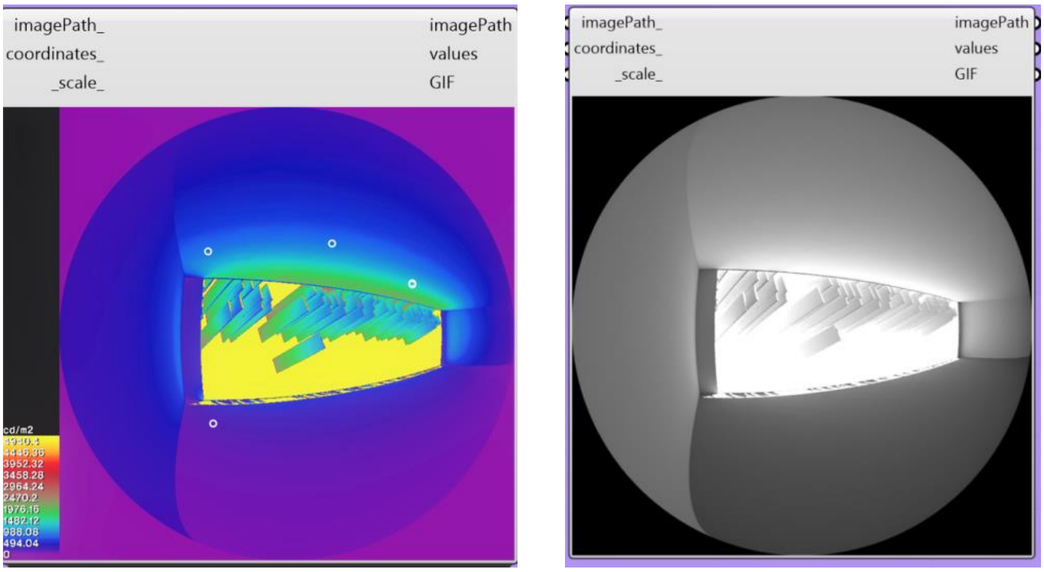


Figure 7-6: Daylight lux in irradiance simulation.

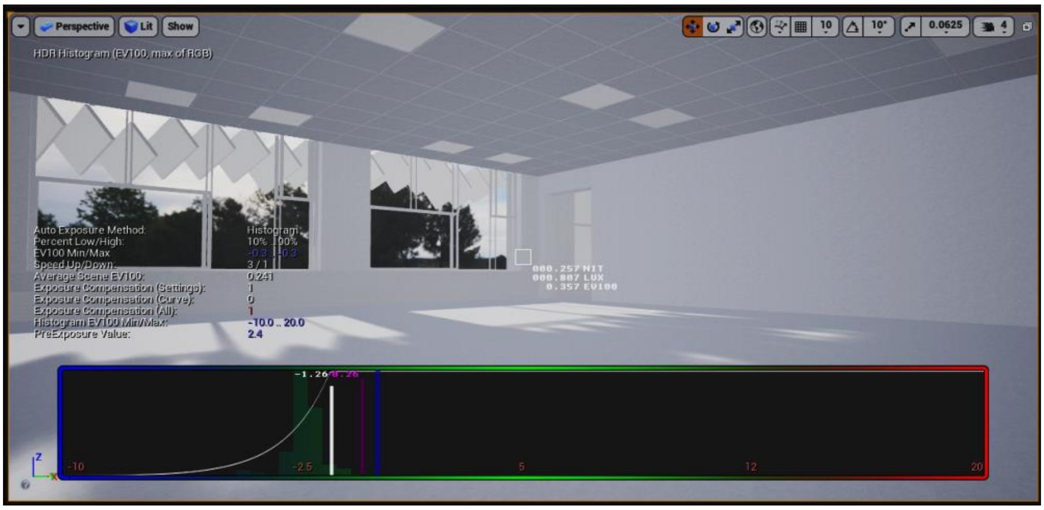


Figure 7-7: Daylight lux in Unreal software.

Table 7-1: Radiance and Unreal illuminance relative error percentage.

Test points	Radiance simulation (lux)	Unreal v5 (lux)	Relative error (%)
1	490	440	11.3
2	498	466	6.8
3	520	480	8.3
4	988	924	6.9
5	1,300	1,105	17
6	1,420	1,100	29
7	1,230	1,120	9.8
8	834	788	5.8
Overall	7,280	6,423	13.3

To measure the illuminance value for both the simulation and Unreal 5, a set of eight points was put in Grasshopper around the window opening and away from the window by 0.6 metres as recommended by LEED; artificial light was used during the simulation process (LEED v4, 2019) (Figs. 7-7 and 7-8). The two values of illuminance were compared to measure the relative error value based on the following formula (Agresti, 1990):

$$Relative\ error\ \%\ \frac{[Simulation_{\mathrm{Lux}} + Unreal_{\mathrm{Lux}}]}{Unreal_{\mathrm{Lux}}}$$

According to the relative error calculations shown in Table 7-1, the total error is 13.3%, which is slightly high by 3.3% of the maximum acceptable values of 10% recommended by Fisher (1992). The total average error is higher than the recommended value, but seven points succeed in achieving the recommended value of not exceeding 10%; only Point 6 exceeds the recommended value by 9%. The reason for this may be because this point is located in the area that receives the most daylight exposure.

The decision to continue an experiment when recommended values are exceeded depends on the nature of the experiment, the specific error and the potential impact on the results. In this case, the daylight luminance received at Point 06 was 1,420 lux measured by Radiance and 1,100 lux measured by Unreal v5. According to standard EN 12464, which specifies daylight in indoor workplaces, the light level recommended for office work is in the range of 500–1,000 lux depending on the activity. For precision and detailed work, the light level may even approach 1,500–2,000 lux; therefore, the difference between daylight measurements is still acceptable and valid.

7-3 Virtual Reality Experiment Workflow

The VR workflow used in this experiment consists of three stages.

- The simulation environment setup, including model creation of the office space, the shading device and daylight parameters used in the simulation, as discussed in Chapter 6.
- The VR environment setup to evaluate the impact of installing a shading device for daylight and view quality.
- Evaluation of participants' responses generated from the collective feedback of the VR experiment.

7-3-1 The Simulation Environment Setup

A 3D model of two typical, connected office spaces was created using Rhino. These office spaces are located in the Maxwell building at Salford University, UK, which consists of nine levels. The two chosen typical office spaces, located on Level 4 and with dimensions of $12 \times 8 \times 3$ m^3 (Fig. 7-8 and 7-9), have been used as a case study to make sure that the outside view content contains sky, context and greenery elements. The first space is the starting point for the VR walkthrough and has no shading device installed at the external or internal façade. The second space, which has the shading device from applying the DVS system, is connected to the first one by a door to allow participants to move between the two spaces and compare them.

Figure 7-8: Outside view content of room at Level 4.

Figure 7-9: Maxwell building at Salford University.

A panoramic picture of the outside view was taken from inside the space near the window and imported to both the DVS system and Unreal software used to establish the VR experiment. To comply with the view quality requirements in rating systems, it is assumed that glaze has visual transmittance of 0.7 VT to provide a clear image of the exterior, not obstructed by frits, fibers, patterned glazing or added tints that distort colour balance, as recommended by LEED and WELL for view quality.

Due to time limitations, only a panelling prototype shading system was used to allow each participant to spend around 10 minutes on the experiment. Shading parameters for each device were optimised through the DVS system as indicated previously in Chapter 6; only the optimum solution was selected and imported to Unreal software to run the VR experiment (Table 7-2). A comfort and well-being map (CW_{map}) was created to predict the daylight and view quality in different zones: the overlit zone near the window, the daylit zone in the middle of the space and the underlit zone at the back of the space.

Table 7-2: The optimised Shading device parameters.

Parameters	Panelling prototype
Angle	*X*=45, *Y*=30
Count	20
Dimensions	50 × 50 cm

7-3-2 The VR Environment Setup

7-3-2-1 Equipment and Software Used

First, the 2D CAD drawings were made in AutoCAD software for the two selected spaces and imported into 3D Studio Max. After that, all surfaces were textured to match the same material used in the simulation according to ASHRAE. After finishing the full textured model, all models were imported into Unreal software using the Datasmith plugin installed in 3D Studio Max. The HTC VIVE headset, which supports both motion controls and whole-room VR, was used in this experiment. Its screen measures 5.5 inches, 538 ppi, at 21,200 × 1,080 (per eye) resolutions. The display can run at a maximum refresh rate of 90 Hz, delivering enhanced brightness and colours. This experiment was run on a desktop computer with Intel(R) Core(TM) i7-8700 CPU @3.20 GHz processor and 64.00 GB RAM.

7-3-2-2 Experiment Procedures

As Creswell (1994) suggests, at least between 15 and 25 interviews are required for an interpretive study. Forty-five participants (25 male and 20 female) were asked to provide their opinions on daylight in the investigated space. The number of participants needed was identified as illustrated by several related studies (Franz et al., 2005; Cauwerts and Bodart, 2013; Heydarian et al., 2014; Chamilothori et al., 2019). To alleviate the presentation-order bias that can arise while viewing physical and VR environments (Chamilothori et al., 2019), participants were randomly separated into two groups, each exposed to the virtual environment.

The experiment was carried out under the condition of an overcast sky. The participants were instructed about the purpose of the study and described the necessary tasks. A brief presentation at the beginning provided participants with an overview of the study's aims, objectives, and instructions on how to use the VR controller. To collect participants' feelings and satisfaction with daylight and view quality that was improved by using the shading device, participants were asked to wear the headset and walk inside the virtual space to indicate the best location for working taking into consideration daylight and view quality as main factors in their choice. Finally, the participants were asked to fill out a questionnaire consisting of six questions to evaluate their feelings and satisfaction regarding daylight and view quality. Another verbal questionnaire was also administered and consisted of the following six questions:

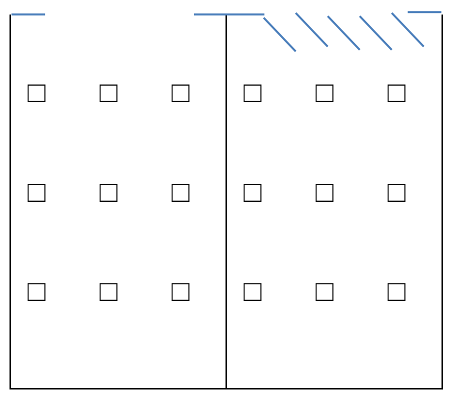
- Q1: Select your best location in Space 1 and Space 2.

This first question aims to achieve the first objective of applying the VR experiment by comparing a participant's choice for the base room (without the shading device) with the other room with the shading device to see whether they still have the same level of satisfaction with the location according to daylight and view quality.

- Q2: How satisfied are you with the brightness of the space?
- Q3: How satisfied are you with the daylight distribution pattern on the ground and walls related to the shading device?
- Q4: How satisfied are you with the outside view access behind the shading device?
- Q5: How satisfied are you with the daylight glare issues?
- Q6: Based on your best location chosen in Space 2 (with shading device), can you select the term that best describes your feelings related to this location?

The questions from Q2 to Q6 aimed to evaluate participant satisfaction with daylight and visible outside view for Space 2 which has a shading device installed. A Likert scale range from 1 to 5 was used to evaluate the participant responses, where 1=very dissatisfied, 2=dissatisfied, 3=neutral, 4=satisfied and 5=very satisfied. The experiment questions focused on the effect of shading on daylight and visible outside view quality (Table 7-3). Question 2 assesses participants' level of satisfaction with the brightness of the space. Question 3 evaluates the daylight distribution pattern on the ground and walls related to the shading device. In Question 4, participants express their level of satisfaction with the visible outside view through the shading device. In Question 5, participants indicate their level of satisfaction with the glare. In Question 6, they select the term that describes their feelings related to the chosen location. This experiment was limited to other factors that may affect participant answers such as daylight conditions, material, furniture and interior design. Therefore, it is important to illustrate at the beginning that this study is only related to daylight quality and view quality received after installing the shading system.

Table 7-3: The VR experiment questionnaire form

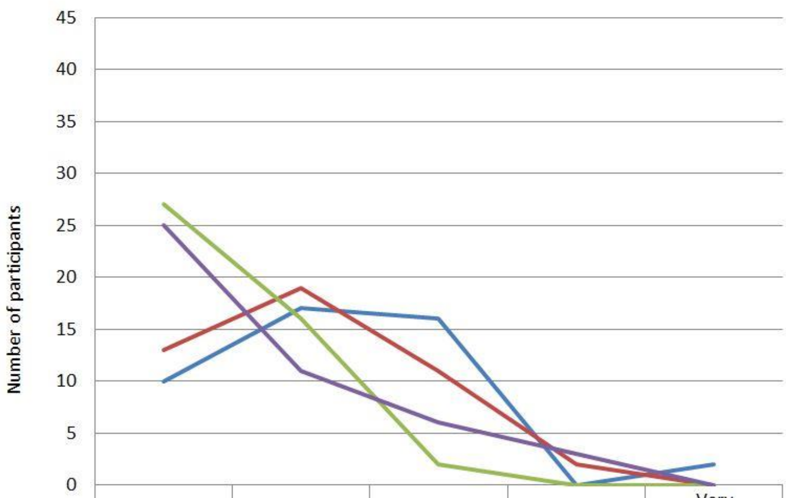
Participant Information for Virtual Reality Experiment 1						
Q1	Select your best location in Space 1 and Space 2.					
	 Space 1 Space 2 (with shading device)					
	(1) Very dissatisfied, (2) Dissatisfied, (3) Neutral, (4) Satisfied, (5). Very satisfied	1	2	3	4	5
Q2	How satisfied are you with the brightness of the space?	☐	☐	☐	☐	☐
Q3	How satisfied are you with the daylight distribution pattern on ground and walls related to the shading device?	☐	☐	☐	☐	☐
Q4	How satisfied are you with the outside view access behind the shading device?	☐	☐	☐	☐	☐
Q5	How satisfied are you with the daylight glare issues?	☐	☐	☐	☐	☐
Q6	Based on your best location chosen in Space 2 (with shading device), can you select the term that best describes your feelings related to this location?					
	Happy	☐				
	Active	☐				
	Cosy	☐				
	Comfortable	☐				
	Gloomy	☐				
	Anxious	☐				
	Other					

7-4 Results and Validation

Different types of graph trends have been used to illustrate the relationships between variables used in the verbal questionnaire. Descriptive Analysis show the level of satisfaction for the five points used in the questionnaire as follows: (1) daylight brightness, (2) daylight distributions, (3) view quality, (4) glare and (5) feelings. An analysis of graph-based networks was used to understand participants' behaviour and attributes in the workspace in the VR experiment. These networks are based on a mathematical model connecting nodes to form the network structure to understand their relationships and how they affect behaviour. By representing these social structures as networks, researchers can apply various mathematical and graph-based methods to quantify structural characteristics and their relationship to behavioural attributes of a population (discussed in detail in Chapter 3). Model analyses were conducted in Gephi, a powerful open-source software tool that is now widely used in network analysis. The network analysis map can show the terms that were most frequently selected based on their weight. To validate the results, the comfort and well-being map and the network social analysis were compared by overlapping the two maps to investigate whether the most chosen zone through the VR experiment is the same zone indicated in the CW_{map}.

7-4-1 Descriptive Analysis

To understand the influence of shading devices on satisfaction with comfort and well-being attributes (brightness, distribution, view quality and glare), a linear graph was used to compare the attributes. The results show that there is an association between daylight brightness and distribution and also between view quality and glare. This may explain why nearly the same number of participants was very satisfied with distribution (10 participants) and brightness (13 participants) whereas most participants were very satisfied with view and glare (Fig. 7-10).



	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
Distribution	10	17	16	0	2
Brightness	13	19	11	2	0
View quality	27	16	2	0	0
Glare	25	11	6	3	0

Figure 7-10: Linear graph illustrating the comfort and well-being attributes.

7-4-1-1 Level of Satisfaction with Comfort and Well-Being Attributes

Regarding satisfaction with daylight brightness, 13 participants were very satisfied, 19 were satisfied and only 2 were dissatisfied (Fig. 7-10).In addition, the majority of participants were satisfied with daylight distribution and 27 people were very satisfied with the view quality to the outside, whereas 16 participants were satisfied. Regarding satisfaction with glare, 25 people were very satisfied with the glare level at the location chosen. As indicated in Figure. 7-15, 19 participants feel comfortable and 16 participants feel happy.

7-4-1-2Influence of Shading on Participants' Favourite Zone

Figure 7-16 shows that 30 participants preferred to sit in the daylit zone. The attributes that affected their choices in this experiment were brightness, distribution, view quality and glare issues. To illustrate the relationship between these attributes, each attribute is visualised using a network analysis technique. This gives us a better understanding of the factors that affect participant feelings. This will be discussed in the following section as the network map is compared with the comfort and well-being map for validation.

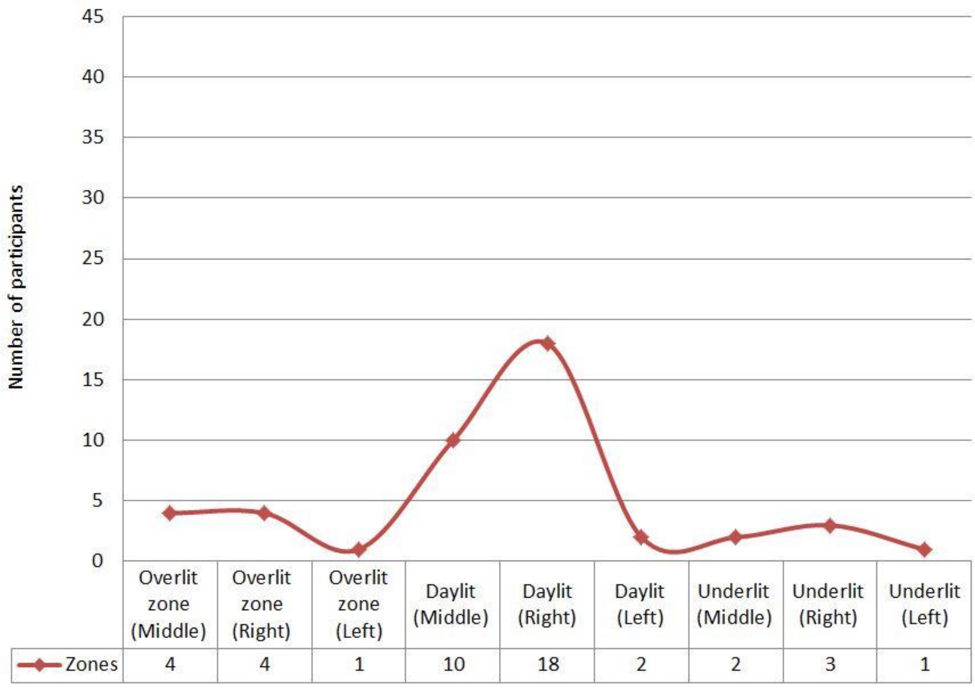


Figure 7-16: Linear graph showing the most zones chosen.

7-4-2 Statistical Analysis

Spearman's test is a nonparametric measure of the strength and direction of association that exists between two variables measured on at least an ordinal scale. Spearman's rank correlation coefficient (r_s) test was conducted in SPSS to check the correlation in more depth between the attributes. As shown in Table 7-4, there are positive and negative correlations and also some attributes show a highly significant correlation. A negative (inverse) correlation occurs when the correlation coefficient is less than 0. This is an indication that both variables move in the opposite direction. Therefore, any reading between 0 and −1 means that the two attributes move in opposite directions. When ρ is −1, the relationship is said to be perfectly negatively correlated. In short, if one variable increases, the other variable decreases with the same magnitude (and vice versa).

