The Use of Useful Daylight Illuminance (UDI) to Test New Designs for Improving Daylight Performance of Office Buildings in Dubai-UAE

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Abstract

Daylighting has often been recognized as a useful source of energy savings and visual comforts. There has been increasing interest in using daylight to save energy in buildings. In the recent years, particular concerns have been raised about offices buildings developments and energy consumption issues in UAE. Many studies have shown that proper daylight space can improve occupant's productivity and it would reduce electric demand about 20%- 30% of the total building energy load. The dynamic nature of daylight poses many challenges when considering metrics that define good and effective daylighting design.

In this research study, the main daylight characteristics and building parameters affecting daylight design are analyzed and discussed through simulations of the main indicators used to quantify what makes good daylighting design in order to refine the most applicable indicator to be used in Dubai's offices.

To achieve this, the study will conduct a series of computer simulations using 3D Max Design to first show the effects of each parameter on the internal daylight efficiency and then provides a simplified metric method for measuring indoor daylight performance. Whereupon many strategies will be suggested leadings to effective solutions meet the daylight requirements of the space, which can contribute reducing the electrical demand, and helps achieve environmentally sustainable building development.

The main outcomes results of this study are:-

- Daylight illuminance falling on vertical surfaces, can be used to determin and evaluate the daylight performance of a building.
- A comparative study to daylight evaluation metrics gave the preference for Useful Daylight Illuminance (UDI) to be the most compatible metric with UAE climate conditions.
- Statistical daylight analysis indicated that north oriented office performs better than other directions.
- Some simple daylighting static systems such as overhangs and shading devices could be used to improve the daylighting efficiency in north and south oriented offices ,while solutions would be more complicated in east and west .
- The effects due to nearby obstructions buildings strongly affect the daylight performance specially in the lower floors.
- Building designers should take into consideration the external environment in order to achieve well preformed office designs.

The output of this study can be used as a pre-design tool to ensure that building spaces meet recommended daylight levels and protected from glare, reflections and direct sunlight. The results can be converted to suggested guidelines towards an effective management for offices regulation that could provide a strong outline for future offices design based not only on theoretical solutions, but also on practical simulations and evaluation tools.

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Chapter1 - Introduction

1.1 Sustainability and Energy consumption in buildings

Recent economic revolution in the Gulf region particularly in Dubai, United Arab Emirates (U.A.E) has led to a sharp increase in the number of new buildings and buildings under construction. This revolution has attracted many businesses to the region and increased job opportunities. Furthermore, several facilities provided by Dubai government have attracted global companies to Dubai. Accordingly, developers have given priority to the construction of commercial buildings in Dubai. That rapid progress for business in Dubai has increased Energy consumption dramatically in the region. Increased demand for electricity is a very critical factor particular for a region like UAE where the capacity to provide renewable energy recourses is very limited. Energy efficiency and strategies to reduce electrical demands that reduce the total power consumption are two important priorities in Dubai efforts to reduce customer bills for electricity.

Daylighting is an effective factor in interior design as it contributes to occupant visual and thermal comfort, occupants' productivity and energy use in buildings. Energy savings would result from increased day lighting efficiency due to reduced electric lighting consumption and due to reduced cooling loads with possibilities of utilizing smaller heating and air-conditioning (HVAC) equipment size.

In commercial buildings, electric lighting and cooling represent two of the largest electric end uses. Li and Lam (1999) and Li (2007) revealed in both studies that the effective daylight design solutions for electric lights and air-conditioning accounts for over 70% of the total electricity consumption in commercial buildings. Air-conditioning accounts for over 50% of the total electricity consumption in commercial buildings and electric lighting comes second with 20–30%.Moreover; heat gain due to electric lighting represents additional percentage of the total cooling load during the hot summer months. Further later investigations (Li Lam and Wong 2005) indicated that the daily energy savings in electric lighting for open plan offices ranged from 1.1 to 1.7 kWh using simple daylight controls. The estimated annual saving was 365 kWh, representing a 33% reduction in energy use for the total electric lighting bill. Such results clearly present the role of day lighting as a key objective for sustainable building design that reduces the building energy consumption and provides reliable long-term benefits, a useful indicator to developers to incorporate the necessary design considerations at project onset.

1.2 Daylight and Sunlight

Daylight – "refers to the level of diffuse natural light coming from the surrounding sky dome or reflected off adjacent surfaces." (www.squ1.com).

Sunlight, on the other hand, refers to direct sunshine and it is much brighter than ambient daylight. The position of the sun changes consistently as the day progresses. The way an individual views the sun from any particular point, ie, whether clearly or obscured is effected by presence or absence of clouds, buildings, topography, foliage, smog etc. The sun also has a varying intensity at different times of the day and also over the course of a year's seasonal changes (www.squ1.com). New Buildings Institute (2003) mentioned that daylight and sunlight illuminance can vary by different locations, times and months. Illuminance caused by sunlight can reach up to 10000lux while diffuse sun light produces illuminance value between 5000 to 20000lux. Moreover, the sun also provides effective radiation outside its visible spectrum. Sunlight has potentially much more heat content per lumen than daylight. Because of all these inconsistencies in daylight and in sunlight, the sun is not the most reliable source for optimum lighting of internal function spaces as these work best within specific ranges of light intensity. e.g to obtain an optimum of 200-2000 lux at worktop level within a typical office space. Furthermore, the sun's intensity is such that it can be a significant source of undesirable glare when falling on a work surface or reflected off a computer screen. As a result, direct sunlight is rarely included in architectural daylighting calculations.

Daylight, however, can be a very effective light source, even on the most dark and overcast day, diffuse daylight is about 5 times more efficient than a normal incandescent globe and as much as twice as efficient as a fluorescent tube. In a typical office building, turning the lights off and substituting daylight alone can reduce overall heat loads by as much as 40% (www.squ1.com).

Daylight levels also vary greatly depending on various factors such as , the amount of cloud cover, type of cloud and the time of day. However, there exist mathematical models that allow the calculation of how bright different parts of the sky will be under different sky conditions. These models allow us to choose a set of worst-case situations around which to design the building.

1.3 Daylight Benefits

Psychologically, the presence of controlled daylight, as has been illustrated in several studies, significantly improves the overall attitude and well-being of the occupants.

"Seasonal Affective Disorder" (SAD) and headaches are related to insufficient light levels. Research carried out by Edwards and Torcellini (2002) and Boyce et al (2003) pointed that use of daylighting decreases the occurrence of headaches, S.A.D, and eyestrain. These ailments occur less as the daylighting level improves by use of proper spectral light. They further demonstrated that daylighting also has a positive effect on the mood for employees which results in increased job satisfaction, work involvement, motivation, organizational attachment, and lowered absenteeism.

Other studies show that office workers' productivity does increase with the quality of natural light. Natural daylighting aids in increasing attention and alertness during the post-lunch dip and has shown to be helpful in increasing alertness for boring or monotonous work (Heerwagen et al 2000). Li and Lam (2001) studied the effects of windowless offices in Hong Kong. Investigation results supported earlier findings (Heerwagen et al 2000) that employees in windowless buildings had much less job satisfaction and were substantially less positive. It was demonstrated by the California Energy Commission (2003) that greater illumination level or glare potential affects office worker performance by decreasing performance by up to 15% - 21%. They further demonstrated that a workers primary view had a positive relationship to performance only if there was no glare potential from that view.

From an energy efficiency standpoint, Li et al (2005) investigation's indicated the potential role that daylight plays in reducing electric demands with up to 33% reduction in energy use for the total electric lighting bill achieved simply by use sun shading protections. The Collaborative for High Performance Schools (CHPS) (2006) pointed out that day lighting can offer great energy savings due to reduced electric lighting loads and in turn, reduced cooling loads. Electric lighting can represent 40 to 50 percent of a building's total energy consumption according to the U.S Green Building Council (USGBC). Turning off unnecessary artificial lights makes a big difference in a company's utility bill and bottom-line. The savings are further compounded because when unnecessary electric lights are on, they generate waste heat that has to be removed by a building's air conditioning system. This saves an additional three to five percent in total energy consumption. Properly designed daylighting can see a reduction in energy consumption for lighting by up to 50 to 80 percent, according to the USCGB.

1.4 Successful Daylight Design

1.4.1 Successful Daylight characteristics and parameters

The CHPS Daylighting Committee (2006) presented the general daylighting performance goals for day lit spaces. Outlined below are characteristics they identified which represent successful day lighting design:

- **Quantity ,** daylight should provide ambient lighting requirements for the most of the year.
- **Quality ,** it has been believed that uniform distribution of daylight helps in reducing uncomfortable high brightness ratios and aid in controlling direct sunlight which causes glare .
- **Usability,** daylight has to allow the user's adjustment and override and provide view and connection to the outdoors.
- **Building Integration,** successful daylighting design must be fully integrated with the architectural expression of the building inside out and other building systems such as HVAC, Electrical, Lighting, Structural, Interior elements.
- **Cost Effective**, in order to convince investors on the benefits of having a daylight efficient building, a daylight system must be implemented within the overall construction budget of the project and it should demonstrate achieving significant energy savings by reducing lighting costs and electricity bill .

In order to achieve the mentioned daylight design characteristics, Li and Tsang (2007) investigated the factors that a designer should consider when designing an efficient daylight building. Li and Tsang (2007) surveyed 35 offices building in Hong Kong to determine the main building parameters affecting the mentioned Daylight characteristics designs. The study indicated five key parameters affecting daylight design:

- **Lease Span:** The lease span is the distance from a fixed interior element, such as the building core, to an exterior window wall. There is a need to concentrate on the lease span in tall office buildings design as the quantity and quality of daylight can be determined by the lease span distance.
- **Glass Type:** Glass type controls the amount of daylight penetrating into an interior in terms of light transmittance and heat transmutation as well. Clear glass provides a high transmission of daylight with typical visible transmittance (VT) of 0.88 but it also allows a large amount of solar heat (high shading coefficient) to pass through into a building. Tinted glass absorbs a considerable amount of infrared light with some reduction of visible light with the VT ranging from 0.23 to 0.51. Reflective glass absorbs more heat than tinted glass and offers good reflecting characteristic in the infrared region with a certain reduction of VT. The VT can be a low of 0.12 with perfect heat protection but the rooms may look gloomy especially with low illumination levels .With an average VT values, occupants can enjoy more natural light as well as maintain a good visual contact with the outdoor
- **Window Area :** For a given glazing type, the critical factor determining the daylight entering a building is the window area. According to Li and Tsang (2007) study, the required window area should be more than one-tenth of the floor area of the room in order to get enough daylight illumination. Higher window heads and wider spaces allow deeper plan room designs.

- **Shading:** Shading devices shade the window from direct sun penetration but may allow diffuse daylight to be admitted that aid in have better distribution of light and prevent the internal spaces from the heat caused by the direct sun radiation
- **External Obstruction:** External obstruction influences the daylighting performance in two aspects. First, is the amount of the sky being obstructed or unobstructed by an adjacent building. Second, the color of the external surface finish that can be considered as the reflected luminance from neighboring buildings.

1.4.2 Direct Sunlight Tolerance

In offices, controlling direct sunlight is critical, it is important to consider direct sunlight control strategies early in the design process to avoid having to resort to more expensive solar control strategies, and less integrated with the rest of the design. Offices could be oriented to the north, where incident sunlight is minimal. Space layout is important, since the location of interior walls can affect the direct sunlight and would dictate the cutoff angles required. The Collaborative for High Performance Schools (CHPS) (2006) pointed out the importance of controlling solar gain by controlling the direct sunbeams penetrating any space. Several strategies were suggested to achieve that purpose by using different shading techniques such as recessed floors and the strategic location of stairwells or less critical component to act as sun shading elements.

1.4.3 Integrated urban fabric and Daylight Design

When considering introducing daylight into a building, surrounding buildings and urban features should be considered in simulations and solution strategies. Depending on specific site conditions, neighboring buildings might obstruct daylight in some cases while in other cases they could provide daylight through reflections.

1.4.4 Solar Control

The daylight in a harsh climate such as found in the UAE, is characterized by high levels of solar radiation and intense sunlight throughout the year. In order for a daylighting design to be effective in improving the energy efficiency of a building, it is critical to consider solar heat gain control of spaces.

1.4.5 Recommended daylight levels in offices

Within a typical office space, different task areas require different lighting levels. It has been recommended by the Illuminating Engineering Society of North America (IESNA) (2003) to use a range between 200 lux to 1500 as the optimum indoor lux ratings for regular office work in accounting, auditing, business, detailed designing & drafting. IESNA suggested that 100 lux in corridors and stairways is sufficient for office occupants. There is no sharp line to describe the quantity of daylight. Interior space's "darkness" or "brightness" varies across different researchers and investigators, as the individual's human eye factor is the only certified scale for daylight levels.

Nabil and Mardaljevic (2006) suggested the term "useful daylight" for the level of illumination between 200 lux and 2000 lux , with illumination <200 accepted as too dark and illumination of <2000 lux considered too bright. However daylight illuminance between 200-1000 lux was suggested by many other investigators to be the convenient daylight level (Selkowitz and Lee, 1998, Li, 2007 and Ko et al, 2008).

1.4.6 What is a high-performance office?

From the preceding discussion about daylight characteristics, parameters and recommended daylight levels; high performance office can be defined as one that :-

• Meets design objectives.

• Maximizes occupant comfort and productivity.

• Minimizes occupant complaints and tenant turnover.

• Maximizes building value to the owner.

• Yields a lifetime of energy efficiency and lower operating costs.

1.5 Daylighting and Dubai offices

The United Arab Emirates lies between latitudes 22°–26.5°N and longitudes 51°–56.5°E It is described as the earth's sun belt. The yearly solar radiation for the UAE is believed to be around 2,200 kilowatt hours per square meter, and the direct illumination falling to the earth exceeds 90000 lux in summer, the second highest in the world (Al-Sallal and Ahmed, 2007). Being on the tropic of cancer (24 deg N) results in that the UAE region receiving the highest annual rate of solar radiation and sun illumination. In such a harsh climate of the UAE, which is characterized by high levels of solar radiation and intense sunlight, the design should minimizes direct sunlight by means of shading and provides diffuse daylight reflected from the ceiling.

Bhavani and Khan (2006) pointed that most buildings in the UAE are not designed to achieve proper daylight level. In office buildings, many offices have deep spaces that are lit from one side only. Many other offices have a fully glazed facade facing east and west which creates serious problems of high brightness contrast and acute glare that result reducing visual comfort and in some cases causing health problems such as headache and fatigue. Aboulnaga (2006) investigated the use and misuse of glass as a building element in offices. He pointed out the extensive use of large area of glazing in Dubai's offices facades without the provision of any protection against overheating and sun glare in summer. He also introduced simulations for 15 existing buildings in Dubai to evaluate the current problem of misused glass. His conclusions reinforced that Daylighting is a real problem in the UAE and that no active solution have been identified. There are currently only suggestions on what architects could do in the design process to achieve good daylight distribution. Al-Sallal (et al. 2006), Al-Sallal (2007), Al-sallal and Ahmed (2007) did recommended techniques that can help to redistribute and filter daylight coming from windows and skylights in order to overcome high brightness and glare problems in educational spaces in the UAE.