There are six negative correlations between (1) location with view ($r_s = -0.265$), (2) feeling with brightness ($r_s = -0.326$), (3) brightness with view ($r_s = -0.157$), (4) distribution with feeling ($r_s = -0.120$), (5) distribution with glare ($r_s = -0.002$) and (6) glare with view ($r_s = -0.120$), but only feelings with brightness showed a significant negative correlation of $p = 0.29$. This may explain why having good daylight is important because the increase in daylight brightness makes participants not feel comfortable or happy. In addition, we should not neglect the negative correlation even if it is not significant as this may become significant if we increase the sample size and improve the types of questions that focus on these aspects. There is a weak negative correlation between both (1) the levels of satisfaction with the view and location nearer to the window and also (2) the levels of satisfaction with daylight brightness and glare, but the correlation between satisfaction with glare and location near the window is significant ($p = <0.001$). This is a very important finding as it explains why most participants did not prefer to sit near windows because they will receive high levels of glare.

Furthermore, there are strong positive correlations and significant associations between location and glare ($r_s = 0.64$, $p = <0.001$) and also between brightness and glare ($r_s = 0.36$, $p = 0.13$). That means, participants scored a high level of satisfaction with glare when they chose to sit away from the window in the daylit or underlit zone. Also, the level of satisfaction with daylight brightness increases when participants experience no glare issues.

7-4-3 VR Experiment Reliability

To obtain accurate results, reliable data must be used. Hence, achieving a high reliability score involves reducing errors in data interpretation (Sarantakos, 2013). As Taber, K.S. (2018) points out Cronbach's alpha from 0.5 to 0.7 shows moderate reliability As shown in Table 7-4, Cronbach's alpha is 0.568 which means the questionnaire is moderately reliable.

Table 7-4: Correlations and Cronbach's alpha test

Spearman's rho		Location	Feelings	Brightness	Distribution	View	Glare
Location	Correlation coefficient	1.000	0.015	0.249	0.128	−0.265	0.649**
	Significance (2-tailed)	.	0.925	0.099	0.402	0.078	<0.001
	N	45	45	45	45	45	45
Feeling	Correlation coefficient	0.015	1.000	−0.326*	−0.120	0.047	0.003
	Significance (2-tailed)	0.925	.	0.029	0.430	0.761	0.983
	N	45	45	45	45	45	45
Brightness	Correlation coefficient	0.249	−0.326*	1.000	0.076	−0.157	0.369*
	Significance (2-tailed)	0.099	0.029	.	0.622	0.304	0.013
	N	45	45	45	45	45	45
Distribution	Correlation coefficient	0.128	−0.120	0.076	1.000	0.043	−0.002
	Significance (2-tailed)	0.402	0.430	0.622	.	0.781	0.988
	N	45	45	45	45	45	45
View	Correlation coefficient	−0.265	0.047	−0.157	0.043	1.000	−0.120
	Significance (2-tailed)	0.078	0.761	0.304	0.781	.	0.433
	N	45	45	45	45	45	45
Glare	Correlation coefficient	0.649**	0.003	0.369*	−0.002	−0.120	1.000
	Significance (2-tailed)	<0.001	0.983	0.013	0.988	0.433	.
	N	45	45	45	45	45	45
		Cronbach's alpha			*N* of items		
		0.568			4		

7-4-4 Validation Outcomes between CW_{map} in Simulation and VR

To validate the DVS system, the comfort and well-being map and the network social analysis were compared by overlapping the two maps to investigate whether the most chosen zone through the VR experiment is the same zone indicated in the CW_{map}.

To quantify the comfort and well-being potential, a parametric algorithm was established (in Chapter 5) to calculate the visible outside view content inside the space. Three sets of points were found related to sky view, context and green view. A new metric – called visible outside view (VOV) – measured the view clarity and content together. As discussed in Chapter 6, the new parametric algorithm was integrated into a multifactor system (DVS system) to optimise between three aspects of daylight quality and view quality at the same time by optimising shading system parameters. The final simulation results were interpreted into the contouring map to show the zones that have good daylight and view quality. The daylight quality was quantified based on five criteria: (1) minimising annual sun exposure (ASE), (2) maximizing spatial daylight autonomy (sDA), (3) maximizing useful daylight illuminance (UDI) (4) maximizing view percentage and (5) minimising daylight glare probability (DGP) (Fig. 7-17).

DVS assessment criteria are:

A multi-objective optimisation was conducted to incorporate the visible outside view (VOV) value (defined previously in Chapter 5) with the daylight and view simulation (discussed in Chapter 6). The VOV percentage and the simulation threshold lines were interpreted as a contouring map using Origin software (Fig. 7-18).

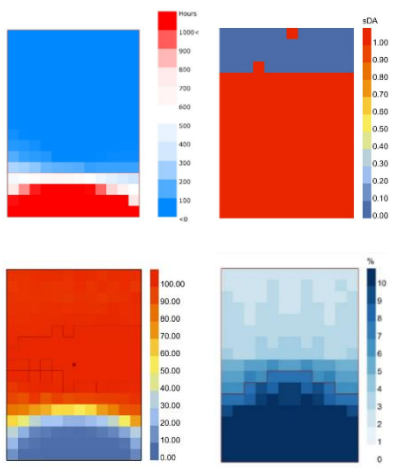


Figure 7-17: Daylight quality simulations.

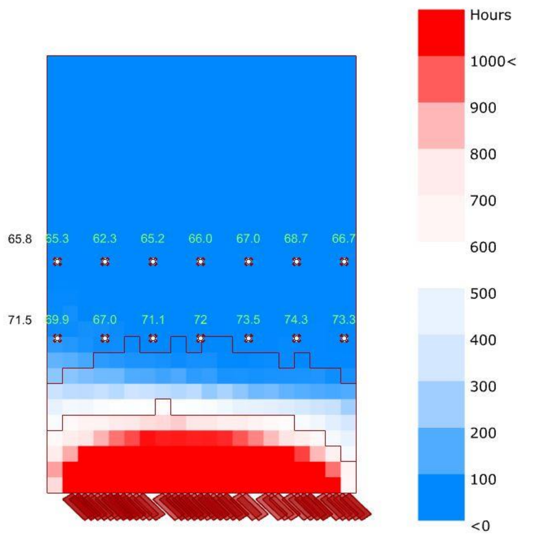


Figure 7-18: VOV and daylight simulation.

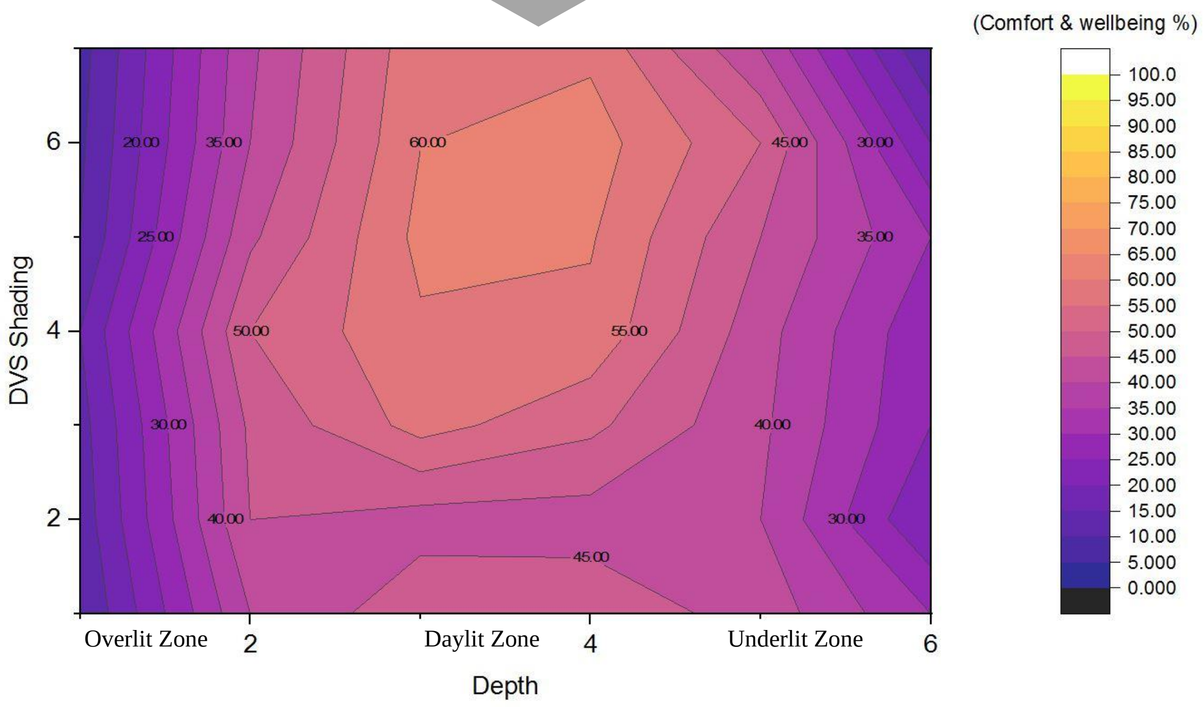


Figure 7-19: Comfort and well-being map (CW_{map}).

As shown in Figure 7-19, the space was divided into three zones: overlit, daylit and underlit zones. The overlit zone was located near the window at a distance of not more than 2 metres and a maximum of 2.5 metres, the daylit zone was located between 2.5 and 4.5 metres and the underlit zone was located at 4.5 to 6 metres. The very bright zone that achieves the assessment criteria was found in the zone between 60% and 56%. This percentage is the average weight of all VOV percentages. However, the CW_{map} shows that the best area with a high well-being and comfort potential is located in the daylight zone on the right side of the space.

7-4-5 Virtual Reality Experiment Output (Network Map)

As shown in Figure 7-20, participants' responses were converted into Edge and Node values to create the network. The network shows that the majority of participants chose the daylit zone for many reasons, including the high level of satisfaction with the outside view and glare and satisfaction with daylight brightness. However, participants' satisfaction with the distribution was natural in this zone, as the majority of the participants were highly satisfied with the outside view and glare and satisfied with daylight brightness.

The results show that the DVS system can predict the zone that has high comfort and well-being potential and view quality. This is not only found near a window in the overlit zone where the daylight quality and glare exceed the recommended values.

Id	
0	P01
1	P02
2	P03
3	P04
4	P05
5	P06
6	P07
7	P08
8	P09
9	P10
10	P11
11	P12
12	P13
13	P14
14	P15
15	P16
16	P17
17	P18
18	P19
19	P20
20	P21
21	P22
22	P23
23	P24
24	P25
25	P26
26	P27
27	P28
28	P29
29	P30
30	P31
31	P32
32	P33
33	P34
34	P35
35	P36
36	P37
37	P38
38	P39
39	P40
40	P41
41	P42
42	P43
43	P44
44	P45
45	Overlit zone (Middle)
46	Overlit zone (Right)
47	Overlit zone (Left)
48	Daylit (Middle)
49	Daylit (Right)
50	Daylit (Left)
51	Underlit (Middle)
52	Underlit (Right)
53	Underlit (Left)
54	Happy
55	Active
56	Cozy
57	Comfortable
58	Gloomy
59	anxious
60	Brightness (Very Satisfied)
61	Brightness (Satisfied)
62	Brightness (Neutral)
63	Brightness (Dissatisfied)
64	Brightness (Very dissatisfied)
65	Distribution (Very Satisfied)
66	Distribution (Satisfied)
67	Distribution (Neutral)
68	Distribution (Dissatisfied)
69	Distribution (Very dissatisfied)
70	View quality(Very Satisfied)
71	View quality (Satisfied)
72	View quality (Neutral)
73	View quality (Dissatisfied)
74	View quality (Very dissatisfied)
75	Glare (Very Satisfied)
76	Glare (Satisfied)
77	Glare (Neutral)
78	Glare Dissatisfied)
79	Glare (Very dissatisfied)

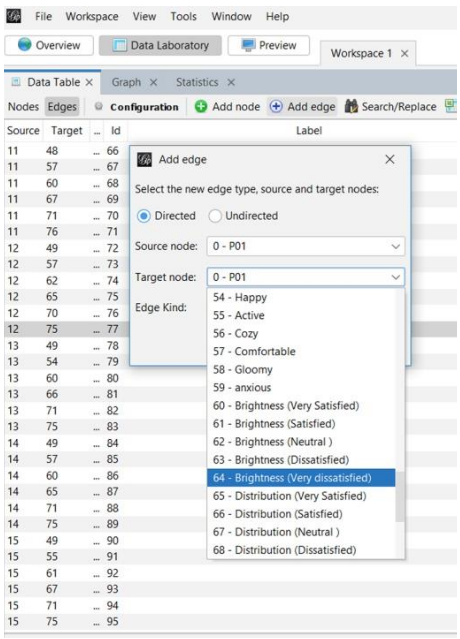


Figure 7-20: Mental network map inputs in Gephi software.

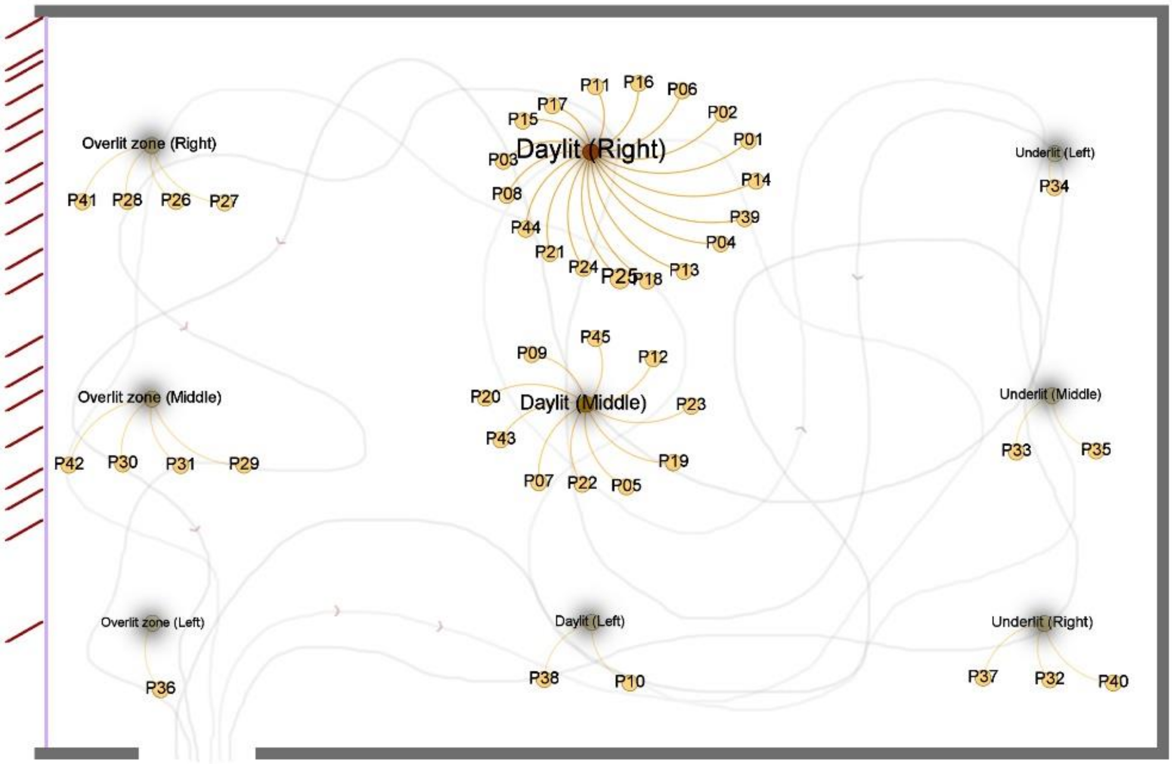


Figure 7-21: Applying Gravity filter in Gephi.

To validate the DVS system, a network graph was produced and overlapped with the CW_{map} to investigate the relationship between participants' responses in the VR experiment and the simulation output. To illustrate the importance of each term, there is a need to measure betweenness centrality that is considered a measure of centrality in a graph based on shortest paths. Betweenness centrality was devised as a general measure of centrality (Freeman, 1977). It was measured automatically using Gephi software by applying a gravity filter to arrange the nodes and edges based on their weight related to nine locations, as shown in Figure 7-21. These locations are the same as the zones used in the VR experiment: overlit, daylit and underlit zones. Each zone has three test points: right, middle and left. Based on the betweenness centrality between each node and edge, as shown in Figures 7-22 and 7-23, most terms that were selected more than once in the VR experiment were located in the same zone that was produced by the DVS system to be on the right of the daylit zone. That means the research aims are achieved and validated by defining a DVS multifactor system of optimising different shading parameters to enhance and predict occupant comfort and well-being potential related to daylight quality and view quality recommended values and standards.

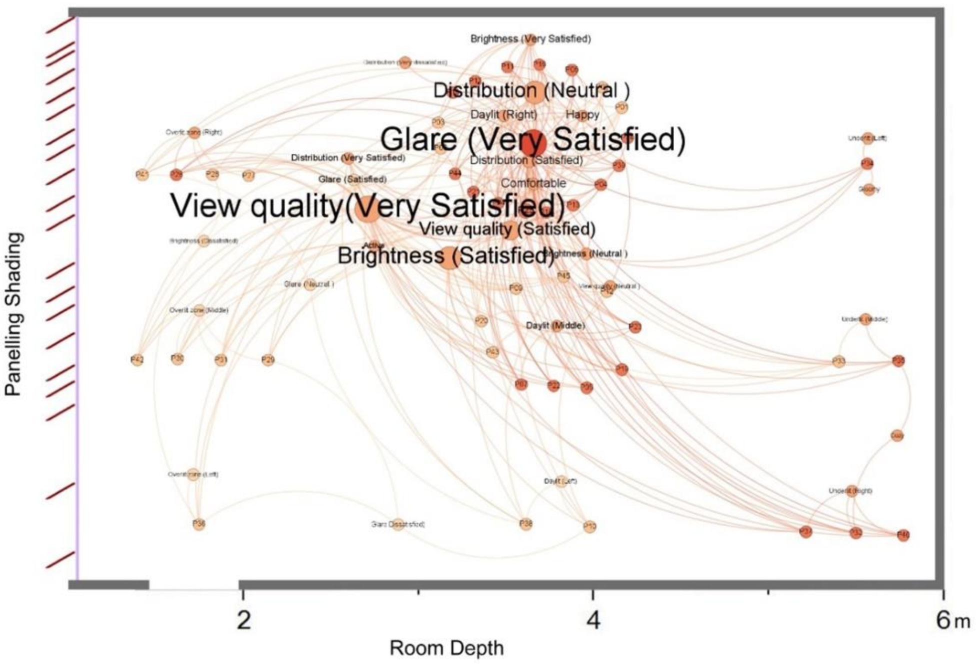


Figure 7-22: Participants' responses related to their location.