In general Dubai designers suffer lack of necessary methods and user friendly tools for environmental evaluation at an early stage of a design. Therefore, there are few published works that are directly linked to the specific topic of this research.

1.6 Motivation of the study

1.6.1 Justification

Architects involved in office design should consider many factors when designing office buildings. It varies from urban surroundings or site characteristics, orientation and architectural design of the building, choice of building materials, shading technique, etc. These factors were not given enough importance in Dubai because of:-

- A lack of up-to-date knowledge among architects, planners and engineers on often misunderstood concepts such as day lighting, thermal capacity and thermal insulation
- Considering daylight in design poses many challenges and difficulties because of the dynamic nature of the sun.
- The lifestyle and the inflation of Dubai Real Estate market has driven people to turn to the easiest and fastest solutions .
- The lack of user-friendly, accessible appropriate simulations soft wares.
- The illusion that it is more expensive to build in a sustainable manner.

In the few past years; as the consequences of “sick buildings” were being felt together with the repercussions of global warming, people have became more sensitive about health and well being. New knowledge started permeating among people to find new energy recourses and to use new strategies to reduce total energy consumption. Daylighting is considered as an important and useful strategy in energy-efficient building designs and operations. A proper daylighting planning can help reduce electrical demand and contribute to achieving environmentally sustainable building development.

1.6.2 Aims and Objectives

The main aims and objectives of this study are summarized as follows:

Investigate what makes a good daylight design and discuss broader daylight characteristics and parameters.

- Investigate Daylight Performance metrics to refine the most consistent meter to be used in Dubai.

- Establish criteria for what should be considered good, adequate, or insufficient daylighting performance.
- Demonstrate how UDI metric can be constructed and used as a fast evaluating metric for different design solutions.
- Define strategies to be applied to increase the day lighting efficiency.
- Propose a pre-design metric to ensure that building meets the recommended daylight level and at the same time protected from glare, reflections and direct sunlight.
- Provide guidelines and recommendations to what designers should include and focus on to design an effective office space.

1.6.3 Questions to be answered through this research

- Which daylighting performance metric that have been proposed in the past can be reliable and Commensurate with UAE climate conditions.
- Which tools to use and what design elements to study according to the variants investigations?
- What are the systems and effective strategies that can be used to enhance daylighting in offices?

Chapter2 - Literature Review

2.1 Introduction to evaluation metric

Evaluation performance metrics are supposed to be “quality measures” for offices with respect to their energy efficiency, safety, quality of design, and so on. It has been used by building designers in the past for comparative studies to provide a guideline to analyze how effective different proposed architectural solutions are.

Performance metrics provides a shortened summarized tool to read the data measurements and get the conclusion in order to find the best solution to be applied for the select strategies. They range from being rather specific, for example, how well one office is oriented, to very general, for example, how efficient a building is.

It has been very difficult however for designers in the past to post clear daylight performance metric.

Reinhart et al (2006) pointed that there were two main reasons creating this difficulty. The first reason is linked to the lack of unity on daylight definition among the different fields of engineering. Architectural engineers defined it as the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment .Lighting Energy Savings Engineers describe it as the replacement of indoor electric illumination needs by natural daylight. Building Energy Consumption pointed it as the use of fenestration systems and responsive artificial lighting, while costing consultants describe it as the use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity. Differences in absorption for daylight scope became a forestation for designers that which definition should be considered when they establish a performance metric.

The second reason from the writer standpoint is the failure of green building rating systems (like LEED and ASHRAE) in guiding design team in implementing efficient day lighting evaluation metric. Besides the basic guidance noted by the United State Green Building Council (USGBC) , no further detailed regulation has been provided and no metrics exist to quantify the effectiveness of such solar control devices .The USGBC does mention glare and thermal control as the common failures for daylighting strategies. They recommend the use of shading devices as a solution for these problems.

We note however that, there is no detail on how the designer can carry out an effective self assessment on various proposed architectural solutions on avoiding glare and direct sunlight. Due to the lack of an efficient evaluation method, several key design parameters are neglected, which puts some day lighting techniques at a subjective disadvantage compared to others. This study tries partially to present such evaluation tool.

2.2 Static Daylight metrics (Daylight Factor)

The use of Static daylight simulation came to reduce the number of simulations needed, that was because this type of simulation neglect season, time of day, direct solar ingress, variable sky conditions, building orientation, or building location.

There presently are several static quantitative performance metrics in use for the implementation of day lighting in office design. Each of these metrics vary according to their definition of daylight and according to the requirements of every area. This study will discuss the most common quantitative metric (Daylight Factor).

Daylight Factor

Daylight factor (DF) is the most common parameter to characterize the daylight situation at a point in a building. The Institute for Research in Construction (2006) defined it as the ratio of the indoor illuminance at a point of interest to the outdoor horizontal illuminance under a standard uniform sky developed by the overcast Commission International de l'Eclairage (CIE). Marsh,(www.squ1.com) defined it as the ratio of the illumination at particular point within an enclosure to the simultaneous un obstructed outdoor illuminance under overcast CIE sky condition expressed in percentage.

Daylight factor enjoys considerable popularity since it is a quantity which can be measured and/or calculated either based on calculation tables or more refined simulation methods.

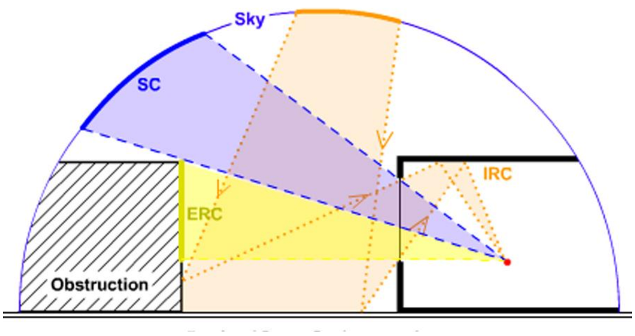


Figure 2.1 Different components of the split flux method(www.squ1.com)

The calculation of daylight factor depend on split flux method which based on the assumption that, ignoring direct sunlight, as been shown in Figure(2.1) the natural light reaches a point inside a building in three ways:

- Sky Component (SC).
  Directly from the sky, through an opening such as a window.
- Externally Reflected Component (ERC)
  light reflected off the ground, trees or other buildings.
- Internally Reflected Component (IRC)
  The inter-reflection of (SC) and (ERC) off other surfaces within the room.

The resulting Daylight Factor is given as a percentage and is simply the sum of each of these three components:

$$DF = SC + ERC + IRC \qquad (1)$$

The main weakness of daylight factor is that the orientation of the investigated building does not influence the daylight factor since the CIE reference sky is rotationally constant and independent of the geographical latitude of the investigated building. Another shortcoming of the daylight factor approach is that the underlying CIE overcast sky tends to underestimate luminance near the horizon. (Reihart, 2006)

Consequently, illuminances in sidelit/toplit spaces are usually under/over predicted. However, daylight factor is commonly used and provides a feeling of how “bright“ or “dark“ the interior of a given building only is. Since it is based on a single sky condition, its credibility to judge the overall daylight situation in a given building in a given location and orientation is intrinsically limited. The main barrier that hindered researchers on investigating alternate metric is that daylight factor is the same for all facade orientations and building locations. This is because daylight factor does not consider season, time of day, direct solar penetration, variable sky conditions, building orientation, or building location.

The reduced variables allow researchers to diminish the number of simulations needed to compare the efficiency of two different designs.

Morris (2002) confirmed that in his investigation to propose an optimum classroom design. He accepted Daylight factor as an evaluating metric justifying that as lighting conditions are changing continually , "absolute sky illumination levels are difficult and often impossible to calculate and determine a clear sky condition as the number of simulations will be in need are too large to be carried by slow simulation engines" (Morris 2002).

Li and Tsang (2007) investigated the main building parameters affecting daylight factor in offices in Hong Kong by conducting a series of Ecotect simulation tests for 35 selected office towers. It would have been very complex and unmanageable for them to carry out different simulations for different skies in different times of the year for 35 buildings.

According to the BBC forecast the average of cloud coverage over the year in Hong Kong exceed 70%, that is Hong Kong has an overcast sky most of the year. This was a proper justification for Morris (2002) and Li (2007) to use daylight factor metric with an overcast sky as the priority of orientation comes last. For analysis of building in regions with predominantly overcast sky it may not be worthwhile to run thousands of simulations to determine orientation and other design factors into consideration. This study is based in Dubai, U.A.E. According to the BBC forecast the average of cloud coverage over the year in Dubai does not exceed 9%. A daylight factor simulation analysis for a building in Dubai cannot be based on an overcast sky condition as this would give grossly inaccurate data. This study tries partially to present a more accurate efficient tool that takes into account the realistic sky.

Aboulnaga (2005) conducted a quantitative analysis in Dubai's towers to assess the impact of glass on the building users' performance in terms of daylight environment. His investigation was to assess whether selected glass provides the recommended daylight factor (DF) and daylight level (DL). He ran many simulations using Ecotect to evaluate the misuse of glass at different offices in Dubai. His results came to reinforce the existence of very high level of (DF) and (DL) in some of Dubai offices. He used the CIE overcast sky for his simulations, the only sky available in Ecotect, his program of choice. As noted above, because the overcast sky model neglects the unique characteristics of a locations atmosphere and building orientation, his findings were inaccurate.

Figure (2.2) shows one of the simulations conducted by Aboulnaga for Burjuman office tower. It is obvious how sky condition has been neglected by Ecotect as the result came similar and uniform from all directions which is not the true situation in reality.

The simulated (DF) and (DL) results for the Burjuman office tower results could be extreme if it has been simulated in a clear sky condition that represents the most frequent sky in UAE.

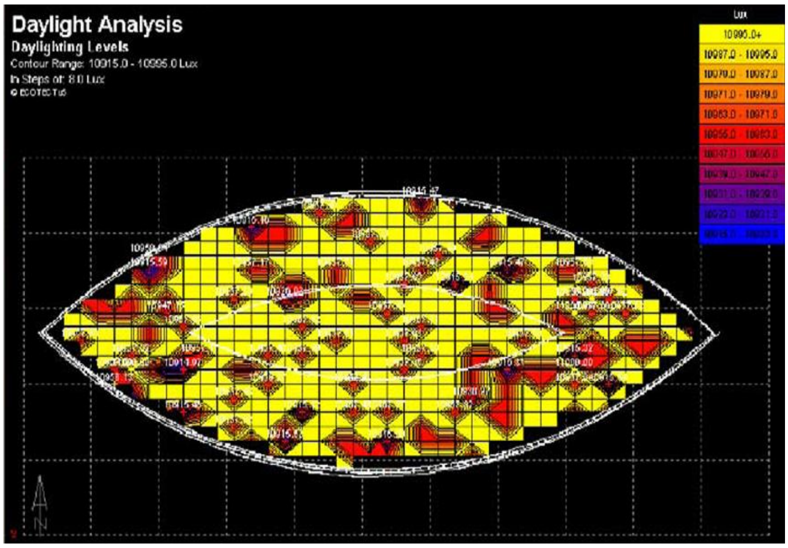


Figure 2.2 DF analysis for Burjuman Offices Tower using Ecotect CIE overcast sky (Aboulnaga 2005).

This approach of “assuming” overcast sky and basing design decisions on data received from such simulations leads to several consequences:-

- Daylight factor investigations do not help in developing glare prevention strategies for different facade orientations, even though problems of glare associated with low solar altitudes are known to be most important for east and west facing facades.
- Daylight factor analysis does not assist in raising a warning flag indicating potential glare problem in certain parts of a building.

Nonetheless, daylight factor remains the most widely used performance measure for daylighting and for the majority of practitioners, "the consideration of any quantitative measure of daylight begins and ends with daylight factor" (Nabil and Mardaljevic, 2005).

2.3 Dynamic Daylight metrics

This section describes dynamic daylight performance metrics as an alternative to the daylight factor-based approaches described in the previous section.

For many years, investigators realized the importance of using dynamic metrics because of its accuracy and correspondence to reality; however, requirements of the dynamic system have made it very difficult or nearly impossible for them to consider it, as it requires the use of three-dimensional CAD software. In addition, to evaluate a single space would require a daylight simulation model to run hundreds of simulations to capture all possible day lighting situations for a building throughout the course of one year.

Nowadays it became more practical to use a dynamic system for the following reasons:

- Access to softwares became affordable in prices for small to medium sized Architectural and Engineering firms.
- Widespread computer, information technology and multimedia among current generation of architects have allowed quicker use of any dynamic metric.
- The boom in computer technology, graphic abilities and multi core processer has caused a dramatic reduction in simulations and rendering time.
- Many developments and upgrading seen in recent softwares has fired competition amongst software development companies leading to availability of more realistic simulation engines.

The key advantage of dynamic daylight performance metrics compared to static metrics is that they consider the quantity and character of daily and seasonal variations of daylight for a given building site together with irregular meteorological events. Dynamic daylight performance metrics are based on time series of illumination within a building. These time series usually extend over the whole calendar year and are based on external, annual solar radiation data for the building site such as the

Energy Plus weather files for over 2000 locations worldwide where can be downloaded from:

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm.

CHPS Daylighting Committee (2006) gave some recommendations for variables that need to be addressed to standardize the calculation of any dynamic metric as:

Time Frame: because of the broad range in daylight level during the coarse of a year, It is important to determine which times of the year to be considered for calculations by considering:

- Counting nighttime hours does not make sense and would drop the overall trend towards lower values.
- Including times of the day where the sun is located in a very low angle at sunrise and sun set will also play a role in reducing the average results.
- It is important to optimize the daylighting design in offices to the occupied day hours, for example, it is make no sense to take 7:00 am into calculations while the offices timing hours is 8:00 am.

Testing Points Consideration: Determining a specific point in a daylit space for use in calculating can be tricky. Where having the testing points to be in the middle not in very deep corners. New technologies have replaced the testing points into formal analysis grid that can offer more accurate calculations.

Target Illuminance: Another variable to define is the illuminance thresholds to use for Daylights Calculations. There was diversity between different committees and investigators about which rang of daylight illuminance should be considered in calculations. As been clarified before, there was a unity in most of the reviews about considering 200 lux to be the lower limit for calculation. However there is still some frustration about the higher limit. While some take it as 1000 lux (Nabil and Mardaljevic, 2006) and others consider 2000 lux (Selkowitz and Lee 1998, Li 2007 Ko et al 2008).This research will try to argue the optimal upper limit of daylight illuminance.