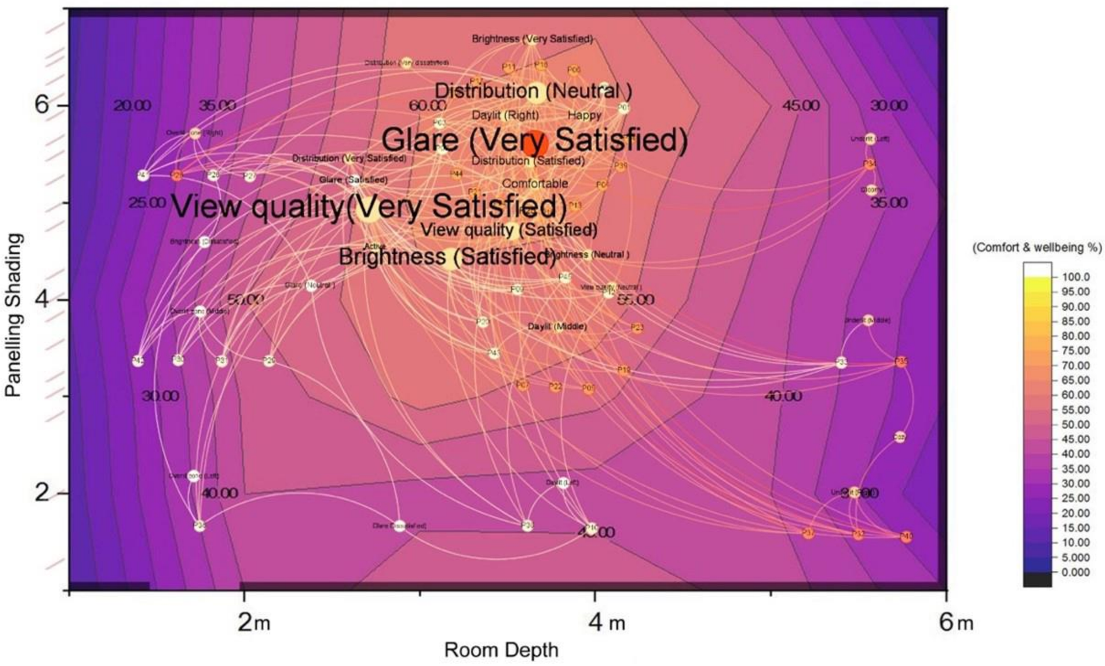


Figure 7-23: Mental network map.

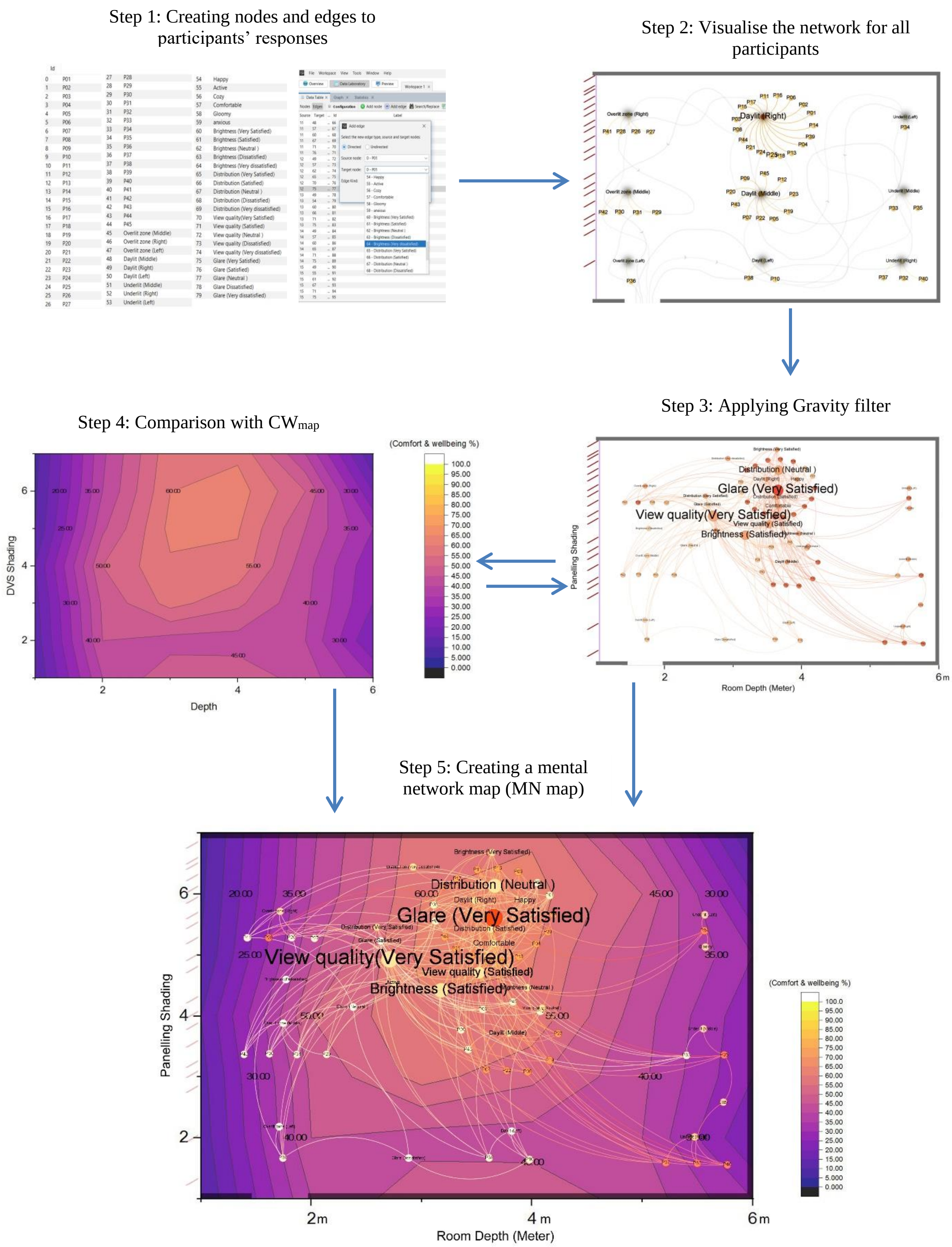


Figure 7-24: Validation steps.

7-5 Conclusion

In this chapter, the DVS multifactor system has been validated by conducting a virtual reality experiment to investigate the system results. The simulation outcomes are visualised on a comfort and well-being map showing the quantitative measurements for the new visible outside view metric (VOV) daylight metrics (discussed in Chapter 5) and daylight quality simulation (discussed in Chapter 6). A 3D model of two typical, connected office spaces located in the Maxwell building (consisting of nine levels) at Salford University, UK, using Rhino. The first space is considered the starting point for the VR walkthrough and has no shading device installed at the external or internal façade. The second space, which has the shading device from applying the DVS system, is connected to the first one by a door to allow participants to move between the two spaces and compare between them. A panoramic picture of the outside view is imported into the DVS system and Unreal software to establish the VR experiment.

To evaluate participants' feelings and satisfaction with daylight and view quality, participants were asked to fill out a questionnaire consisting of six questions to indicate their best zone. A Likert scale of 1 to 5 was used to evaluate participants' responses, where 1=very dissatisfied, 2=dissatisfied 3=neutral, 4=satisfied and 5=very satisfied. The experiment results were analysed using description and statistics to measure the reliability and association between attributes. The results demonstrate that there is an association between daylight brightness and distribution and also between view quality and glare. In addition, they show that 30 participants preferred the daylit zone. Spearman's test showed negative and positive correlations. These correlations explain why most participants did not prefer to sit near windows because of high levels of glare. The level of satisfaction with daylight brightness increases when participants have no glare issues. In addition, participants scored a high level of satisfaction with glare when they chose to sit away from the window in the daylit or underlit zone.

To validate the DVS system, a network graph was compared with the CW_{map} to investigate the relationship between participants' responses in the VR experiment and the simulation output. The comparison indicates that the optimal comfort and well-being zone results from the optimisation of daylight, view quality and shading device (Daylit zone at the right side of the opening) are identical to the most preferred zone chosen by the participants in the VR experiment (Figure 7-24). This result illustrates how seat location inside the working environment may have a negative or positive impact on occupant well-being and productivity. The results also demonstrate that architects and decision-makers should not neglect the impact of shading devices as they can affect the size and location of comfort and well-being zones internally. This means that building orientation is very important at the primary design stages and has a significant impact on daylight quality and view quality.

CHAPTER EIGHT: Conclusions and Recommendations

8.1 Introduction

This chapter concludes the thesis using the findings and recommendations outlined in previous chapters. Chapter 2 presents a systematic literature review conducted to define recommendations and guidelines about daylight comfort and well-being in the working environment. Chapter 3 discusses the research methodology employed for this study. Chapter 4 is a qualitative study of comfort and well-being dimensions through an online questionnaire. The aim of this qualitative study is to determine variables that occupants use in the daylit zone to describe their feelings and satisfaction with daylight and outside view quality in their working environment. Chapter 5 discusses a new parametric algorithm established to create a facilitation tool to quantify the well-being potential (WP) index for the view quality by combining view content (greenery, sky, context) and view clarity (shading system) in one indicator called the visible outside view (VOV). Chapter 6 presents a new multifactor system that is defined to integrate daylight quality, visible outside view (VOV) indicator and shading parameters in one system called the DVS system. This system aims to define the optimum shading parameters that have high comfort and well-being potential. As a result, a comfort and well-being map (CW_{map}) was defined to predict the best zones that achieve high comfort and well-being potential for daylight and view quality and the shading device used. Chapter 7 presents the protocol used to validate the DVS system; a network graph was produced and overlapped with the CW_{map} to investigate the relationship between participants' responses in the VR experiment and the simulation output.

8.2 Addressing Research Objectives

Five objectives were formulated for this research (Section 1.5.2 in Chapter 1) to facilitate achieving the main aim of the research: to define a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms as a means to enhance occupant comfort and well-being potential related to daylight quality and view quality recommended values and standards (Section 1.5.1 in Chapter 1).

Section 2.4 of Chapter 2 reveals that outside view content has been measured using quantitative and qualitative methods. The literature review shows that evaluating the outside view content is often based on questionnaire results. Limited studies provide a qualitative method to measure outside view quality based on ray-tracking simulation methods or rendering photorealistic views.

Several researchers focused only on assessing daylight and view access using computational methods considering view access percentage, shading device parameters and glare issues (Sherif et al. 2015; Amundadottir et al. 2017; Pesenti et al. 2015; Sheikh & Asghar 2019; Jayathissa et al. 2018; Mahmoud & Elghazi 2016; Tabadkani et al. 2018; Domjan et al., 2023; Yao et al., 2024;). Although these approaches optimise daylight and view quality, only view access and view clarity have been considered in this thesis. Moreover, existing tools are sometimes too complicated and need the outside environment to be fully built using three-dimensional (3D) modelling software; some tools are not designed to simultaneously optimise between the optimal shading device and view quality. Also, the measurement accuracy is still based on the outside build accuracy to match the context of the real environment such as tree scale and position and the surrounding buildings. In related studies, (Pilechiha, 2020; Hellinga & Hordijk, 2014; Turan et al., 2021; Lee & Matusiak, 2022; Jaeha et al., 2022; Rizi et al., 2024) little attention has been given to obstruction elements to outside view such as shading devices. This may be explained by the difficulty of measuring the visible outside view (VOV) ratio. However, applications outside academia are limited; some software can be used to measure the view quality with different approaches.

The literature review shows that there is no research yet to combine outside view content and clarity in one metric. However, view clarity and view content are related to each other as conflicted targets, but most researchers only focus on assessing view quality factors (content, clarity and access) separately. This study produces a new metric that aims to quantify the outside view quality based on combining view content and view clarity together in one metric called visible outside view (VOV), which forms the specific knowledge gap investigated by this research (see Section 1.4 in Chapter 1). In addition, there is no tool, application or software found yet to integrate daylight quality, outside view quality and shading devices in an optimisation process. This study proposes a new method to design an automated shading system by using multi-objective evolutionary algorithms (MOEAs) connecting daylight quality and outside view quality to provide better seat arrangement with higher comfort and well-being potential.

Therefore, this research aims to address the knowledge gap in designing shading systems with high comfort and well-being (see Section 1.6.2 in Chapter 1). The literature review shows that most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analysing the geometry outside using 2D and 3D software. There are drawbacks to each method. Well-being is a subjective matter and the study needs to be objective to be more scientific in approach. Therefore, there is a need for both qualitative and quantitative data. In addition, using ray-tracking methods needs the outdoor environment to be fully built into the simulation software, which takes more time to complete the simulation and iteration process. Although prior research has identified a few methods that could be used in assessing view quality, these methods have drawbacks related to the time consumed and the level of accuracy needed to build the outside view environment (trees, buildings and other objects).

In this study, a new facilitation tool is defined using an image processing technique to evaluate both view content and clarity and the impact of installing two kinds of shading systems (horizontal and vertical) with indicated parameters for testing (see Section 1.6.2 in Chapter 5). The proposed facilitation tool presented in this study is integrated with the new DVS multifactor system (see Section 1.6.2 in Chapter 6) that takes into consideration daylight quality, view quality and shading device. The five objectives of this research have been achieved as follows.

8-2-1 Objective 1

The first objective was 'to determine the current understanding of daylight standards and rating system recommendations to improve occupant well-being'. This objective has been achieved in Chapter 2 by conducting a systematic literature review to define recommendations and guidelines about daylight comfort and well-being in the working environment. The review started with a chronological overview and presents daylight metrics. It examined their underlying methodologies to define the gaps in using these metrics to assess daylight non-visual effects and the need to use building rating systems guidelines and recommendations to enhance this assessment. After that, a thematic analysis was conducted to extract the relative recommendations and metrics on how these building rating systems can contribute to comfort and well-being in terms of daylight. These recommendations and metrics are used as standard parameters in the quantitative stage later through the simulation process.

8-2-2 Objective 2

The second objective was ‘to determine the significant terms used by occupants that affect their feelings and satisfaction with daylight and outside view in relation to their seat location inside the working environment’. This objective has been achieved in Chapter 4 by conducting a qualitative analysis through an online questionnaire to determine variables that occupants use in the daylit zone to describe their perception of daylight (visual and non-visual effects) and outside view quality in their working environment. These terms help to identify participants’ spatial cognitive (SC) map towards well-being and comfort. The result shows that view quality was only found in the overlit zone where the daylight quality was not fair or bright nor had enough light to see. The research hypothesis states that the multifactor system that integrates daylight quality, view quality and shading system can improve people’s comfort and well-being potential internally. Therefore, the hypothesis supposed that daylight illuminance, daylight distribution, location, view type and feelings should have a strong association. The statistical analysis indicated that daylight distribution is the most significant variable with $p<0.001$ and the significance score of shading systems is 0.02. Also, location, which is defined by overlit, daylit and underlit zones, is the second most significant variable with a score of 0.004; daylight illuminance is the third most significant variable with a score of 0.008; and the last significant variable is view type with a significance score of 0.02.

8-2-3 Objective 3

The third objective was ‘to provide a method to quantify visible outside view content as an indicator for quantifying occupant well-being’. A quantitative approach in Chapter 5 applied a parametric analysis of the outside view to quantify the visible outside view content based on the recommendation metrics and variables related to comfort and well-being to achieve the optimal seat arrangement while using automated shading systems. A new facilitation tool was proposed to quantify the visible outside view (VOV) by analysing the outside view image by converting the view content into red, blue and green (RGB) pixels using an image processing technique. VOV measured occupants’ ray-tracking percentage to the visible outside view content taking into consideration the blind factor of shading. An indicator starting from 0% to 100% quantified the outside view content including shading systems, which then related the overall VOV to the visible outside view quality as a factor of well-being potential (WP).

8-2-4 Objective 4

The fourth objective was 'to define a new multifactor system to test different shading alternatives using simulation and genetic algorithms to optimise both daylight quality and view quality'. This objective has been achieved in Chapter 6 by using multi-objective evolutionary algorithms (MOEAs) to integrate daylight quality and visible outside view (VOV) quality and shading systems to improve occupants' comfort and well-being potential internally. This algorithm was embedded with a dashboard to be improved in the future and be made available in the market. This dashboard aims to optimise daylight quality and view quality in multi-objective optimisation to achieve the optimum shading parameters.

8-2-5 Objective 5

The fifth objective was 'to validate the new multifactor system (DVS system)'. This objective has been achieved in Chapter 7. To improve the accuracy of the validation process, there is a need to compare the simulation model output with the virtual reality experiment output (Neymark, et al., 2002). The experiment in the present study checked the accuracy of the DVS system through three aspects: (1) the virtual environment creation, (2) the shading device import and export process from the simulation output to the VR platform and (3) the daylight and view outside parameters to match the real-world situation.

The DVS multifactor system was validated by conducting a virtual reality experiment to investigate the system results. The simulation outcomes were visualised on a comfort and well-being map showing the quantitative measurements for the new visible outside view (VOV) daylight metrics (discussed in Chapter 5) and daylight quality simulation (discussed in Chapter 6). The network graph resulting from the analysis of participants' responses was compared with the comfort and well-being map (CW_{map}) to investigate the relationship between participants' responses in the VR experiment and the simulation output. The comparison indicates that the optimal comfort and well-being zone resulting from the optimisation of daylight, view quality and shading device is identical to the most preferred zone chosen by the participants in the VR experiment.

8.3 Contribution to Knowledge

This thesis attempts to effectively contribute to filling the knowledge gap for defining a new multifactor system of optimising different shading parameters using virtual simulation and genetic algorithms to enhance occupant comfort and well-being potential in relation to daylight quality and view quality. This study also provides a foundation for future research and improves our understanding of the importance of creating spaces that have high comfort and well-being potential as this affects occupants' satisfaction and consequently improves their productivity in the working environment. It also provides a facilitation tool to evaluate the view from the outside while installing shading devices. The proposed multifactor system highlights to decision makers and architects the importance of choosing the view at early stages of design because it affects occupants' comfort and well-being internally. Research contributions can be categorized as in the following sections (Fig. 8-4).

8-3-1 Contribution 1: A New Indicator to Evaluate View Content called visible Outside View (VOV)

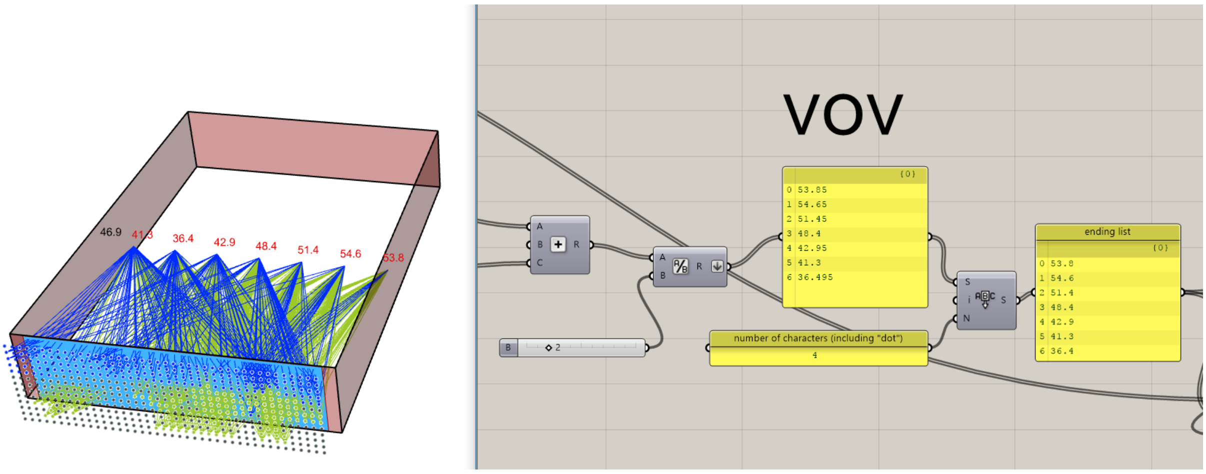


Figure 8-1: The VOV algorithm.

In this study, a new facilitation tool is defined to evaluate the impact of installing shading systems on window view contents and well-being potential inside the working environment. Recent research on view quality has focused on quantifying the outside view content using questionnaires to rank some images to the outside view based on occupant preferences and feelings. Other techniques use the computational ray-tracking method, which needs the outside context to be fully built in three dimensions with a sufficient level of accuracy to match the real environment context in scale and position. Little attention has been given to the impact of shading devices on the view quality and how it can contribute to well-being. The new facilitation tool developed here can measure the visible outside view ratio taking into consideration the blind factor due to the installation of shading devices. It combines view clarity and view content together in one metric called VOV content + clarity (VOV sky, greenery, mass–blind ratio). A parametric analysis between the internal field of view (FOV) and outside view content was performed by importing the outside view image and converting the view content into red, blue and green (RGB) pixels using the image sample modifier (Fig. 8-1). This new tool measures the ray-tracking percentage to the visible outside view content so that people can see the views through the shading system, starting from 0% to 100% which is related to promoting the well-being potential (WP). A new formula is produced to measure the mean value of WP for the space:

Equation 02 $$WP\% = \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$

8-3-2 Contribution 2: A New Multifactor System that Integrates Daylight, View Content (VOV) and Shading called the DVS System

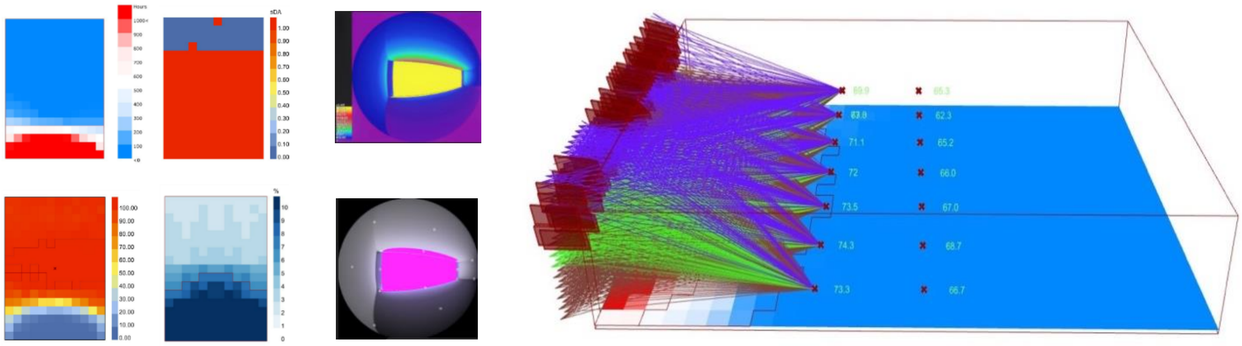


Figure 8-2: The DVS multifactor system.

This contribution is considered the most important one. In related studies in the literature review, I found a lack of consideration of obstruction elements such as shading devices to outside view may be explained by the difficulty of measuring this factor. Recently, software has been found in the market, such as ClimateStudio and Cove. Tools that measure view quality according to LEED v4.01 and EN 17037 with the function to measure the blind factor aim to measure the visible view access to the outside, but these tools are not connected to the visible outside view content (greenery, art, context, sky).

The literature review show that there is no tool, application or software yet to integrate daylight quality, outside view quality and shading devices in an optimisation process. This new multifactor system (DVS) has been defined to quantify the outside view quality and daylight quality at the same time by optimising shading system parameters (Fig. 8-2). The assessment criteria will follow LEED v.01. The system runs a series of simulations related to daylight quality and view quality assessment criteria. The design variables are re-evaluated if necessary to achieve the fitness goal in the final phase.

The simulation work to achieve these objectives include (1) minimising annual sun exposure (ASE), (2) maximizing spatial daylight autonomy (sDA), (3) maximizing useful daylight illuminance (UDI), (4) maximizing view percentage and (5) minimising daylight glare probability (DGP).

8-3-3 Contribution 3: A New Interpretation of the DVS Simulation Results to Create a Comfort and Well-Being Map (CW_{map})

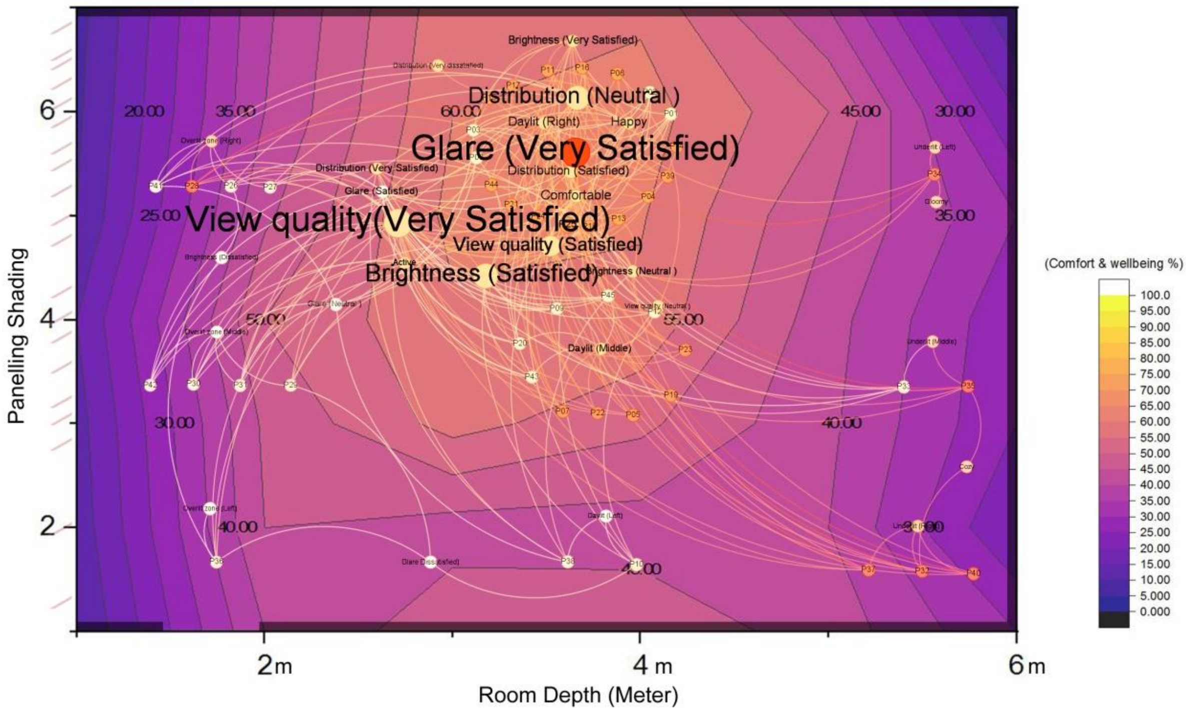


Figure 8-3: The integration of CW_{map} and MN_{map} systems.

To validate the DVS system, a new approach was utilised to overlap the comfort and well-being map (CW_{map}) resulting from the DVS system and the mental network map (MN_{map}) resulting from the virtual reality experiment (Fig. 8-3). To illustrate the importance of each term, there is a need to measure betweenness centrality, which is considered a measure of centrality in a graph based on shortest paths. By applying the Gravity filter found in Gephi software, the nodes and edges are arranged based on their weight-related to nine locations, as shown in Figure 8-3. These locations are the same as those used in the VR experiment (i.e. overlit, daylit and underlit zones). Each zone has three test points: right, middle and left. Two different software were used to interpret the results:

- For the CW_{map}, the value of WP% was input in Origin software to create a contouring map using the same space dimensions as used in the case study. As shown in Figure 8-3, the space was divided into the overlit, daylit and underlit zones. The overlit zone was located near the window at a distance of not more than 2 metres and a maximum of 2.5 metres, the daylit zone was located between 2.5 and 4.5 metres and the underlit zone was located at 4.5 to 6 metres. The very bright zone that achieves the assessment criteria was found in the zone between 60% and 56%. This percentage is the average weight of all WP percentages.
- For the mental network map, analysis of graph-based networks was used to understand participants' behaviour and attributes in the workspace used in the VR experiment. This graph is based on a mathematical model connecting nodes to form the network structure (Figure 8-3). Model analyses were conducted in Gephi, a powerful open-source software tool that is now widely used in network analysis.

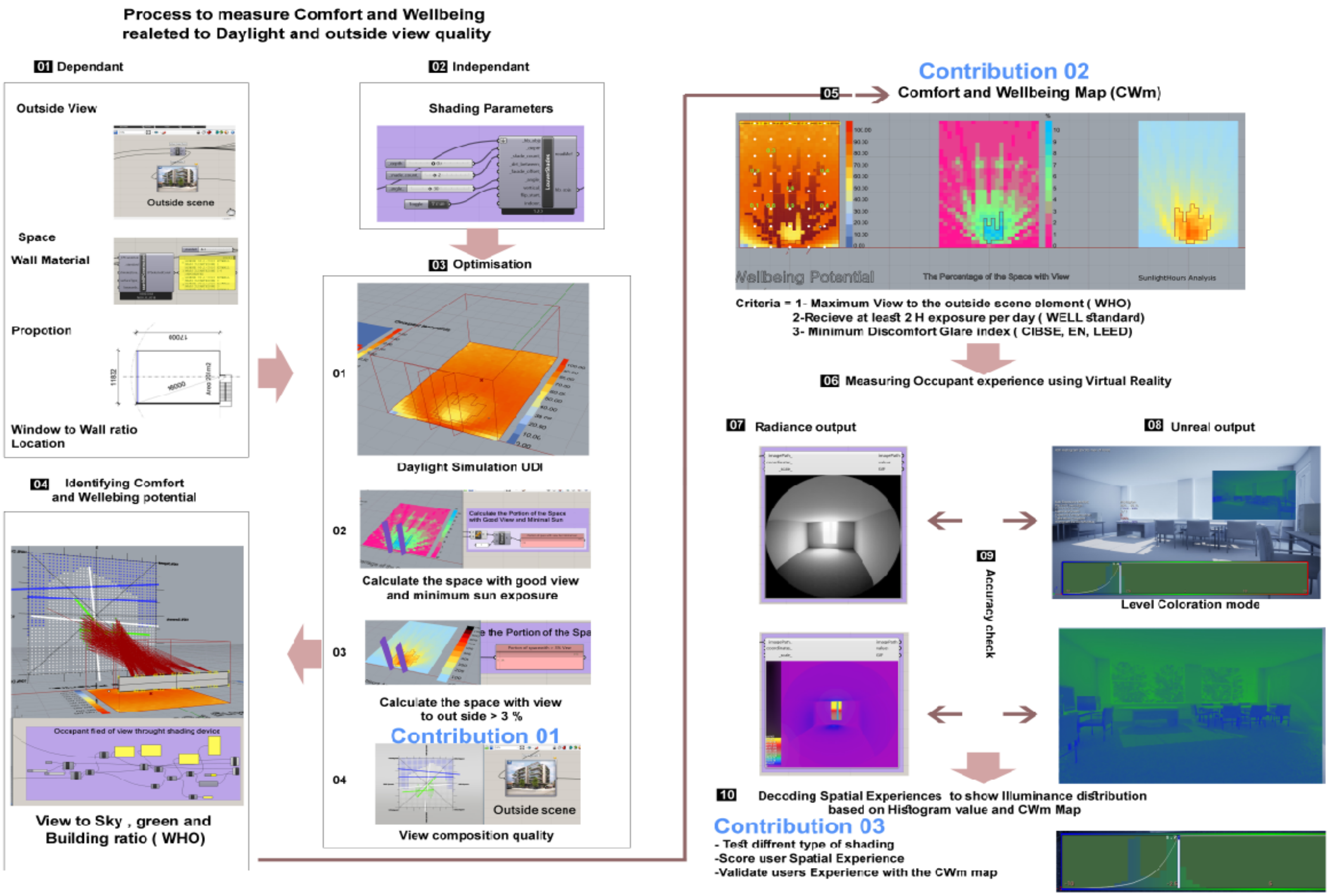


Figure 8-4: Contributions to knowledge.

8-4 Recommendations for Future Research

The use of algorithmic design has been adopted by several researchers (As indicated in Chapter 2 Table 2.17) to address a range of architectural design problems. One of these problems is to find the optimal configuration of shading devices that achieves multi-objectives, aiming to minimise daylight issues such as glare and maximise the view access to the outside. Plugins for daylight simulations that employ multi-objective evolutionary algorithms (MOEAs) have been developed to find multiple pareto-optimal solutions. The main difference between these platforms is represented in how the algorithm works to analyse the data to find the optimal shading device solutions.

This study used simulation and experimental methods to evaluate daylight and view quality comfort while using a shading device. Although justification has been made regarding the choice of software and plugins in Chapter 7, such as Honeybee, Ladybug, Radiance and Wallacei plugin, there are other plugins that can do the same work using different algorithms. This research used multi-objective evolutionary algorithms (MOEAs) to solve and optimise multi-conflicted objectives in one system. A multi-objective optimisation was made using two different plugins. The first plugin is called Wallacei and it is based on non-dominated sorting genetic algorithm II (NSGA-II). There is a need to address the differences between the entire algorithm of Wallacei and other multi-objective plugins such as Octopus that are based on different algorithms called strength pareto evolutionary algorithms (SPEAs).

8-4-1 New Facilitation Tool (VOV)

In this study, a new facilitation tool was defined to quantify the outside view quality based on combining view content and view clarity together in one indicator called visible outside view (VOV). The VOV algorithm might be miscalculated if the building colour was green or blue. Therefore, the saturation level should be adjusted inside Grasshopper to make sure that the selected pixels are related to only sky and green landscape. In addition, weather and time of day were not considered when selecting static photos. The method proposed can only be used for venetian blinds, mullions, overhangs or fins but does not work for roller shades since the openness (holes) is very small and hard to model in Rhino. However, it does provide views of the outdoors but it minimises the view clarity. This study applied LEED assessment criteria that state that view glazing should provide a clear image of the outside environment. Therefore, the study was limited to using only clear glass and not working with the transparent blinds and small meshes, which takes more time and may cause a system crash to run the iteration.

In the proposed tool, the view content quality as a factor of well-being potential (WP) obtained from sky and vegetation is considered the sum of all VOV to sky and greenery without any consideration of the impact of sky and greenery separately. As stated by LEED, ‘the design should achieve at least one of these elements: nature/art/urban landmarks’. According to WELLv2^{TM}, ‘[a] number of layers [were] received by the occupant, such as sky, landscape and foreground. A score was given to rank the view quality: unacceptable, acceptable, good and excellent.’ In addition, the European standard EN 17037 stated, ‘the view credit score is achieved if at least one of the outdoor layers – sky, landscape or ground – is visible’. Therefore, the proposed tool takes the overall percentage of VOV_{sky} and $VOV_{greenery}$. In future work, there is a need to establish a real experiment to compare both WP_{sky} and $WP_{greenery}$ measured by the proposed tool and participants’ satisfaction level to the outside view content to quantify the impact of the sky view and greenery view separately.

The concept of well-being is a subjective matter widely used in psychology to describe a sphere of feelings that refers to what is intrinsically valuable to an individual. In this thesis, WP% could be an objective measure based on the visible outside view percentage (VOV%) that occupants can see from inside a space taking into consideration the blind factor of the shading system that could obscure the view quality. To validate the proposed indicator, a real experiment is needed to involve the human factor in the workflow process. This helps to understand the correlation between the quantitative and qualitative results of the occupants’ subjective perception of the view quality. However, real case studies were not feasible due to time- and cost-consuming research activities. This also did not allow for evaluation in the early design stages that is needed to design efficient and supportive buildings. Thus, a preliminary assessment of occupants’ perception is needed in the future using virtual reality and immersive virtual environments, starting from the 3D model.

8-4-2 New Multifactor System (DVS)

In relation to daylight research, it is important to include all factors that may affect the simulation results; for example, the furniture, landscape features and desk orientation. Due to time constraints, it was important to not make the system more complex as this would take more time to run the optimisation process. As window frames sizes may affect the view quality to the outside, window mullions were excluded from the simulation to keep the simulation fast. In addition, the building orientation plays a very important role at the primary design stages related to daylight quality; however, this research did not include this parameter in the optimization.

As the focus of this study was to assess the impact of view content in shading design generally, the view access was limited. A fixed parameter was used in the simulation and optimisation process, as the window-to-wall ratio was 90%. For view clarity, the glazing had visual transmittance of 0.7 VT, as recommended by LEED and WELL in their view quality credit. Future studies should consider a wider variety of window sizes as it affects the daylight and view quality.

Finally, this study found that the shading strategy should not be the same at all levels. In primary design stages, shading devices considering the view to the natural elements positively affects occupants' comfort and well-being potential. These findings suggest that the proposed algorithm needs to be implemented with building energy to produce more holistic systems. This will be an effective way to deeply connect efficient and sustainable buildings with the human dimension.

9--References

Aamer H. (2021). Bio-Form Mimicry in Architectural Design (The Influence of Biomimicry on Building Behaviour). Thesis. http://dx.doi.org/10.13140/RG.2.2.14934.98882

Abd Alhamid, F., Kent, M., & Wu, Y. (2024). Quantifying window view quality: A review on view perception assessment and representation methods. *Building and Environment*,Volume 227, Part 2. https://doi.org/10.1016/j.buildenv.2022.109742

Abdelrahman, M., & Coates, P. (2022a). *Themes of wellbeing associated with daylighting practice and shading systems in working environment.* Conference: Resilience in Research and Practice. University of Salford, Uk.

Abdelrahman, M., & Coates, P. (2022b). *Wellbeing in Daylighting Studies*. PLEA 2022—36th Conference on Will cities survive?, Santiago, Chile.

Abdelrahman, M., Coates, P., & Ogbonda, U. (2023a). *Assessment of Daylighting, View and Air Quality Requirements: An Integrated Approach for Healthy Buildings.* Conference: Healthy Buildings 2023 – Asia and pacific rim At: Tianjin, China.

Abdelrahman, M., Coates, P., & Poppelreuter, T. (2023b). Visible outside view as a facilitation tool to evaluate view quality and shading systems through building openings. *Journal of Building Engineering*, Volume 80. https://doi.org/10.1016/j.jobe.2023.108049

Acosta, I., Campano, M. A., Leslie, R., & Radetsky, L. (2019). Daylighting design for healthy environments: Analysis of educational spaces for optimal circadian stimulus. *Solar Energy, 193,* 584–596. https://doi.org/10.1016/j.solener.2019.10.004

Aksamija, A. (2018). *Methods for integrating parametric design with building performance analysis*. ARCC Conference. https://www.arcc-journal.org/index.php/repository/article/view/459/363

Al-Masrani, A., Al-Obaidi, K., Zalin, N., & Aida Isma, M. (2018). Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. Solar Energy,Volume 170. https://doi.org/10.1016/j.solener.2018.04.047

Al-Obaidi, K., Arkam, M., Ismail, M., & Abdul Rahman, A. (2017). Designing an integrated daylighting system for deep-plan spaces in Malaysian low-rise buildings. *Solar Energy*,Volume 149, Pages 85-101. https://doi.org/10.1016/j.solener.2017.04.001

Altomonte, S. (2009). *Daylight and the occupant: Visual and physio-psychological well-being in built environments*. PLEA2009—26th Conference on Passive and Low Energy Architecture, Quebec City, Canada.