Location and Climate: A more accurate approach would be to use the most representative climate data available for a given projects site. There are 58 typical climate data stations providing hour-by-hour climate data all around the UAE according to the official statistic by the metrological authority in UAE (2006).

2.3.1 Daylight Autonomy

The definition of daylight autonomy being "the percentage of the year when a minimum illuminance threshold is met by daylight alone "goes at least as far back as 1989 when it was mentioned in a Swiss norm Association Suisse des Electriciens, (1989). After that it disappeared until the new millennium when (Reinhart and a Walkenhorst, 2001) proposed this metric to replace daylight factor (DF) because as he stipulated, DF had many limitations for the prevention of direct sunlight parallel with daylight factor predictions. "Actual climate in which the building is placed is not considered. A building in Vancouver, Canada, (latitude 49° N), a climate renowned for its rainy winters, is treated the same as a building in Regina, Canada, (latitude 50° N), a climate characterized through clear winter days with a snow covered ground for several months of the year." Reinhart and Walkenhorst (2001).

The daylight autonomy at a point in a building was defined later with some modifications as the percentage of occupied hours per year, when the minimum illuminance level can be maintained by daylight alone, or it is the percentage of time over a year at which daylight can provide a given illuminance for a given point. "if a space requires a minimum of 200 lux on the work plane, any hour that does not provide at least 200 lux of daylight illuminance counts as 0% daylight and any hour that exceeds 200 lux of daylight illuminance counts as 100% daylight" Reinhart and Walkenhorst (2001). Essentially, this method only gives credit to daylight when it exceeds the required illuminance and does not give any credit for partially daylight points.

In contrast to the more widely used daylight factor, daylight autonomy considers all sky conditions throughout the year. Daylight Autonomy (DA) can work very efficiently to detect low day lit spaces, but the main limitations to that metric is the absence of having any upper limit to alert of overexposing areas or glare problems as it give a value of 100% for any point that exceed 200 lux. Another important limitation is that DA cannot be utilized to identify the specific problem area in the design. DA gives the efficiency as a final percentage, an example, office X achieves a daylight autonomy of 60%, meaning the office achieve 200 lux for 60% of the whole year. It however neglects the areas where the shortage, 40% arises from and also any over exposed areas.

2.3.2 Continuous Daylight Autonomy

Continuous Daylight Autonomy (DA con) recently proposed by Rogers (2005). Another set of metrics represents dynamic sky conditions measurements. Continuous Daylight Autonomy use the same technique of Daylight Autonomy but this metric gives partial credit to time steps when the daylight illuminance lies below the minimum illuminance level

(200lux). "In the case where 500 lux are required and 400 lux are provided by daylight at a given time step, a partial credit of 400lux/500lux=0.8 is given for that time step. The result is that instead of a hard threshold the transition between compliance and non-compliance becomes softened" Rogers (2005). A partial involvement of low daylight illuminance at a space is still beneficial as study was indicating that illumination preferences vary between individuals and that many office occupants tend to work at lower daylight levels than the commonly referred level. However, lack of upper threshold criteria in Continuous Daylight Autonomy is the main limitation where there is no indication for occurrence of direct sunlight or other potentially glary conditions.

2.3.3 Useful Daylight Illuminances

Useful Daylight Illuminances (UDI) was proposed by Nabil and Mardaljevic (2006). It is a dynamic daylight performance metric based also on work plane Illuminances. UDI aims to determine when daylight levels are 'useful' for the occupant, The UDI scheme applied by determining the occurrence of daylight illuminances that:

1. Are within the range defined as useful (i.e. 200–2000 lx).

2. Fall short of the useful range (i.e. less than 200 lx).

3. Exceed the useful range (i.e. greater than 2000 lx).

The suggested range was founded on reported occupant preferences in daylight offices. The system proposes that if the daylight illuminance is too small (i.e. below minimum), it may not contribute in any useful manner to either the perception of the visual environment or in the carrying out of visual tasks. Conversely, if the daylight illuminance is too great (i.e. above a maximum), it may generate visual or thermal discomfort, or both. Illuminances that fall within the bounds of minimum and maximum were called useful daylight illuminances. However bins given by Nabil and Mardaljevic (2006) for Low, Useful and High daylight illuminance might vary across various investigators in different regions depending on their interpretation of the vision term (Useful). Ko et al (2008) pointed that the range between 200-1000 lux is the most desired daylight illuminance in most internal space. Li (2007) also considered 1000 lux as the upper illuminance level. From his standpoint, 2000 lux still considered accepted value for human eye but this value would lead for more heat gain, which is not acceptable for Hong Kong subtropical climate.

The UDI scheme is both informative and simple. It is more complex than the daylight autonomy method, but it gives a much better approach into the sequential dynamics of daylight illumination. In particular, it gives an indication of the predilection for high levels of illumination that are linked with discomfort glare and heat gains. "UDI is based primarily on human factor considerations, high values of achieved UDI might well be associated with low energy usage for electric lighting, and possibly also for cooling but high values of daylight Autonomy does not indicate thermal and visual problems " Nabil and Mardaljevic (2006). In addition, UDI metrics provides a more informative and comprehensive assessment of daylight conditions than that which can be gained from daylight autonomy.

2.4 Summary of Daylighting Metrics

The daylight factor is widely used and it provides a feeling of how “bright“or “dark“ the interior is. Daylight factor approach is therefore inapplicable for realistic, daylight conditions. Daylight factor is equal in all four facades, since it is based on a single sky condition. Its credibility to judge the overall daylight situation in a given building is as such limited.

On the other hand Dynamic metrics offer a far more realistic account of true daylighting conditions than the highly idealized daylight factor approach The three dynamic metrics all have their merits and shortcomings.

Daylight autonomy only relies on task-specific minimum illuminance levels that have the advantage of already being well established for different space types, but it's been blemished for excluding the high values of illumnance which make it insufficient to determine the heating and glare problems.

Continuous daylight autonomy retains the concept of space–specific design illuminances but introduces partial credit for daylight contributions that lie below the design illuminance. This softens the transition between compliance and noncompliance but also that metric was failed to give any warning flag for the high threshold of daylighting, which could lead to visual and thermal problems.

Useful Daylight Illuminances (UDI) require upper and lower thresholds that first have to be established for different building zones, requiring further research. UDI is more complex metric and gives more information about the space situation. It provides an effective mechanism to flag the zone in a building in which a shading device is needed, which makes it attractive for initial design investigations that concentrates on the daylighting/shading performance of the fixed building form.

From previous investigation for different static and dynamic metrics characteristics, UDI would be the best metric to comply with UAE’s climate as it considers the different types of skies and its high flexibility to capture the weak and the over exposed areas.

Chapter3 – Methodology

3.1 Different methods used in the past for daylight design

For many years, daylighting design was relied on client expectations and architect experience. Simple methods were introduced in early developments for daylighting testing methods were mainly involved with quantity of daylight as an engineering solution. The continued reliance on daylighting and high expenses of energy led investigators to introduce mathematical methods as an attempt to increase daylighting performance. Today, modern performance methods are just as varied as different technologies that take place in daylight design. Methods of testing daylight varied from the past include many types of mathematical formulas, model types and simulation softwares.

Manual Tools

Manual mathematical methods are some of the earliest methods for daylight testing. The use of manual tools enables designers to obtain rough calculations for the amount of daylight penetrating a space. Edwards (2002) investigated different manual methods been used for daylight design. He pointed out the Waldram diagram as a diagram prepared for evaluation of the extent of the sky seen through the window. It comprised of a grid of a linear horizontal axis and non-linear vertical axis to take account of the inconsistent nature of illumination and non-uniform luminance of the sky vault. Surrounding buildings for the selected testing point are represented on this diagram as vertical and horizontal lines giving a rough idea about sun availability in horizon Figure (3.1).