Altomonte, S., & Allen, J. (2020). Ten questions concerning well-being in the built environment. *Building and Environment*, *180*, Article 106949. https://doi.org/10.1016/j.buildenv.2020.106949

American Psychological Association. (2013). *Stress in America: 2013* [Press releases]. https://www.apa.org/news/press/releases/stress/2013/default

Amith, M., Fujimoto, K., & Tao, C. (2019). *NET-EXPO: A Gephi Plugin Towards Social Network Analysis of Network Exposure for Unipartite and Bipartite Graphs*. In: Stephanidis, C. (eds) HCI International 2019. Communications in Computer and Information Science, vol 1034. Springer, Cham. https://doi.org/10.1007%2F978-3-030-23525-3_1

Amundadottir, M. L., Rockcastle, S., Sarey Khanie, M., & Andersen, M. (2017). A human-centric approach to assess daylight in buildings for nonvisual health potential visual interest and gaze behaviour. *Building and Environment*, *113*, 5–21. https://doi.org/10.1016/j.buildenv.2016.09.033

Andrews, F. M., & McKennell, A. C. (1982). Response to Guttman & Levy's article 'On the definition and varieties of attitude and wellbeing'. *Social Indicators Research*, *10*(2), 175–185. https://doi.org/10.1007/BF00302509

ASHRAE Press (Eds.). (2006). Chapter 4: Architectural design impacts. In *The ASHRAE GreenGuide* (2nd ed., pp. 55–72). Butterworth-Heinemann. https://doi.org/10.1016/B978-193374207-6/50007-4

Azari, R., Garshasbi, S., Amini, P., Rashed-Ali, H., & Mohammadi, Y.(2016). Multi-objective optimisation of building envelope design for life cycle environmental performance. *Energy and Buildings*,Volume 126. https://doi.org/10.1016/j.enbuild.2016.05.054

Baker, N., Fanchiotti, A. & Steemers, K. (1993). Daylight Design of Buildings: A Handbook for Architects and Engineers. Routledge.

Bastian, M., Heymann, S., & Jacomy, M. (2009). *Gephi: An open source software for exploring and manipulating networks*. International AAAI Conference on Weblogs and Social Media.

Berson, D. M., Dunn, F. A., & Takao, M. (2002). Phototransduction by retinal ganglion cells that set the circadian clock. *Science*, *295*(5557): 1070–1073. https://doi.org/10.1126/science.1067262

BEST Directory. (2022). DIAL+ Lighting. Building Energy Software Tools, formerly hosted by the U.S. Department of Energy. https://www.estia.ch/daylighting

Bian, Y., & Luo, T. (2017). Investigation of visual comfort metrics from subjective responses in China: A study in offices with daylight. *Building and Environment*, Volume 123. https://doi.org/10.1016/j.buildenv.2017.07.035

Bluyssen, P. M. (2009). The indoor environment handbook: How to make buildings healthy and comfortable. London: Earthscan.

Boubekri, M., Lee, J., MacNaughton, P., Woo, M., Schuyler, L., Tinianov, B., & Satish, U. (2020). The impact of optimised daylight and views on the sleep duration and cognitive performance of office workers. *International Journal of Environmental Research and Public Health*, *17*(9), Article 3219. https://doi.org/10.3390/ijerph17093219

Boyce, PR., & Cuttle, C. (1990). Effect of correlated colour temperature on the perception of interiors and colour discrimination. *Lighting Res Technol* 22(1):19–36

Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., & Rollag, M. D. (2001). Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. *Journal of Neuroscience*, *21*(16), 6405–6412. https://doi.org/10.1523/JNEUROSCI.21-16-06405.2001

BRE Global. BREEAM UK New Construction: Non-Domestic Buildings. Technical Manual SD5076 – 0.1 (Draft), 2014. https://www.scribd.com/document/386330743/SD5076-DRAFT-BREEAM-UK-New-Construction-2014-Technical-Manual-ISSUE-0-1

British Standards Institution (BSI). (2021). *Light and lighting: Lighting of work places*. BS EN 12464-1:2021. BSI Standards Publication.

Bryman, A. (2012). *Social Research Methods*. OUP Oxford

Canada Standards Association. (2013). *Psychological health and safety in the workplace: Prevention, promotion, and guidance to staged implementation* [National Standard of Canada annual report]. https://www.canada.ca/en/employment-social-development/services/health-safety/reports/psychological-health.html

Cantin, F., & Dubois, M-C. (2011). Daylighting metrics based on illuminance, distribution, glare and directivity. *Lighting Research & Technology*, 43(3):291-307. https://doi.org/10.1177/1477153510393319

Carlucci, S., Causone, F., De Rosa, F., & Pagliano, L. (2015). A review of indices for assessing visual comfort with a view to their use in optimisation processes to support building integrated design. *Renewable and Sustainable Energy Reviews*, Volume 47. https://doi.org/10.1016/j.rser.2015.03.062

Caruso, G., & Kämpf, J. (2015). Building shape optimisation to reduce air-conditioning needs using constrained evolutionary algorithms. *Solar Energy*,Volume 118. https://doi.org/10.1016/j.solener.2015.04.046

Cauwerts, C., & Bodart, M. (2013). *Validation of a questionnaire for assessing perceptions of lighting characteristics in daylit spaces.* Engineering, Environmental Science

CEN. (2018). European Daylight Standard (EN 17037). *Brussels: Comité Européen de Normalisation*. https://velcdn.azureedge.net/~/media/marketing/ee/professional/28mai2019%20seminar/veluxen17037tallinn28052019.pdf

CEN. (2021). CEN/TC 33 European Standard, CSN EN 14501 Blinds and shutters – Thermal and visual comfort – Performance characteristics and classification. Comité Européen de Normalisation, Brussels. https://standards.iteh.ai/catalog/standards/cen/8b0257b8-f10b-4994-ae49-2493d6cd12ab/en-14501-2021

Chamilothori, K., Wienold, J., & Andersen, M. (2019). Adequacy of Immersive Virtual Reality for the Perception of Daylit Spaces: Comparison of Real and Virtual Environments. *LEUKOS*, 15(2–3), 203–226. https://doi.org/10.1080/15502724.2017.1404918

Chamilothori, K., Wienold, J., Moscoso, C., Matusiak, B., & Andersen, M. (2022). Subjective and physiological responses towards daylit spaces with contemporary façade patterns in virtual reality: Influence of sky type, space function, and latitude. *Journal of Environmental Psychology*, Volume 82, https://doi.org/10.1016/j.jenvp.2022.101839

Chang, C., & Chen, P. (2005). Human Response to Window Views and Indoor Plants in the Workplace. *HortScience HortSci*, *40*(5), 1354-1359. https://doi.org/10.21273/HORTSCI.40.5.1354

Chantrelle, F., Lahmidi, H., Keilholz, W., El Mankibi, M., & Michel, P. (2011). Development of a multicriteria tool for optimising the renovation of buildings. *Applied Energy*, Volume 88, Issue 4, https://doi.org/10.1016/j.apenergy.2010.10.002

Chartered Institution of Building Services Engineers. (2005). *Lighting Guide LG7: Offices*. CIBSE.

Cho, Y., Karmann, C., & Andersen, M. (2023). *A VR-based workflow to assess perception of daylit views-out with a focus on dynamism and immersion. Journal of Physics.* Conference Series, Volume 2600, Daylighting & electric lighting. http://dx.doi.org/10.1088/1742-6596/2600/11/112002

CIE, C. (2016). 218: Research Roadmap for Healthful Interior Lighting Applications. *Report. International Commission on Illumination*, Vienna, Austria.

ClimateStudio. (2022). Solemma LLC. https://www.solemma.com/climatestudio

Collis, J., & Hussey, R. (2014). *Business research: A practical guide for undergraduate and postgraduate students*. 4th ed. Hampshire, England: Palgrave Macmillan.

Corne , D., & Bentley, P. (2001). *Creative Evolutionary Systems (The Morgan Kaufmann Series in Artificial Intelligence)*. 1st Edition, Kindle Edition. Morgan Kaufmann.

Couvelas, A., Phocas, M. C., Maden, F., Matheou, M., & Olmez, D. (2018). Daylight performance of an adaptive façade shading system integrated on a multi-storey office building. In *Proceedings of the 13th Conference on Advanced Building Skins* (pp. 423–432). ABS, Bern, Switzerland, 1–2 October 2018.

Cove.Tools. (2022). CoveTool Software. https://www.cove.tools/

CRC Press.

Creswell, J. W. (1994). *Research design: Qualitative & quantitative approaches.* Sage Publications, Inc.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage Publications, Inc.

Crisp, R. (2020). Well-being. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2020 edition). Metaphysics Research Lab, Stanford University.

Cross, N. (2023). Design thinking: What just happened?. Design Studies,Volume 86. https://doi.org/10.1016/j.destud.2023.101187

Daily News Egypt. (2021). https://www.dailynewsegypt.com/2021/04/05/95-of-companies-worldwide-focus-on-employee-mental-health-in-2021-ejb-member/

Dale, K., & Burrell, G. (2007). *The Spaces of Organisation and the Organisation of Space*. Bloomsbury Academic

Danielsson, C. B., & Bodin, L. (2008). Office Type in Relation to Health, Well-Being, and Job Satisfaction Among Employees. *Environment and Behavior*, 40(5), 636-668. https://doi.org/10.1177/0013916507307459

David De, V. (2001). *Research Design in Social Research.* SAGE Publications Ltd

Deb, K. (2008). *Introduction to Evolutionary Multiobjective Optimization*. (eds) Multiobjective Optimization. Lecture Notes in Computer Science, vol 5252. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-88908-3_3

Dewa, C., S., & McDaid, D. (2011). Investing in the mental health of the labour force: Epidemiological and economic impact of mental health disabilities in the workplace. In I. Z.

Dobrica, S. (2020). COVID-19 and work from home: Digital transformation of the workforce. *The Grey Journal*, *16*(2), 101–104.

Domjan, S., Arkar, C., & Medved, S. (2023). Study on occupants' window view quality vote and their physiological response. *J. Build.* Eng. 68 (2023), 106119. https://doi.org/10.1016/j.jobe.2023.106119

Dudzińska, A. (2021). Efficiency of Solar Shading Devices to Improve Thermal Comfort in a Sports Hall. *Energies* 14, no. 12: 3535. https://doi.org/10.3390/en14123535

Elhadad, S., Baranyai, B., & Gyergyák, J. (2018). The impact of building orientation on energy performance: A case study in new Minia, Egypt. *Pollack Periodica Pollack Periodica*, 13(3), 31-40. https://doi.org/10.1556/606.2018.13.3.4

Elkadi, H., & Al-Maiyah, S. (2021). *Daylight, design and place-making* (1st ed.). Routledge.

Eltaweel, A., Yuehong Su, Qinghua Lv, & Hui Lv.(2020). Advanced parametric louver systems with bi-axis and two-layer designs for an extensive daylighting coverage in a deep-plan office room. Solar Energy,Volume 206. https://doi.org/10.1016/j.solener.2020.06.035

El-Zeiny, R. (2018). Interior Design of Workplace and Performance Relationship: Private sector corporations in Egypt. *Asian Journal of Environment-Behaviour Studies*. 3. 10.21834/aje-bs.v3i7.263. http://dx.doi.org/10.21834/aje-bs.v3i7.263

Elzeyadi, I. (2012). Workplace design: Health and healing impacts of daylight in the workplace. *World Health Design*, 60–67.

Erberich, P., & Graeber, K. (2020). *Circadian Lighting Design: Leveraging the Melanopic Efficacy of Luminous Radiation Metric*. (accessed on 1 April 2024), Available online: https://cltc.ucdavis.edu/publication/lda-research-matters-circadian-lighting-design-leveraging-melanopic-efficacy-luminous

Ercan,B., & Elias-Ozkan, S. (2015). Performance-based parametric design explorations: A method for generating appropriate building components. *Design Studies*,Volume 38. https://doi.org/10.1016/j.destud.2015.01.001

Evins, R. (2013). A review of computational optimisation methods applied to sustainable building design. *Renewable and Sustainable Energy Reviews*,Volume 22,Pages 230-245. https://doi.org/10.1016/j.rser.2013.02.004

Farley, K. M. J., & Veitch, J. A. (2001). *A room with a view: A review of the effects of windows on work and well-being*. Technical Report, Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario, Canada, 33pp. https://doi.org/10.4224/20378971

Fathy, F., Mansour, Y., Sabry, H., Refat, M., & Wagdy, A. (2020). Conceptual framework for daylighting and facade design in museums and exhibition spaces. *Solar Energy*, Volume 204. https://doi.org/10.1016/j.solener.2020.05.014.

Figueiro, M., Brons, J., & Plitnick, B., Donlan, B., Leslie, Rp., & Rea, Mark. (2011). Measuring circadian light and its impact on adolescents. *Lighting research & technology* (London, England : 2001). 43. 201-215. 10.1177/1477153510382853. http://dx.doi.org/10.1177/1477153510382853

Fisher, A (1992). *Tolerances in lighting design*. In Proceedings of the CIE seminar on computer programs for light and lighting, (pp. 102–103). Vienna, Austria. Fuchs, P. Virtual Reality Headsets - A Theoretical and Pragmatic Approach. CRC Press.

Fissore, V., Silvia, F., Giuseppina, E., Louena, S., & Arianna, A. (2023). Indoor Environmental Quality and Comfort in Offices: A Review. *Buildings* 13, no. 10: 2490. https://doi.org/10.3390/buildings13102490

Fletcher, G. (Ed.). (2016). *The Routledge handbook of philosophy of well-being*. Routledge. https://doi.org/10.4324/9781315745329

Flor, J., Aburas, M., Abd-Alhamid, F., & Wu, Y. (2021). Virtual Reality as a tool for evaluating user acceptance of view clarity through ETFE double-skin façades. *Energy and Buildings*, 231, Article 110554. https://doi.org/10.1016/j.enbuild.2020.110554

Flores-Villa, L., Unwin, J., & Raynham, P. (2020). Assessing the impact of daylight exposure on sleep quality of people over 65 years old. *Building Services Engineering Research and Technology*. 41(2):183-192. https://doi.org/10.1177/0143624419899522

Franz, G., von der Heyde, M., & Bülthoff, H. (2015). An empirical approach to the experience of architectural space in virtual reality—exploring relations between features and affective appraisals of rectangular indoor spaces. *Automation in Construction*, Volume 14, Issue 2. https://doi.org/10.1016/j.autcon.2004.07.009

Freeman, L. C. (1977). *A Set of Measures of Centrality Based on Betweenness. Sociometry*, 40(1), 35–41. https://doi.org/10.2307/3033543

Fuchs, P. Virtual Reality Headsets - A Theoretical and Pragmatic Approach.

Gill, H., & Butler, D. (2020). *Mental health and wellbeing in the workplace: A practical guide for employers and employees* [Audiobook]. Gildan Media.

Goldberg, D.E., & Holland, J.H. (1988). Genetic Algorithms and Machine Learning. *Machine Learning* 3, 95–99. https://doi.org/10.1023/A:1022602019183

Grinde, B., & Patil, G.G. (2009). Biophilia: does visual contact with nature impact on health and well-being?. *Int J Environ Res Public Health*. 2009 Sep;6(9):2332-43. https://doi.org/10.3390%2Fijerph6092332

Grix, J. (2002). Introducing students to the generic terminology of social research. *Politics*, 22(3), 175–186. https://doi.org/10.1111/1467-9256.00173

Guilford, J. P., & Smith, P. C. (1959). A system of color preferences. *American Journal of Psychology, 72*(4), 487–502. https://doi.org/10.2307/1419491

Gumport, N., Dolsen, E., & Harvey, A. (2019). Usefulness and utilization of treatment elements from the Transdiagnostic Sleep and Circadian Intervention for adolescents with an evening circadian preference. *Behaviour Research and Therapy*,Volume 123,103504. https://doi.org/10.1016/j.brat.2019.103504

Hascher, R., Jeska, S., & Klauck, B. (2002). *Office Buildings: A Design Manual (Design Manuals).* Birkhäuser GmbH; Illustrated edition.

Healy, M., & Perry, C. (2000). Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research: An International Journal, 3*(3), 118–126. https://doi.org/10.1108/13522750010333861

Hegazy, M., Yasufuku, K., & Abe, H. (2021). Evaluating and Visualising perceptual impressions of daylighting in immersive virtual environments. *Journal of Asian Architecture and Building Engineering*, 20(6), 768–784. https://doi.org/10.1080/13467581.2020.1800477

Heiselberg, P. (2007). Integrated Building Design. Department of Civil Engineering, *Aalborg University*. DCE Lecture notes No. 17. https://vbn.aau.dk/ws/portalfiles/portal/13726608/Integrated_Building_Design

Hellinga, H., & Hordijk, T. (2014). The D&V analysis method: A method for the analysis of daylight access and view quality. *Building and Environment*, *79*, 101–114. https://doi.org/10.1016/j.buildenv.2014.04.032

Heschong, L. (2003). *Windows and offices: A study of office worker performance and the indoor environment*. Technical Report, California Energy Commission, 143pp.

Heschong, L., Wymelenberg, V. D., Andersen, M., Digert, N., Fernandes, L., Keller, A., Loveland, J., McKay, H., Mistrick, R., Mosher, B., Reinhart, C., Rogers, Z., & Tanteri, M. (2012). *Approved method: IES spatial daylight autonomy (sDA) and annual sunlight exposure (ASE)*. New York: Illuminating Engineering Society, p. 14.

Hevey ,D. (2018). Network analysis: a brief overview and tutorial. *Health Psychol Behav Med*, 6(1):301-328. https://doi.org/10.1080/21642850.2018.1521283

Heydarian, A., Pantazis, E., Carneiro, J., Gerber, D., & Becerik-Gerber, B. (2016). Lights, building, action: Impact of default lighting settings on occupant behaviour. *Journal of Environmental Psychology*,Volume 48. https://doi.org/10.1016/j.jenvp.2016.11.001

Heydarian, A., Carneiro, J., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2014). *Immersive Virtual Environments: Experiments on Impacting Design and Human Building Interaction*. Caadria2014_161. https://doi.org/10.52842/conf.caadria.2014.729

Holland, J.H. (1984). *Genetic Algorithms and Adaptation.* In: Selfridge. O.G., Rissland, E.L., Arbib, M.A. (eds) Adaptive Control of Ill-Defined Systems. NATO Conference Series, vol 16. Springer, Boston, MA. https://doi.org/10.1007/978-1-4684-8941-5_21

Hopkinson, R., & Kay, J. (1972). *Lighting of Buildings*. Faber & Faber http://dx.doi.org/10.1051/shsconf/20196402015

Hui, X., Huiling, C., & Li, X. (2021). Non-visual effects of indoor light environment on humans: A review. *Physiology & Behavior*, *228*, Article 113195. https://doi.org/10.1016/j.physbeh.2020.113195

Integrated Environmental Solutions (IES). (2022). IES Virtual Environment. Intelligent Communities Lifecycle. https://www.iesve.com/

International Code Council. (2021). *International green construction code: A comprehensive solution for high-performance buildings*. 13 May 2021. https://www.amazon.co.uk/2021-International-Green-Construction-Council/dp/1609839765

International Commission on Illumination. (2008). *4th Conference of computer science, mathematics and logic*. University of Athens, Athens, Greece.

International Living Future Institute. (2019). *Living Building Challenge[SM] 4.0. A visionary path to a regenerative future*. https://living-future.org/wp-content/uploads/2022/08/LBC-4_0_v14_2_compressed.pdf

Jacobs, K.W., & Suess, J. F. (1975). Effects of four psychological primary colors on anxiety state. *Perceptual and Motor Skills*, *41*(1), 207–210. https://doi.org/10.2466/pms.1975.41.1.207

Jaeha, K., Michael, K., Katharina, K., & Timur, D. (2022). Seemo: A new tool for early design window view satisfaction evaluation in residential buildings. *Building and Environment. Volume 214*. https://doi.org/10.1016/j.buildenv.2022.108909

Jamrozik, A., Clements, N., Hasan, S. S., Zhao, J., Zhang, R., Campanella, C., Loftness, V., Porter, P., Ly, S., Wang, S., & Bauer, B. (2019). Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: A controlled crossover study. *Building and Environment*, *165*, Article 106379. https://doi.org/10.1016/j.buildenv.2019.106379

Jayathissa, P., Caranovic, S., Hofer, J., Nagy, Z., & Schlueter, A. (2018). Performative design environment for kinetic photovoltaic architecture. *Automation in Construction*, *93*, 339–347. https://doi.org/10.1016/j.autcon.2018.05.013

Kellert, S. R., Heerwagen, J. H., & Mador, M. L. (Eds.). (2011). *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life* (Chapter 15, pp. 253–254). London: Wiley.

Kelloway, E. K., & Cooper, C. (2021). *A research agenda for workplace stress and wellbeing*. Edward Elgar. https://doi.org/10.4337/9781789905021

Keskin, Zeynep. (2019) *Investigating the effect of daylight on seating preferences in an open-plan space: A comparison of methods.* PhD thesis, University of Sheffield. https://etheses.whiterose.ac.uk/24559/

Khademagha, P., Aries, M. B., Rosemann, A., & van Loenen, E. J. (2016). Implementing non-image-forming effects of light in the built environment: A review on what we need. *Building and Environment*, *108*, 263–272. https://doi.org/10.1016/j.buildenv.2016.08.035

Kim, D., Luong, H., & Nguyen, T. (2024). Optimising the Shading Device Configuration of Kinetic Façades through Daylighting Performance Assessment. *Buildings*, 14, 1038. https://doi.org/10.3390/buildings14041038

Kirimtat, A., Kundakci, B., Chatzikonstantinou, L., & Sariyildiz, S. (2016). Review of simulation modeling for shading devices in buildings. *Building and Environment*, *53*, 23–49. https://doi.org/10.1016/j.rser.2015.08.020

Kitchin, R. M. (1994). Cognitive maps: What are they and why study them? *Journal of Environmental Psychology*, *14*(1), 1–19. https://doi.org/10.1016/S0272-4944(05)80194-X

Klein, T. (2013). *Integral façade construction: Towards a new product architecture for curtain walls*. TU Delft.

Ko, W. H., Kent, M. G., Schiavon, S., Levitt, B., & Betti, G. (2021). A Window View Quality Assessment Framework. *LEUKOS*, *0*(0), 1–26. https://doi.org/10.1080/15502724.2021.1965889

Konstantzos, I., Tzempelikos, A., & Chan, Y. C. (2015). Experimental and simulation analysis of daylight glare probability in offices with dynamic window shades. *Building and Environment*, *87*, 244–254. https://doi.org/10.1016/j.buildenv.2015.02.007

Kreutzberg, A., & Naboni, E. (2019). *360° VR for Qualifying Daylight Design*. SHS Web Conf. 64 02015.

Kuckartz, U., & Rädiker, S. (2019). *Analyzing qualitative data with MAXQDA: Text, Audio, and Video*. Springer.

Laing, A. (2005). *New Patterns of Work: The Design of the Office*. Routledge.

Larson, G., & Shakespeare, R. (1988). *Rendering with Radiance: Art and Science of Lighting Visualisation (Morgan Kaufmann Series in Computer Graphics and Geometric Modeling)*. Morgan Kaufmann Publishers In.

Lartigue, B., Lasternas, B., & Loftness, V. (2014). Multi-objective optimisation of building envelope for energy consumption and daylight. *Indoor and Built Environment*, 23(1):70-80. https://doi.org/10.1177/1420326X13480224

Leather, P., Pyrgas, M., Beale, D., & Lawrence, C. (1998). Windows in the Workplace: Sunlight, View, and Occupational Stress. *Environment and Behavior*, 30(6), 739-762. https://doi.org/10.1177/001391659803000601

Lee, B., & Cassell, C. (2013). Research methods and research practice: History, themes and topics. *International Journal of Management Reviews,* 15(2), 123–131. https://doi.org/10.1111/ijmr.12012. DOI: https://doi.org/10.1111/ijmr.12012

Lee, E. S., & Matusiak, B. S. (2022). Advocating for view and daylight in buildings: Next steps. *Energy & Buildings*, *265*, Article 112079. https://doi.org/10.1016/j.enbuild.2022.112079

Lee, J., Boubekri, M., Liang, F. (2019). Impact of Building Design Parameters on Daylighting Metrics Using an Analysis, Prediction, and Optimisation Approach Based on Statistical Learning Technique. *Sustainability* 2019, *11*, 1474. https://doi.org/10.3390/su11051474

Lei, Q., Shaoyu, L., Chao, Y., & Yi, Qi. (2022). Post-Occupancy Evaluation of the Biophilic Design in the Workplace for Health and Wellbeing. *Buildings* 12 (4): 417. https://doi.org/10.3390/buildings12040417.

Leslie, R. P., Radetsky, L. C., & Smith, A. M. (2012). Conceptual design metrics for daylighting. *Lighting Research & Technology*, *44*(3), 277–290.

Lewis, J. (1994). Aftereffects of near-death experiences: A survival mechanism hypothesis. *Journal of Transpersonal Psychology*, *26*(2), 107–115.

Li, W., & Samuelson, H. (2020). A new method for Visualising and evaluating views in architectural design. *Developments in the Built Environment*, *1*, Article 100005. https://doi.org/10.1016/j.dibe.2020.100005

Lin, T., Le, A., & Chan, Y. (2022). Evaluation of window view preference using quantitative and qualitative factors of window view content. *Building and Environment*,Volume 213. https://doi.org/10.1016/j.buildenv.2022.108886

Lin, T.-Y., Le, A.-V., & Chan, Y.-C. (2022). Evaluation of window view preference using quantitative and qualitative factors of window view content. *Building and Environment*, *213*, Article 108886. https://doi.org/10.1016/j.buildenv.2022.108886

Lin, W., & Juan, Y. (2024). Examining the association between healing environments and work performance. *Journal of Building Engineering*, Volume 84, 2024, 108624, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2024.108624

Lottrup, L., Stigsdotter, U. K., Meilby, H., & Claudi, A. G. (2015). The Workplace Window View: A Determinant of Office Workers' Work Ability and Job Satisfaction. *Landscape Research*, 40(1), 57–75. https://doi.org/10.1080/01426397.2013.829806

Machairas, V., Tsangrassoulis, A., & Axarli, K. (2014). Algorithms for optimisation of building design: A review. *Renewable and Sustainable Energy Reviews*,Volume 31, Pages 101-112. https://doi.org/10.1016/j.rser.2013.11.036

MacKerron, G., & Mourato, S. (2013). Happiness is greater in natural environments. *Global Environmental Change*, *23*(5), 992–1000. https://doi.org/10.1016/j.gloenvcha.2013.03.010

Mahdavi, A., & Farhang, T. (2017). On the Quality Evaluation of Behavioural Models for Building Performance Applications. *Journal of Building Performance Simulation* 10, no. 5–6 ,554–64. https://doi.org/10.1080/19401493.2016.1230148

Mahmoud , A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimise daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. *ELSEVIER, Solar Energy* 126, 111–127. https://doi.org/10.1016/j.solener.2015.12.039

Makki, M., Navarro-Mateu, D., & Showkatbakhsh, M. (2022). Decoding the Architectural Genome: Multi-Objective Evolutionary Algorithms in Design. *Technology|Architecture + Design*, 6(1), 68–79. https://doi.org/10.1080/24751448.2022.2040305

Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research & Technology*,41(3):261-283. doi:10.1177/1477153509339703

Marfella, G. (2010). *Five Speculative Points for a Building Type*. Conference: AUBEA 2010: Construction Management(s). http://dx.doi.org/10.13140/RG.2.1.3310.8002

Markus, T. A. (1967). The function of windows: A reappraisal. *Building Science*, *2*(2), 97–121. https://doi.org/10.1016/0007-3628(67)90012-6

Matusiak, B. S. (2020). No-Greenery Line and Greenery-View Factor, New Architectural Design Tools. *Journal of Daylighting*. 7 (2020) 282-286. https://dx.doi.org/10.15627/jd.2020.24

Matusiak, B. S., & Klöckner, C. A. (2016). How we evaluate the view out through the window. *Architectural Science Review*, *59*(3), 203–211. https://doi.org/10.1080/00038628.2015.1032879

McArthur, J. J., & Powell, C. (2020). Health and wellness in commercial buildings: Systematic review of sustainable building rating systems and alignment with contemporary research. *Building and Environment*, *171*, Article 106635. https://doi.org/10.1016/j.buildenv.2019.106635

McMullin, P., & Price, J. (2016). *Introduction to Structures (Architect's Guidebooks to Structures.* Routledge

Mehmood, M. U., Chun, D., Zeeshan, H., Jeon, G., & Chen, K. (2019). A review of the applications of artificial intelligence and big data to buildings for energy efficiency and a comfortable indoor living environment. *Energy and Buildings*, *202*, Article 109383 https://doi.org/10.1016/J.ENBUILD.2019.109383

Mental Health Commission of Canada. (2022). *Changing directions, changing lives: The mental health strategy for Canada*. https://www.mentalhealthcommission.ca/wpcontent/uploads/drupal/MHStrategy_Strategy_ENG.pdf

Moore, E. O. (1981). A prison environment's effect on health care service demands. *Journal of Environmental Systems*, *11*(1), 17–34. https://doi.org/10.2190/KM50-WH2K-K2D1-DM69

Munaaim, C., Al-Obaidi, M., Ismail, R., & Rahman, A. (2014). A review study on the application of the fibre optic daylighting system in Malaysian buildings. I*nternational Journal of Sustainable Building Technology and Urban Development*, 5(3), 146–158. https://doi.org/10.1080/2093761X.2014.901931

Myriam B.C. Aries., Jennifer A. Veitch., & Guy. R. Newsham. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology*,Volume 30, Issue 4. https://doi.org/10.1016/j.jenvp.2009.12.004

Nabil, A., & Mardaljevic J. (2005). Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Lighting Research & Technology*. 2005;37(1):41-57. https://doi.org/10.1191/1365782805li128oa

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings*, *38*(7), 905–913.

Natephra, W., Motamedi, A., & Fukuda, T. (2017). Integrating building information modeling and virtual reality development engines for building indoor lighting design. Vis. in Eng. 5, 19. https://doi.org/10.1186/s40327-017-0058-x

National Landscapes Association. (2023). *Welcome to National Landscapes, where our stories come to life.* https://national-landscapes.org.uk/news/welcome-to-national-landscapes?ref=practical-emu.pikapod.net

National Alliance on Mental Illness (NAMI). (2022). *NAMI 2019 annual report*. https://www.nami.org/NAMI/media/NAMI-Media/PDFs/Financials/2019NAM-AnnualReport-web.pdf

Neymark, J., Judkoff, R., Knabe, G., Le, H., Dürig, M., Glass, A., & Zweifel, G. (20102). Applying the building energy simulation test (BESTEST) diagnostic method to verification of space conditioning equipment models used in whole-building energy simulation programs,Energy and Buildings,Volume 34, Issue 9. https://doi.org/10.1016/S0378-7788(02)00072-5

Ng, P.M.L., Lit, K.K., & Cheung, C.T.Y.(2022). Remote work as a new normal? The technology-organization-environment (TOE) context. Technol. Soc. 70, 102022. https://doi.org/10.1016/j.techsoc.2022.102022

Nguyen, A., Reiter, S., & Rigo, P. (2014). A review on simulation-based optimisation methods applied to building performance analysis. *Applied Energy*,Volume 113. https://doi.org/10.1016/j.apenergy.2013.08.061.

Overheating: Approved Document O. (2022). https://www.gov.uk/government/publications/overheating-approved-document-o

Owl Labs. (2021). *State of remote work 2021* (5th ed.). https://owllabs.com/state-of-remote-work/2021

Pallant, J. (2016). *SPSS Survival Manual: A step by step guide to data analysis using IBM SPSS*. (6th ed.). Routledge. https://doi.org/10.4324/9781003117407

Peel, M., Finlayson, B., & Mcmahon, T. (2007). Updated World Map of the Köppen-Geiger Climate Classification. *Hydrology and Earth System Sciences Discussions*. 4. 10.5194/hess-11-1633-2007.http://dx.doi.org/10.5194/hess-11-1633-2007

Pesenti, M., Masera, G., & Fiorito, F. (2015). Shaping an origami shading device through visual and thermal simulations. *Energy Procedia*, *78*, 346–351. https://doi.org/10.1016/j.egypro.2015.11.663

Pettersson, R. (1988). Image format. *Visual Literacy Newsletter*, *17*(5).

Pilechiha, P., Mahdavinejad, M., Rahimian, Farzad., Carnemolla, P., & Seyedzadeh, S. (2020). Multi-objective optimisation framework for designing office windows: quality of view, daylight and energy efficiency. *Applied Energy*, *261*, Article 114356. https://doi.org/10.1016/j.apenergy.2019.114356

Qi, X., Luo, Z., Ghahramani, A., Zhuang, D., & Sun, C. (2024). A study of subjective evaluation factors regarding visual effects of daylight in offices using machine learning. *Journal of Building Engineering*,Volume 86,2024,108906,ISSN 2352-7102. https://doi.org/10.1016/j.jobe.2024.108906

Rafati, N., Hazbei, M., & Eicker, U. (2023). Louver configuration comparison in three Canadian cities utilizing NSGA-II. *Build. Environ*. 229, 109939. https://doi.org/10.1016/j.buildenv.2022.109939

Rea, M. S. (2005). *IESNA lighting handbook: Reference and application* (9th ed.). Illuminating Engineering Society of North America (IESNA).

Rea, M. S., & Figueiro, M. S. (2016). Light as a circadian stimulus for architectural lighting. *Lighting Research & Technology*, *50*(4), 497–510.

Reinhart, C. F., & Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings*, *33*(7), 683–697.

Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2013). Dynamic Daylight Performance Metrics for Sustainable Building Design. *The journal of the illuminating Engineering Society of North America*, 3(1), pp. 7– 31. https://doi.org/10.1582/LEUKOS.2006.03.01.001

Rizi, R. A., Bagherzadeh, F., Schnabel, M. A., & Bakshi, N. (2024). A design methodology to consider occupants' spatial adjustment and manage view content in adaptive façade design for improving visual comfort. *Architectural Engineering and Design Management*, 20(1), 168–190. https://doi.org/10.1080/17452007.2023.2259394

Robert McNeel & Associates.(2014). Rhino software. https://www.rhino3d.com/

Roche, Liam., Dewey, E. & Littlefair, P. (2000). Occupant reactions to daylight in offices. *Lighting Research & Technology - LIGHTING RES TECHNOL*. 32. 119-126. 10.1177/096032710003200303. http://dx.doi.org/10.1177/096032710003200303

Rohde, L., Steen Larsen, T., Jensen, R. L., Larsen, O. K., Jønsson, K. T., & Loukou, E. (2020). Determining indoor environmental criteria weights through expert panels and surveys. *Building Research & Information*, 48(4), 415–428. https://doi.org/10.1080/09613218.2019.1655630

Ryan, E., & Sanquist. T. (2012). Validation of building energy modeling tools under idealized and realistic conditions, *Energy and Buildings*,Volume 47. https://doi.org/10.1016/j.enbuild.2011.12.020

Salford City Council, n. d. *Salford's green space*. https://www.salford.gov.uk/planning-building-and-regeneration/salfords-natural-environment/greenspace/

Sarantakos, S. (2013). *Social Research*. 4th edition, Palgrave Macmillan

Saunders, M., Lewis, P., & Thornhill, (2015). *A. Research Methods for Business Students*. Pearson

Schönborn, A., & Junge, R. (2021). Redefining Ecological Engineering in the Context of Circular Economy and Sustainable Development. *Circ.Econ.Sust*. 1, 375–394. https://doi.org/10.1007/s43615-021-00023-2

Schweizer, C., Edwards, R. D., Bayer-Oglesby, L., Gauderman, W. J., Ilacqua, V., Juhani Jantunen, M., Lai, H. K., Nieuwenhuijsen, M., & Künzli, N. (2007). Indoor time–microenvironment–activity patterns in seven regions of Europe. *Journal of Exposure Science & Environmental Epidemiology*, *17*(2), 170–181. https://doi.org/10.1038/sj.jes.7500490

Sheikh, W. T., & Asghar, Q. (2019). Adaptive biomimetic facades: Enhancing energy efficiency of highly glazed buildings. *Frontiers of Architectural Research*, *8*, 319–331. https://doi.org/10.1016/j.foar.2019.06.001

Sheng, W., Ishikawa, k., Tanaka, H., Tsukamoto, A., & Tanaka, S. (2015). Photorealistic VR Space Reproductions of Historical Kyoto Sites based on a Next-Generation 3D Game Engine. *Japanese Journal of Simulation Society*, Volume 1 Issue 1 p. 188-204. https://doi.org/10.15748/jasse.1.188

Sherif, A., Sabry, H., Wagdy, A., & Arafa, R. (2015). *Daylighting in hospital patient rooms: Parametric workflow and genetic algorithms for an optimum façade design*. In Proceedings of the 14th Conference of International Building Performance Simulation Association (pp. 1383–1388), Hyderabad, India. https://doi.org/10.26868/25222708.2015.2775

Showkatbakhsh, M., & Makki, M. Multi-Objective Optimisation of Urban Form: A Framework for Selecting the Optimal Solution. *Buildings* 2022, *12*, 1473. https://doi.org/10.3390/buildings12091473

Steemers, K. (2021). Architecture for well-being and health. *VELUX Commercial Blog*. https://commercial.velux.co.uk/blog/daylight/architecture-for-well-being-and-health

Taber, K.S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Res Sci Educ 48, 1273–1296* . https://doi.org/10.1007/s11165-016-9602-2abadkani, A., Banihashemi, S., & Reza Hosseini, M. (2018). Daylighting and visual comfort of oriental sun responsive skins: A parametric analysis. *Building Simulation*, 11(4), 663–676. https://doi.org/10.1007/s12273-018-0433-0

Tennent, J. (2013), *The Economist Numbers Guide: The Essentials of Business Numeracy*. 6th ed., Economist Books. London.

Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *The Journal of Physiology*, *535*(Pt 1), 261–267. https://doi.org/10.1111/j.1469-7793.2001.t01-1-00261.x

The WELL Building Standard. (2024). Q1 2024 Addenda. https://www.well.support/your-guide-to-the-q1-2024-addenda~3cd90b3d-adf0-49ef-af6e-d61c2008381b (Accessed:2024)

The WELL Building Standard. (2024). The WELL Building Standard™ (WELL v2,Q1-Q2). https://v2.wellcertified.com/en/wellv2/overview (Accessed:2024)

Ticleanu, C. (2021). Impacts of home lighting on human health. *Lighting Research & Technology*, *53*(5), 453–475. https://doi.org/10.1177/14771535211021064

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, *55*(4), 189–208. https://doi.org/10.1037/h0061626

Tuaycharoen, N., & Tregenza, P.R. (2007). View and discomfort glare from windows. *Lighting Research & Technology*. 2007;39(2):185-200. doi:10.1177/1365782807077193

Tunahan, G., Altamirano, H., Teji, J.U., & Ticleanu C. (2022). Evaluation of Daylight Perception Assessment Methods. *Front Psychol*. 13:805796. https://doi.org/10.3389%2Ffpsyg.2022.805796

Turan, I., Chegut, A., Fink, D., & Reinhart, C. (2021). Development of view potential metrics and the financial impact of views on office rents. *Landscape and Urban Planning*, *215*, Article 104193. https://doi.org/10.1016/j.landurbplan.2021.104193

U. S. Green Building Council (USGBC). (2019). LEED v4 for Building Design and Construction. Updated 25 July 2019. https://www.usgbc.org/resources/leed-v4-building-design-and-construction-current-version

Ulrich, R. S. (1979). Visual landscapes and psychological well-being. *Landscape Research*, *4*(1), 17–23. https://doi.org/10.1080/01426397908705892

Ulrich, R. S. Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, *11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7

Valdez, P., & Mehrabian, A. (1994). Effects of color on emotions. *Journal of Experimental Psychology*, *123*(4), 394–409. https://doi.org/10.1037/0096-3445.123.4.394

Valente, T. W. (2010). *Social networks and health: Models, methods, and applications*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195301014.001.0001

Veitch, J. A. (2004). What's new in lighting research? The broad view, Proceedings of International Symposium on Workplace Lighting, Dublin, Ireland.