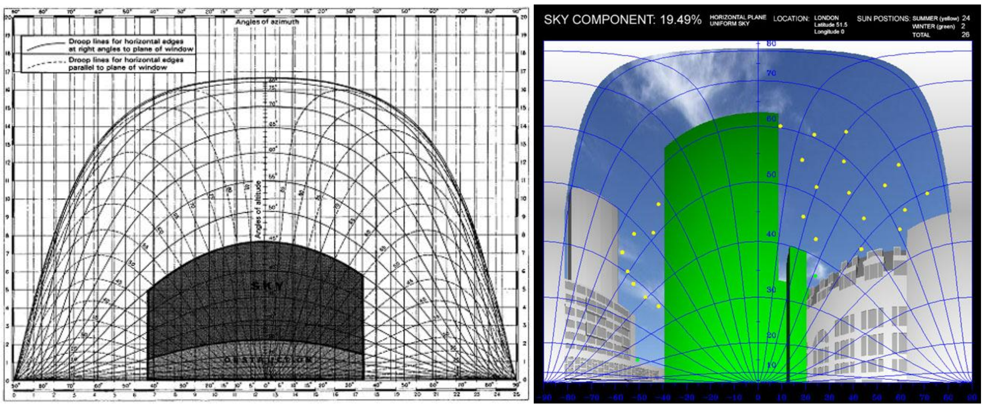


Figure 3.1 The Waldram diagram as manual daylight testing method (www.waterslade.com)

Edwards (2002) also studied another method called Building Research Station (BRS). A daylight protractor was the tool utilized for this method of daylight testing and it gave direct reading of the sky component in percentages Figure(3.2). This method measured the sky component and made calculations on the externally reflected components from the obstructed buildings area. However, this method is very difficult for internal use where high degree of accuracy is required in calculations.

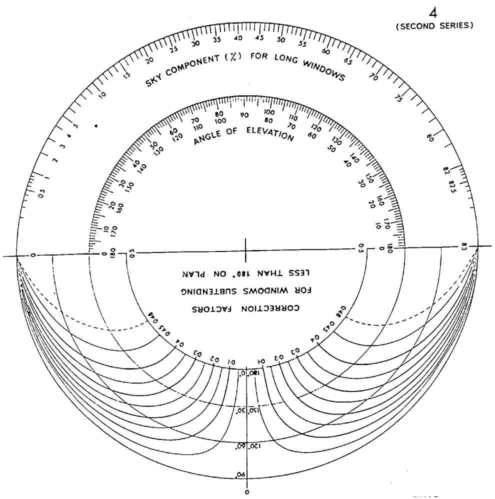


Figure 3.2 BRS Sky Component Protractor for Horizontal Glazing (personal.cityu.edu.hk)

Mathematical Tools

These methods used mathematical formulas to test daylight availability in the space. Ernest Orlando Lawrence Berkeley National Laboratory (1998) pointed (Feasibility Factor)(FF) as a formula that aims to determine roughly the amount of daylight that can be achieved in various areas of a selected space. FF is measured by using the following formula:

$$WWR \times VT \times OF = FF \quad (2).$$

- Window to Wall Ratio (WWR) is the Net glazing area (window area minus mullions and framing, or ~80% of rough opening) divided by gross exterior wall area.
- Visible Transmittance (VT) is the percentage of light amount that can pass through the glass panel to the interior of a room , this number varies from .4 for a double glaze tinted glass to 1 for clear glass.
- Obstruction factor (OF) is the percentage of obstructed view from the window center. The value of OF vary from .4 for heavily obstructed window to 1 for unobstructed window.

If Feasibility Factor (FF) more than >0.25, then daylighting has significant energy saving. If Feasibility Factor less than <0.25, then the designer should remove obstructions, increasing window area, or increase VT in order to reduce the factor amount above 0.25. This formula can help designers to have a very quick idea about how bright is the place, but again it misses out on accuracy where the final scale has only two cases <0.25 and >.25 . Moreover, this method cannot give any idea about glare and over exposed areas in the tested place.

The previous testing methods can only be applied to very simple spaces in shapes and materials where the distribution of light in a complex space requires more accurate tools and complex formulas. Also the results produced by the previous methods doesn't have any kind of visual presentation format to be presented for normal people and clients.

Scale Model

Scale model is one of the widely used methods for daylight testing. Light wavelength behaves in a similar manner inside a scale model at 1:50 as it would in the actual space. Scale model gives a clear idea to clients about what is happening in the design. This is very important to insure client's satisfaction about design outcome.

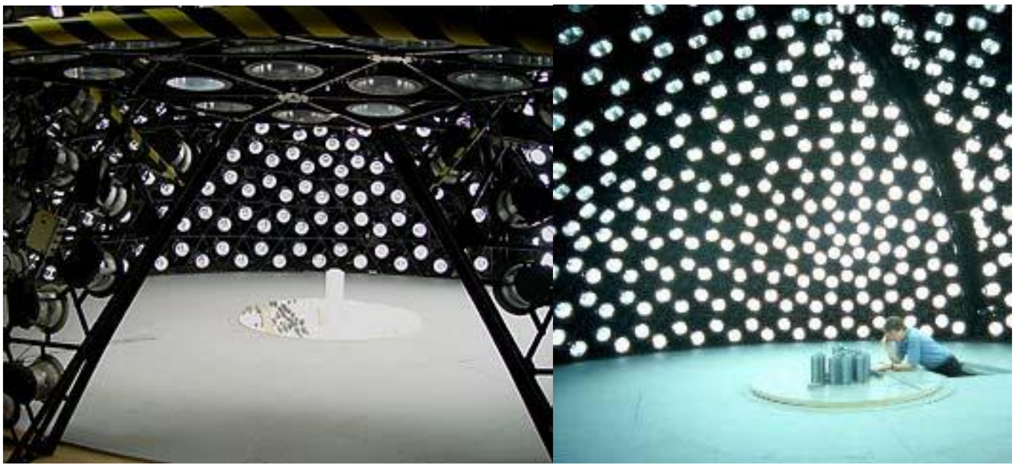


Figure 3.3 Artificial sky dome at Welsh School of Architecture (www.cardiff.ac.uk)

Edwards (2002) studied the use of scaled model outdoor under real sky conditions and inside under artificial sky Figure (3.3). He pointed that testing under artificial sky dome has major advantage over real sky for it's ability to control sky conditions. The artificial sky can model different conditions by adjustable laminar around the dome's frame in any location at any time during the year. Daylight illuminance levels in any space measured by using photometric sensor placed inside the model and the results are directly converted to the linked computer.

Furthermore, Edwards (2002) pointed many advantages for using scale model as testing method. This method can provide designer with quantitative results, which can be used to determine the quality and sufficiency of daylight as calculations or photographs. In addition, different scenarios for materials, colors, furniture and reflections can be easily managed for testing in scaled model. Shading techniques can be easily added and adjusted in scale model. However, from the author perspective detailed model can be very expensive especially when they have internal furniture details. Also using the real material sometimes gives incorrect results where some fabrics or textures cannot be scaled easily. Moreover artificial sky dome is very expensive technology and it is not available to everyone but mainly constructed in affluent universities for study purposes or in specialized research centers. On the other hand, the dynamic movements of the sun made testing under real sky ineffective for investigators to test models where it needs one year testing in order to determine different daylight cases. Next section will investigate simulation as alternate testing method.

3.2 Computer Simulation as Method of testing

Aburdene (2001) defined the simulation term in general as, the process of developing a simplified model of a complex system and using the model to analyze and predict the behavior of the original system in reality. However, Reinhart (2006) defined daylight simulation particularly, as a computer-based calculation, which aims to predict the amount of daylight available in a building either under selected sky conditions (static simulation) or during the course of the whole year (dynamic simulation). Computer simulations give very wide options for changing it's parameters and to study daylight in different locations. Simulations calculate quantity values like illuminance and luminance. Results can be presented by different outputs as real image, false color mapping or presenting values in numeric numbers. The technology boom and recent awareness about the importance of sustainability as a design method have opened the door for many different companies to enter into competition to develop sustainable simulation engines.

Next section will run a comparison between three major simulation softwares 3D Max Design, Radiance and Daysim. Ecotect was excluded from the following comparison as it is using only uniform over cast sky, which cannot be acceptable for UAE's climate.

3D Max Design vs. Radiance\Daysim

The unique high technology of 3D Max Design Exposure technology made a significantly Superior against the other simulation softwares like (Daysim ,Ecotect and Radiance) which are using the technology of Radiance backward raytracer combined with a daylight coefficient approach.

Radiance backward raytracer is a lighting simulation program that was initially developed by Greg Ward in the late eighties at Lawrence Berkeley National Laboratory (Ward and Rubinstein, 1988). The program generally enjoys the status of a 'gold standard' among daylight simulation programs. Rinhart et al (2006) conducted a survey of close to two hundred daylighting modelers from twenty-seven countries which expressed a strong bias towards Radiance. However, Daysim is limited edition from Radiance but it has been developed to be a practical tool to develop indoor illuminances under multiple sky conditions when Radiance Classic could not achieve it within a reasonable time frame. In spite of this Daysim, still uses the same technology of raytracer combined with a daylight coefficient approach.

Reinhart and Fitz (2009) investigated the performance of three programs (3D Max Design, Radiance and Daysim) through running of Daylighting simulations for a room and compare the results to the collected data from the existing real room in order to review the capabilities and performance of each software. The British Building Research Establishment (BRE) has offered a very rich data set of indoor illuminances in a full-scale test room Figure (3.4). For many years, the data set consisted of measured indoor and outdoor illuminances as well as direct and diffuse outdoor irradiances for five daylighting test cases of varying complexity. The collected data from (BRE) were compared to simulation results from 3ds Max Design and Daysim\Radiance for the same model and same location. Results retrieved are as outlined:

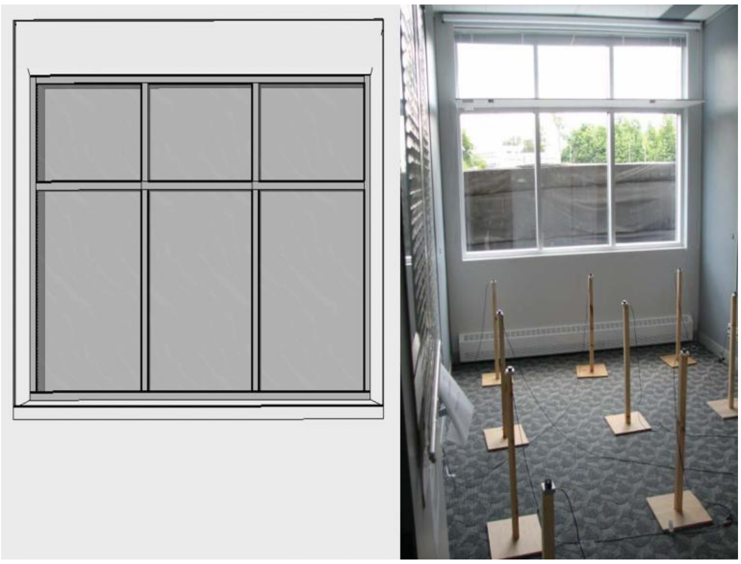


Figure 3.4 Full-scale test room in (BRE) (Christoph Reinhart 2009)

- The results suggest that the accuracy of all programs is sufficient for typical daylighting design investigations of spaces with complexity comparable to the five daylighting test cases.

- Simulation times for the daylighting test cases under a sunny sky were 0.6 to 4 hours for Radiance Classic compared to 12 seconds for 3ds Max.
- For an hourly time step, annual simulation calculation time would be around 15 hours for Daysim while it took 5 to 7 hours for 3D Max Design.

The previous results suggest that 3D Max Design is the best tool for daylighting simulations design decisions, as it is fair to state that it is significantly faster than Radiance Classic for daylight factor or CIE clear sky simulations and Daysim for annual simulation calculation. "Since Daysim and Radiance are really the only programs that have thus far been rigorously validated. This finding is not that surprising given that both programs are based on very comparable models: They use the same sky model and a backward raytracer for the global illumination simulation". Reinhart and Fitz (2009).

3D Max Design as a simulation tool

From the results been pointed by Reinhart and Fitz (2009), 3D Max Design was recommended as the best tool for daylight simulation due to its significant speed and it,s combining features of both software Radiance and Daysim modeling. 3D Max Design (with its mental ray software raytracer for the global illumination calculation) selected to be the preferred simulation software in this study.

3.3 Determine parameters of field investigations in line with intent of the study

The field investigation shall aim to collect data on daylight illuminance falling on vertical building's facades and office interior spaces in Dubai in order to evaluate the Daylight performance through using (Useful Daylight illuminance) evaluation metric.

The study will focus on the most prestigious business address in Dubai, the Sheikh Zayed Road. This is home to most of Dubai's skyscrapers, including the Emirates Towers and the Burj Dubai. The highway also connects other new developments such as the Palm Jumeirah, Dubai Marina and Dubai Waterfront. Along the road runs the Red Line of Dubai Metro and an artery of new office development along this road. According to Dubai Statistics Center (2006), 47% of Dubai offices are located on this road and more than 60% of the highway is still undeveloped or currently under construction.

Figure 3.5 Shiekh Zayed Road the most attractive and prestigious spot in the Middle East (www.dubai.ae)

The study will focus in particular on two distinct set of tests:-

3.3.1 Direct and diffuse illuminance falling on vertical external facades

With regards to orientations vis a vis the sun path at different times of the day across the year with relation to:

- **The cumulative frequency distribution of the outdoor illuminance,** which will provide valuable information on the predication of the probable electric lighting savings and the amount of heat received by that elevation.
- **The effect of building setback** from neighboring plots and its effects on daylighting especially for offices on lower floors.

- **Office buildings geometry**, using Google earth, a quick survey for Sheikh Zayed Road Buildings plans geometries came up with the following: Out of 63 high-rise office buildings road over 30-storeys tall, 78% were square, 12% were rectangular, 6% were circular and 4% were triangular. This means that there has been a tendency to use a square plan when the building height is increased. Second, in structural terms, the square plan resists loads equally in all directions and is more economical compared with rectangular forms. Buildings with symmetrical plans are less susceptible to lateral wind impact than unsymmetrical buildings, and are more efficient than curved and irregular shapes. For these reasons, a square plan was considered in this research.

Figure 3.6 (right)Google earth survey show a 78% of SZR offices building s have a square Geometry while 12% were rectangular , 6% circular and 4% triangular. (www.googleearth.com) and (left) Arial view for SZR (www.dubai.ae).