Veitch, J. A., Bisegna, F., Hubalek, S., Knoop, M., Koga, Y., Noguchi, H., Schierz, C., Thorns, P., & Vries, A. de. (2016). *Research roadmap for healthful interior lighting applications*. CIE Technical Report 218. International Commission on Illumination (CIE). https://cie.co.at/publications/research-roadmap-healthful-interior-lighting-applications

Velarde, M., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes—Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, *6*(4), 199–212. https://doi.org/10.1016/j.ufug.2007.07.001

W3C. (2022). Portable network graphics (PNG) specification (3rd ed.). W3C First Public Working Draft, 25 October. https://www.w3.org/TR/png/#3sample

Waldram, P., & Waldram, J. (1923). Window Design and the Measurement and Predetermination of Daylight Illumination. *The Illuminating Engineer (London)*, 16 (1923) pp. 90-122.

Walker. P. (2014). *Early Access popularity growing, but only 25a full game*. https://www.gamesindustry.biz/early-access-popularity-growing-but-only-25-percent-have-released-as-a-full-game. (Accessed 1/6/2024)

West, M. J. (1985). *Landscape views and stress response in the prison environment* [Unpublished MLA thesis]. University of Washington, Washington, D. C.

Wilson, E. O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press. https://doi.org/10.4159/9780674045231

Wong, I. (2017). A review of daylighting design and implementation in buildings. *Renewable and Sustainable Energy Reviews*,Volume 74. https://doi.org/10.1016/j.rser.2017.03.061

World Health Organisation. (2022a). *Mental health: Fact sheet*. https://www.euro.who.int/__data/assets/pdf_file/0004/404851/MNH_FactSheet_ENG.pdf

World Health Organization. (2021b). *Green and blue spaces and mental health: New evidence and perspectives for action*. WHO Regional Office for Europe. https://apps.who.int/iris/handle/10665/342931

Xiao, H., Cai, H., & Li, X. (2021). Non-visual effects of indoor light environment on humans: A review. *Physiology & Behavior*, *228*, Article 113195. https://doi.org/10.1016/j.physbeh.2020.113195

Yao, T., Lin, W., Bao, Z., & Zeng, C. (2024). Natural or balanced? The physiological and psychological benefits of window views with different proportions of sky, green space, and buildings. *Sustainable Cities and Society*,Volume 104, 105293. https://doi.org/10.1016/j.scs.2024.105293

Yildirim, M., Gocer, O., Globa, A., & Brambilla, A. (2024). Investigating restorative effects of biophilic design in workplaces: a systematic review. *Intelligent Buildings International*, 1–43. https://doi.org/10.1080/17508975.2024.2306273

Yin, R, K. (2003). *Case study research, design and methods*. (3rd ed., vol. 5). Thousand Oaks: Sage.

Yu, X., & Su, Y.(2015). Daylight availability assessment and its potential energy saving estimation –A literature review. *Renewable and Sustainable Energy Reviews*,Volume 52. https://doi.org/10.1016/j.rser.2015.07.142.

Zhang, Lo., Zhang, Li., & Wang,Y.(2016). Shape optimisation of free-form buildings based on solar radiation gain and space efficiency using a multi-objective genetic algorithm in the severe cold zones of China. *Solar Energy*,Volume 132. https://doi.org/10.1016/j.solener.2016.02.053

Zhou, P., Yang, X. L., Wang, X. G., Hu, B., Zhang, L., Zhang, W., Si, H.-R., Zhu, Y., Li, B., Huang, C.-L., Chen, H.-D., Chen, J., Luo, Y., Guo, H., Jiang, R.-D., Liu, M.-Q., Chen, Y., Shen, X.-R., Wang, X., &Li-Shi, Z. (2020). A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*, *579*, 270–273. https://doi.org/10.1038/s41586-020-2012-7

Appendix 01 : Questionnaire Survey

PARTICIPANT INFORMATION FOR VIRTUAL REALITY EXPERIMENT
An investigation of the use of shading systems and daylight optimisation to enhance occupants' comfort and well-being in the working environment focused on Cairo commercial buildings

School of the Built Environment
The University of Salford
Manchester
M5 4WT
Name of researcher: Mohamed Salah Mansour Abdurrahman
Email: m.salahmansourabdelrahman@edu.salford.ac.uk
Name of supervisor: Dr Paul Coates
Email: s.p.coates@salford.ac.uk

Dear Participant,

My name is Mohamed Salah, a PhD candidate at the School of the Built Environment, University of Salford, UK. I am currently undertaking a study in architecture and daylight throughout workspaces to improve occupant comfort and well-being. This research aims to define a new multifactor system using virtual simulation and virtual reality (VR) techniques to establish the potential of daylight to increase comfort and well-being of occupants in workspaces. This multifactor system aims to enhance occupant comfort and well-being inside the working environment by optimising shading systems, daylight quality and outside view quality.

This experiment aims to produce a new method to assess occupant perception of daylight quality in the workspace using VR by converting the histogram video produced from the software used (which is called Unreal) to true and false colour according to the daylight exposure produced in the virtual environment.

Participants will be asked to complete in a simple 15-minute the questionnaire and the VR experiment to evaluate the effect of using shading devices on your daylight zone ratio. First, the participant will walk through the virtual model and select the most comfortable places to work by using a VR headset.

Then, they will be asked to select the most preferable shading device configuration that gives them a sufficient level of daylight quality and outside view at the same time in relation to their seat preference inside the workspace. That means they will be able to walk through the virtual model with the ability to select from four types of shading configurations (horizontal blends, vertical blends, overhang and pattern mesh) that were produced before during the simulation process. After finishing the VR experiment, the participant will be asked to answer a few questions about their satisfaction with the daylight quality via a questionnaire with Likert scale answers (strongly agree to strongly disagree).

There are minimal risks associated with participation in this research project. There may be some risks associated with using a VR headset. In some circumstances, extended use of these headsets may result in short-term simulator sickness. Simulator sickness encompasses a broad range of symptoms, including fatigue, headaches, eye strain, dizziness or nausea. Please note that if any of these occur you should inform the researcher, cease participation in the study immediately and not operate heavy machinery (including motor vehicles) for at least half an hour after the incident. If you require time to rest after the experiment, you are welcome to stay in the room for up to half an hour after conclusion of the session.

All comments and responses will be coded (i.e. it will be possible to re-identify you). A re-identifying code stored separately to personal information (e.g. name, address) will only be accessible to the researcher, and the code plus all identifying information will be destroyed after finishing the PhD research. Any personal information that could potentially identify you will be removed or changed before files are shared with other researchers or results are made public. Any data collected as part of this research project will be stored securely. Data will be stored for a minimum of 5 years, and can be disclosed if it is to protect you or others from harm, if specifically required by law, or if a regulatory or monitoring body such as the PhD Ethics Committee requests it.

Thank you for your participation.

Mohamed Salah
PhD candidate, University of Salford
m.salahmansourabdelrahman@edu.salford.ac.uk

An investigation of the use of shading systems and daylight optimisation to enhance occupants' comfort and well-being in the working environment focused on Cairo commercial buildings

School of the Built Environment
The University of Salford
Manchester
M5 4WT

Name of researcher: Mohamed Salah Mansour Abdurrahman
Email: m.salahmansourabdelrahman@edu.salford.ac.uk
Name of supervisor: Dr Paul Coates
Email: s.p.coates@salford.ac.uk

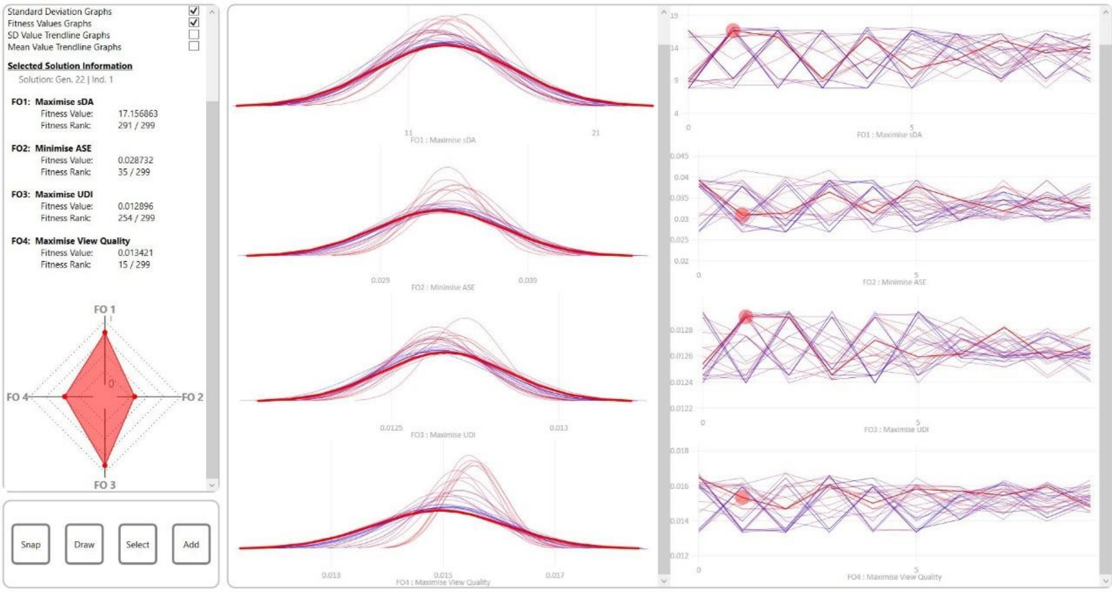
Please initial box

1. I confirm that I have read the information sheet dated 14/9/2022 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐
3. (If appropriate) I understand that the information collected about me will be used to support other research in the future, and may be shared anonymously with other researchers. ☐
4. I agree to take part in the above study. ☐
5. I have been given the name and email address of the researcher, Mohamed Salah (m.salahmansourabdelrahman@edu.salford.ac.uk) to contact if I have questions about this research. ☐

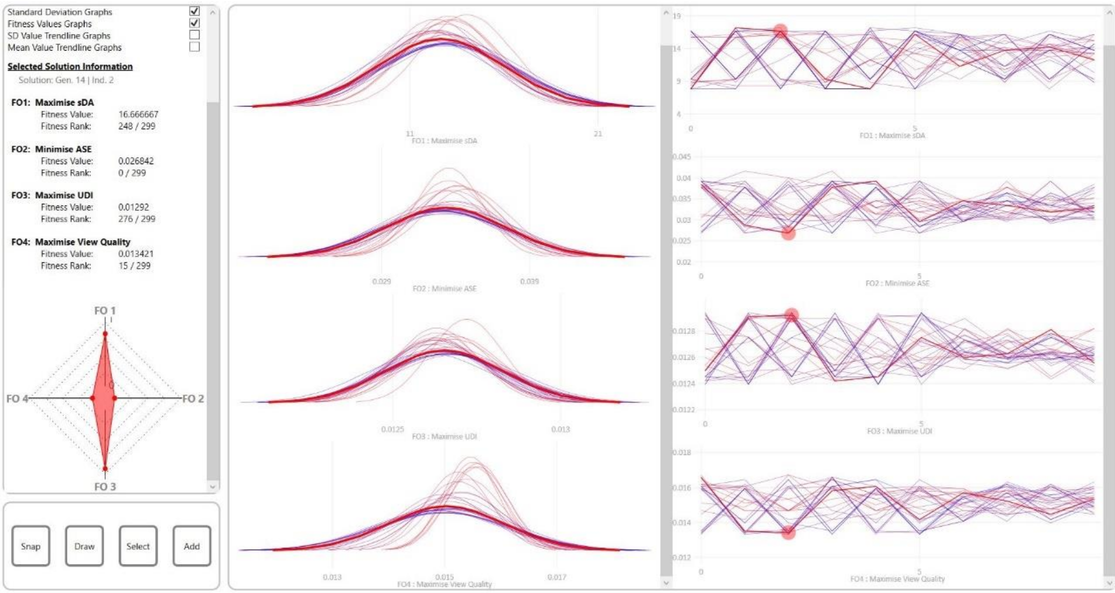
______________________	______________________	______________________
Name of Participant	Date	Signature

Appendix 02: Multi objectives optimisation results

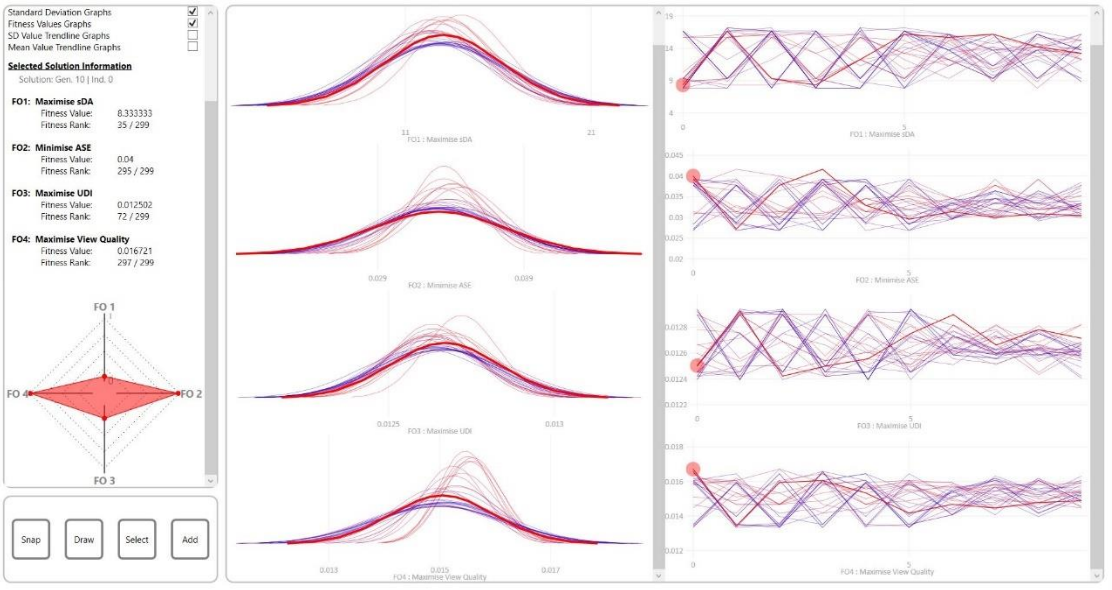
- *Gen. 22, S 01*



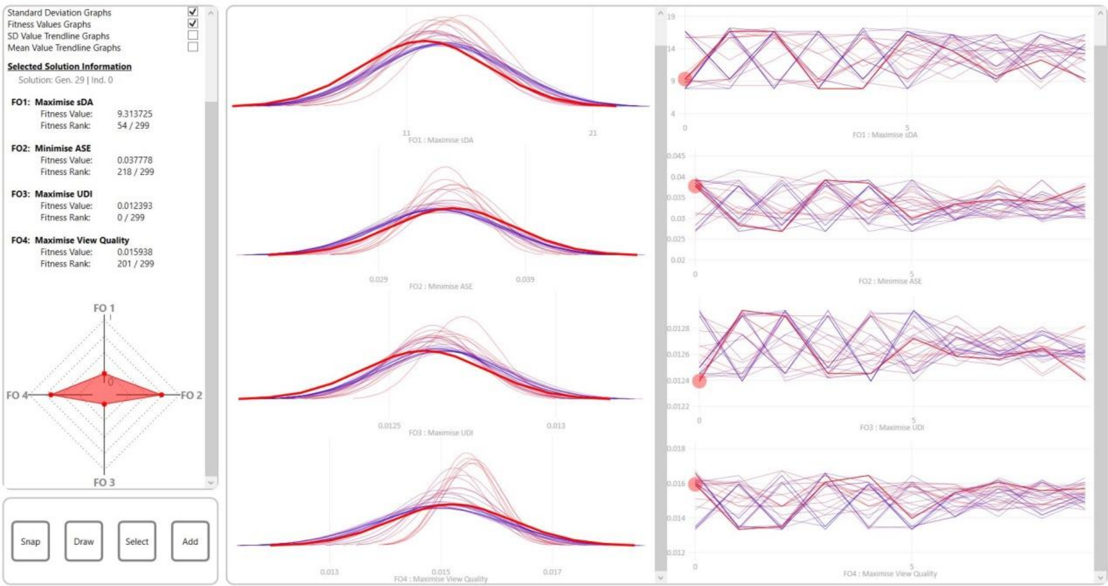
- *Gen,14. S 02*



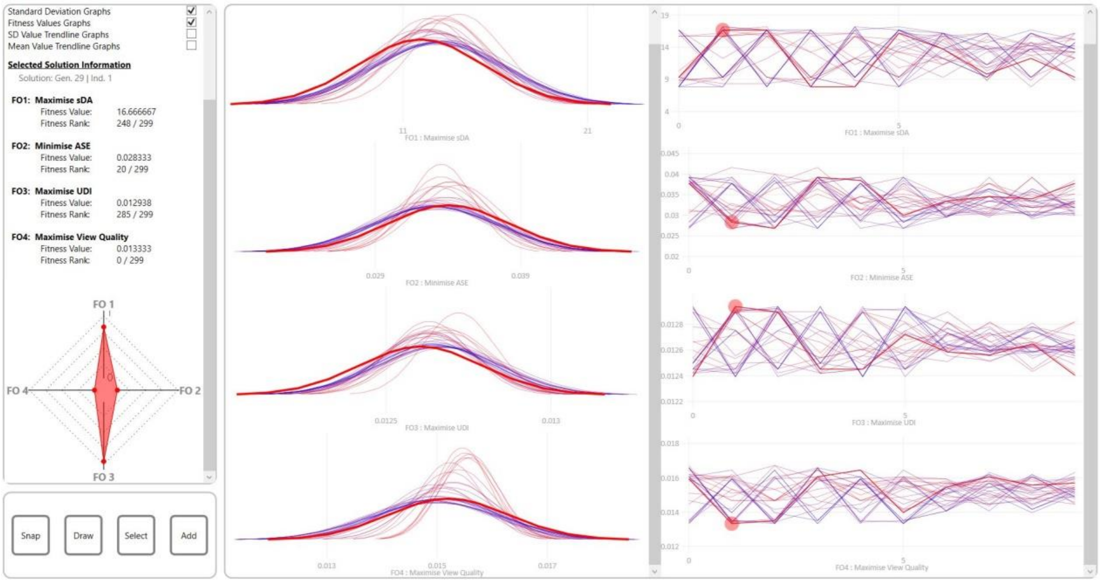
- *Gen.10, S 00*



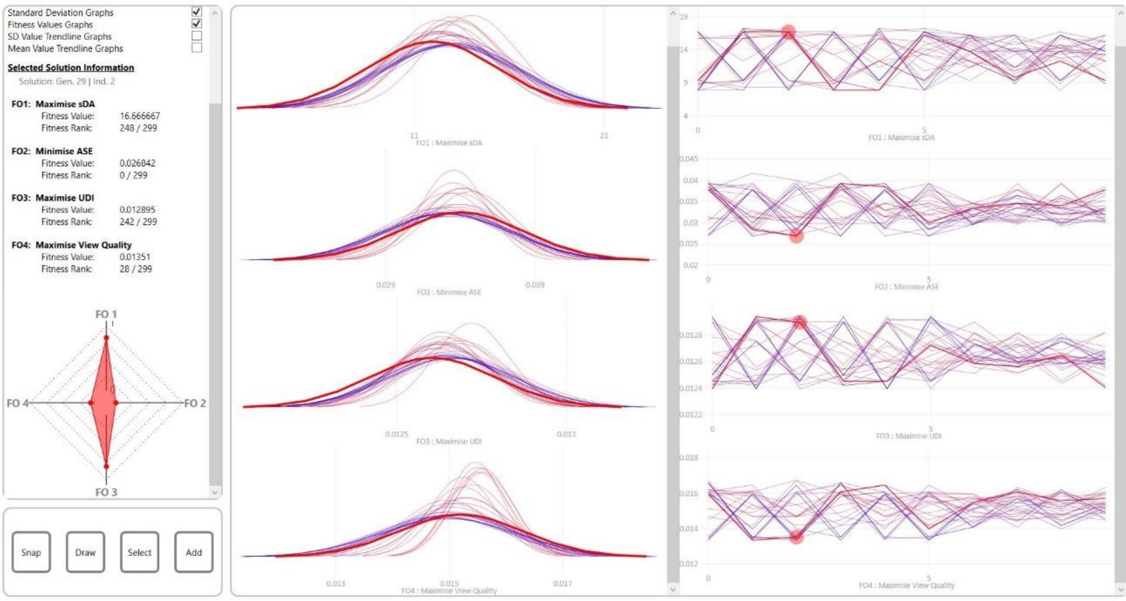
- *Gen.29, S 00*



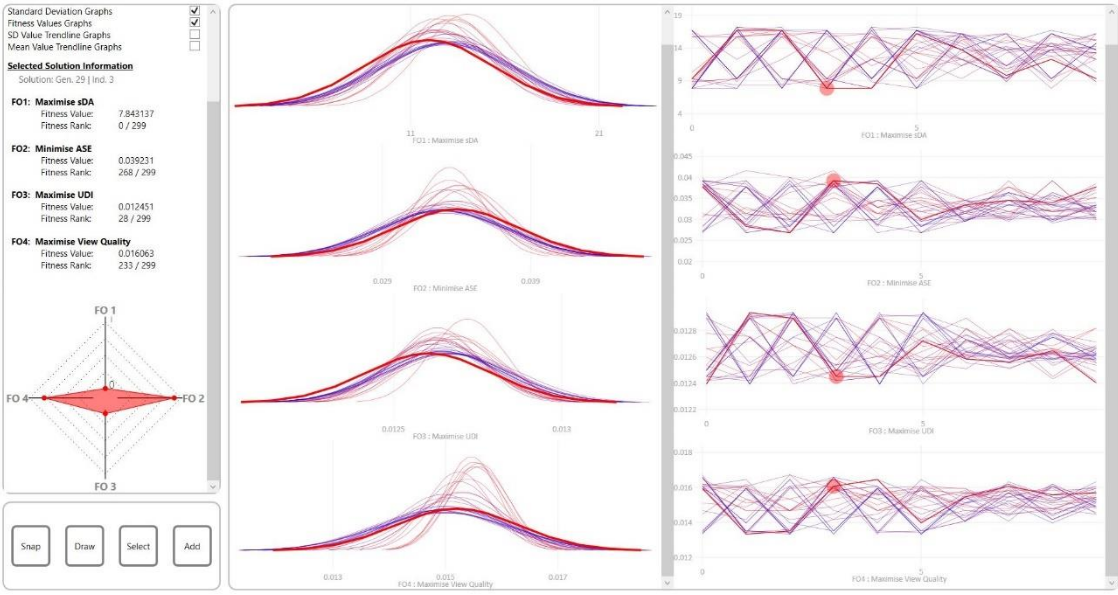
- *Gen.29, S 01*



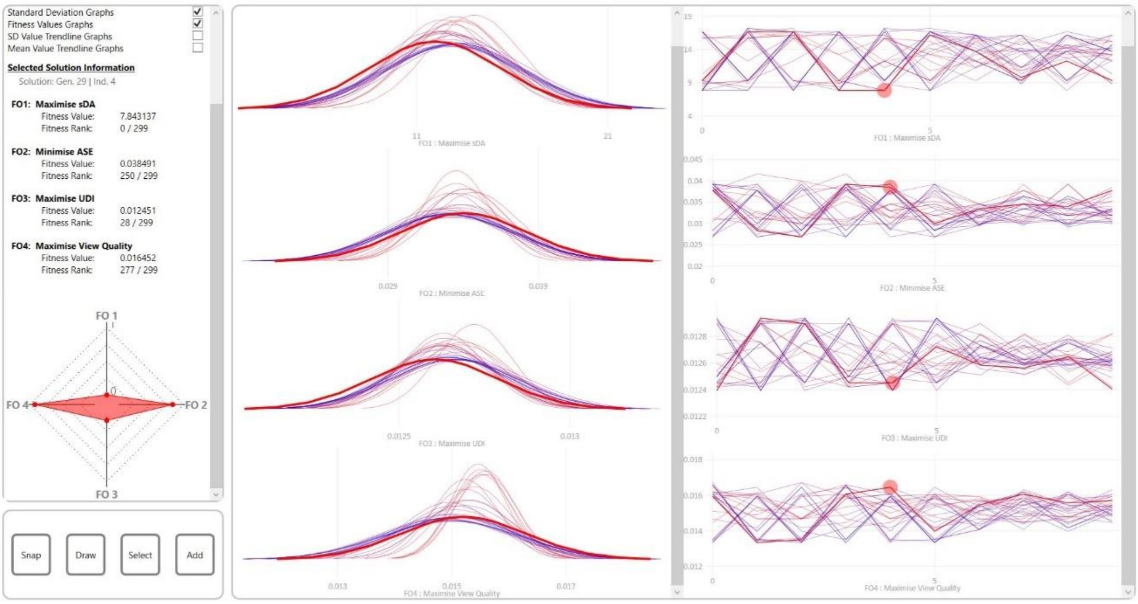
- *Gen.29, S 02*



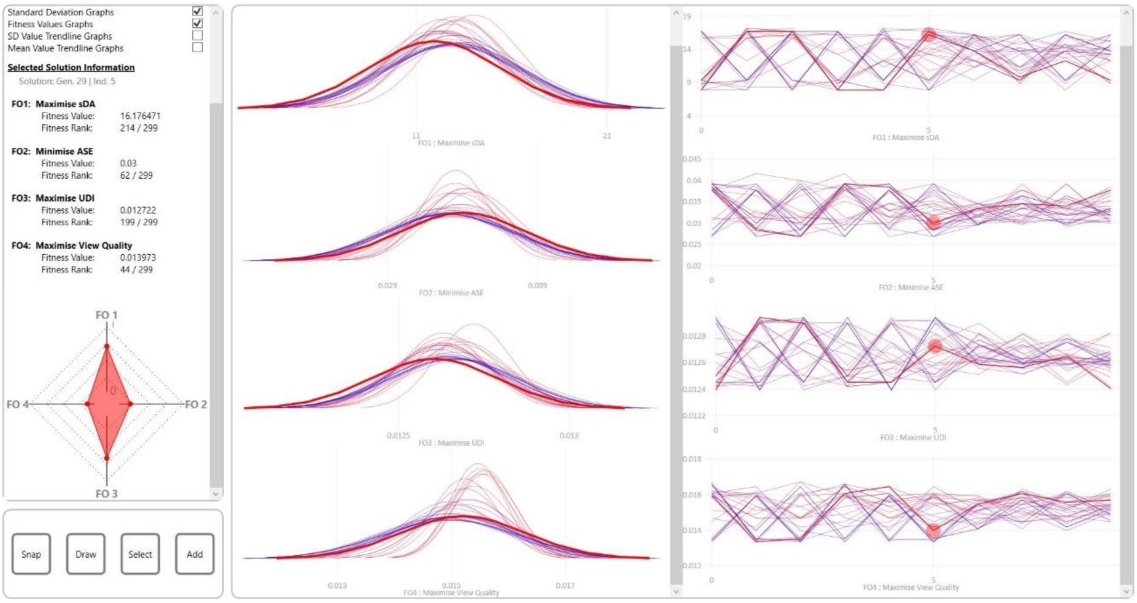
- *Gen.29, S 03*



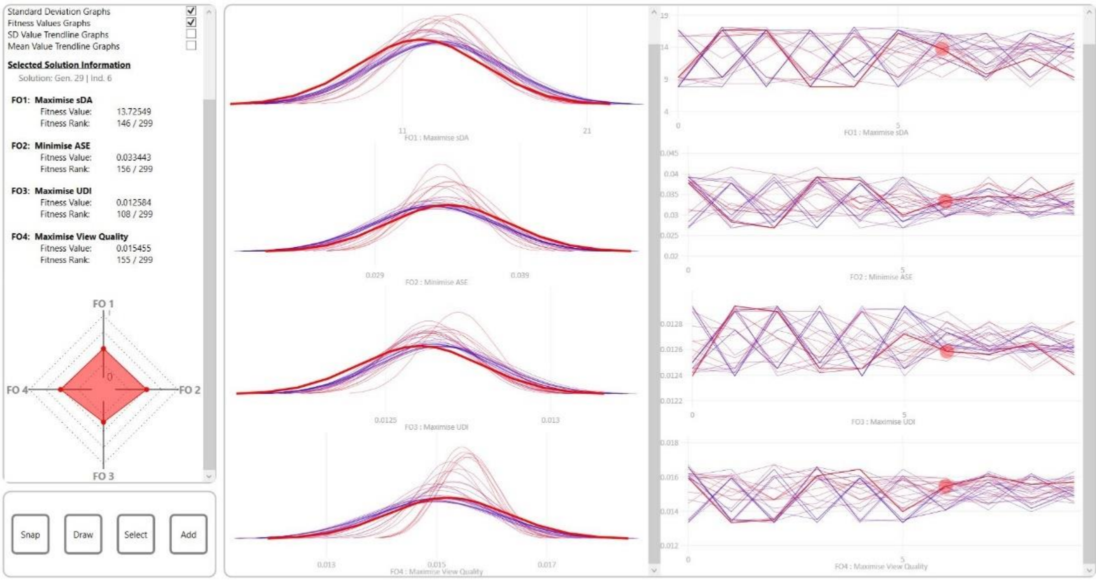
- *Gen.29, S 04*



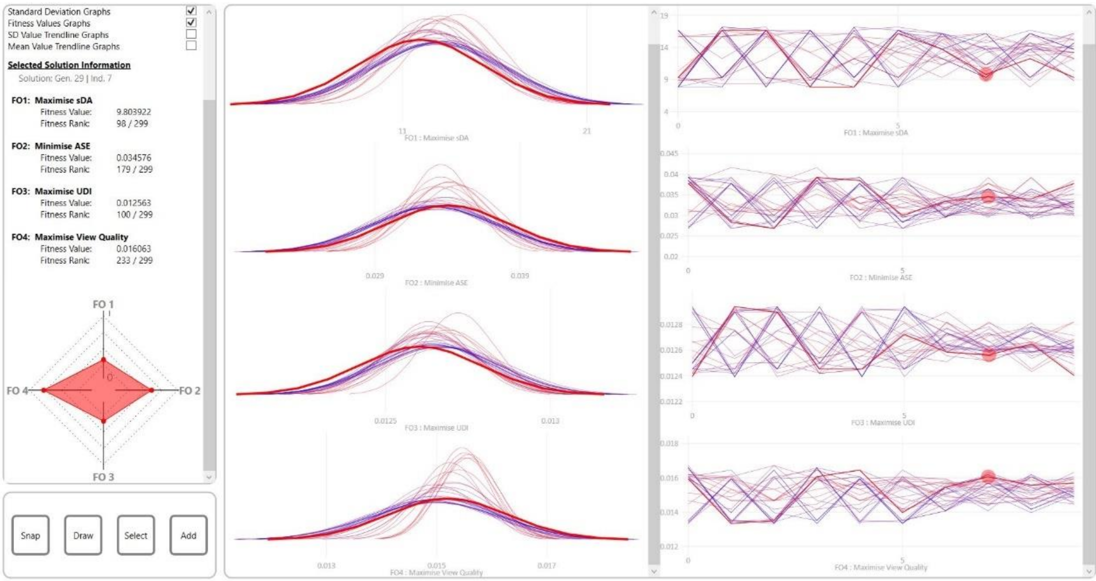
- *Gen.29, S 05*



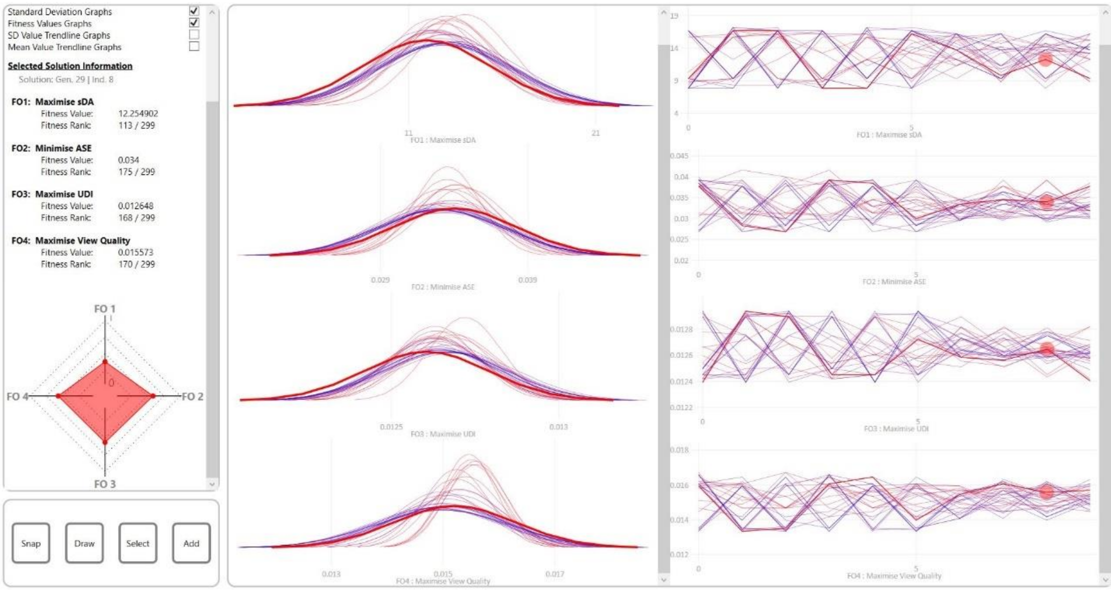
- *Gen.29, S 06*



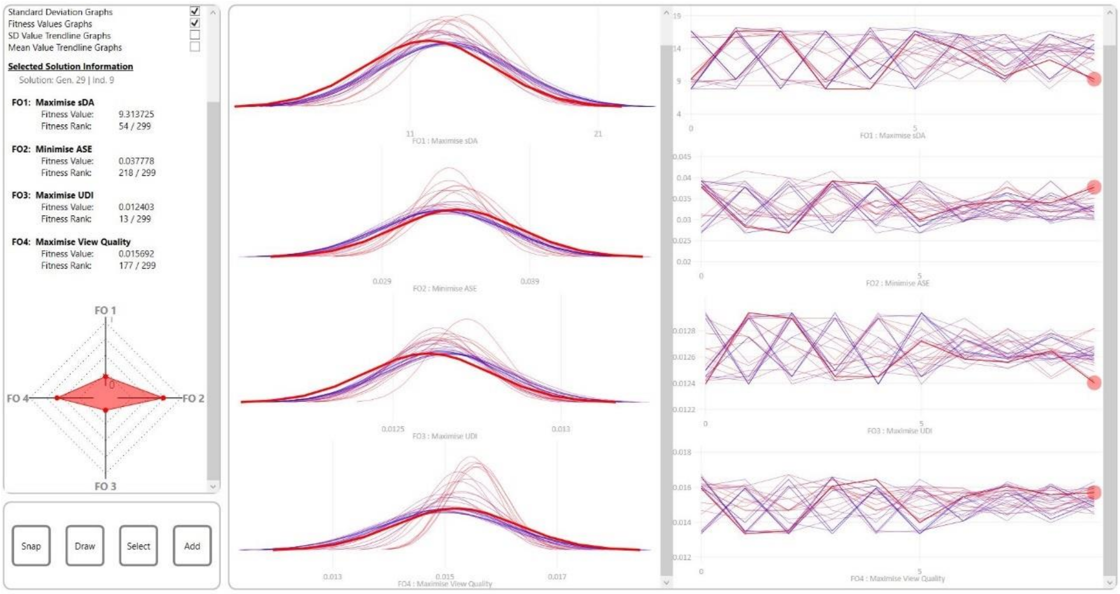
- *Gen.29, S 07*



- *Gen.29, S 08*



- *Gen.29, S 09*


Standard Deviation Graphs
Fitness Values Graphs
SD Value Trendline Graphs
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 29 | Ind. 9
FO1: Maximise sDA
Fitness Value: 9.313725
Fitness Rank: 54 / 299
FO2: Minimise ASE
Fitness Value: 0.037778
Fitness Rank: 218 / 299
FO3: Maximise UDI
Fitness Value: 0.012403
Fitness Rank: 13 / 299
FO4: Maximise View Quality
Fitness Value: 0.015692
Fitness Rank: 177 / 299
FO 1
FO 2
FO 3
FO 4
Snap
Draw
Select
Add

Appendix 03: List of Publications

	Chapter	Papers Name	Publisher	Cite	Status
CH1	Introduction				
CH2	Themes of well-being associated with daylight and shading systems	**Paper 1** Well-being in daylight studies: A literature review	Conference (publish and present): 36th PLEA International Conference that will take place in Chile. Rank (A1)	Abdelrahman, M., & Coates, P. (2022b).	Published
		Paper 2 Themes of well-being associated with daylight practice and shading systems in working environment	IPGRC 2022 (publish and present): Resilience in Research and Practice	Published Abdelrahman, M., & Coates, P. (2022a).	Published
CH3	Methodology				
CH4	Qualitative analysis for comfort and well-being in terms of daylight (Online Questionnaire) (Stage 3)	**Paper 3** Spatial cognitive map for assessing daylight impact on occupant comfort and well-being		Done	In review process
CH5	Quantitative assessment of visible outside view quality as a new metric to measure well-being potential. (Stage 1)	**Paper 4** Visible outside view quality as a new metric to measure well-being potential	Journal: *Journal of Building Engineering* (Rank Q1)	Abdelrahman, M., Coates, P., & Poppelreuter, T. (2023b).	Published
CH6	Quantitative assessment of daylight, outside view and shading systems (multifactor system) (Stage 2)	**Paper 5** A new multifactor system for designing healthy shading devices: A case study in Egypt, Cairo	Journal: *Build Environment* Q1	Done	In review process
CH7	Qualitative analysis of the multifactor system	**Paper 6** Subjective impressions inside deep-plan workspace: an experimental study in virtual reality		Not yet	