3.3.2 The Daylight performance of office interiors with regard to:

- Space orientation,
- Choice of glazing,
- Sun shading elements utilized,

These two sets of data will be measured using computer simulation to provide measurements for the whole year, which then will be converted to the selected Daylight evaluation metric. Accurate relevant information to assist planners, designers/ developers in the development of more sustainable buildings on Sheikh Zayed Road and possibly avoid pitfalls of previous developments with regard to solar performance will be retrieved from this study.

3.4 Identification of relevant case studies modeling and characteristics

3.4.1Sheikh Zayed Road Modeling

For the purpose of collecting the first set of data on “Direct and Diffuse illuminance falling on vertical external facades with regards to orientation” and in order to create an accurate simulation of the built office space on

Sheikh Zayed road, computer model will be constructed for part of SZR buildings .

Model characteristics

- The model will include current and under construction buildings on the road from interchange 01 to interchange 03 to accurate scale Figure (3.7).

- Several light meters (grid analysis) will be placed on the vertical facades in different locations and orientations to work as sensors detecting the daylight values falling on various elevations.

- This study will assume a reflectance value of .8 for the towers as the majority of the towers are curtain glazed, and .4 for the base to represent hard landscaping and tarmac roadway Marion Landry and Pierre-Felix Breton (2009).

- All data will be converted to excel format in order to find way to summarize the massive amount of data resulted from the dynamic simulation through the whole year.

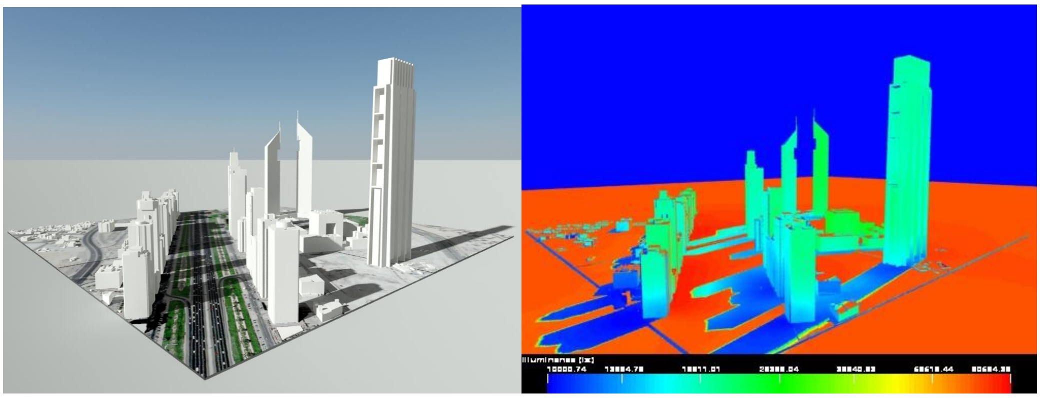


Figure 3.7 (left) rendered image for SZR model by 3D Max Design, (right) false color render for SZR represent illuminance measurements for different surfaces in the model.

Urban Planning, Orientation and Building Regulations on Sheikh Zayed Road

Several urban properties for Sheikh Zayed Road developments are evident from the prepared model Figure (3.8):

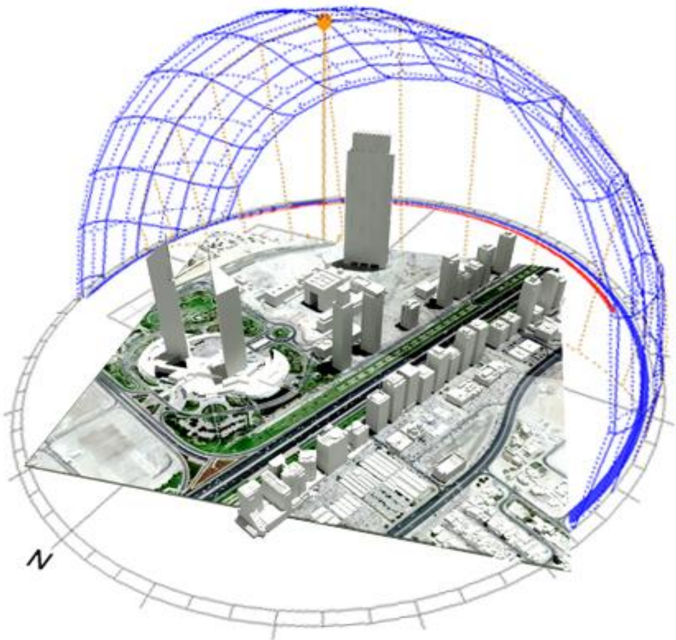


Figure 3.8 Ecotect model indicating for SZR Orientation and sun path .

- SZR road runs nearly from North to South .
- The plots along the road are predominantly equally divided with majority of the plots measuring 40 meter in width (road elevation) and 90 meter in length.
- A setback for each plot is 5 meter from the neighbor side. The building regulation however permits the construction of balconies that project a max of 1.5 meters beyond the building line on upper

floors. Minimum distance between buildings is 10 meters where there is no limit for maximum setback distance. There is no setback required from the roadside.

- The General layout for buildings is square with approx 30mX30m towers on the front side with the rear of the plot utilized as a multi-storey car parking.

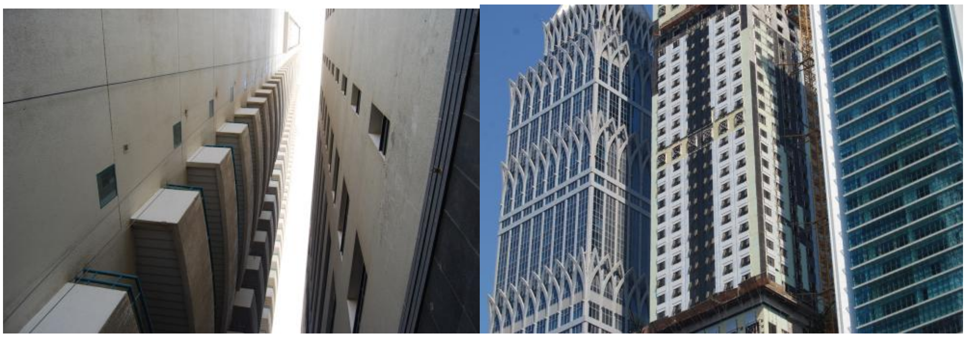


Figure 3.9 (right) 78% of Towers at SZR have 30X30m plan with 10 meter setback. (left) upside view between two buildings in SZR shows the small separation distance between buildings. (personal archive 7/2009)

3.4.2 The Generic Office Design modeling

For the purpose of the second set of tests (internal tests), a Generic Office model was constructed to determine the illuminance levels in different internal spaces with different orientations and parameters.

The typical plot size along SZR and the building regulations have dictated in a way the form of most of the offices towers developments with a majority of the towers taking a similar external mass form and interior offices divisions. Furthermore, the overriding desire to create a visually impressive prestigious building with the dominant elevation oriented to face the highway have lead to the development of a “typical” SZR office tower as described below Figure (3.10):-

1. As plot size is similar, most developers have developed a typical office footprint of 30mX30m,

2. An economical central core of approximately 10mX10m,

3. Offices therefore have a lease span of 10 meters where lease span represent the distance between the office's windows to the building core.

4. Buildings setbacks of 5metres from the neighboring plot.

5. Main curtain glazed façade facing SZR, that is, either East Façade for building west of SZR or West Façade for buildings East of SZR.

6. Floor to ceiling height is 3meters. (for a typical floor)

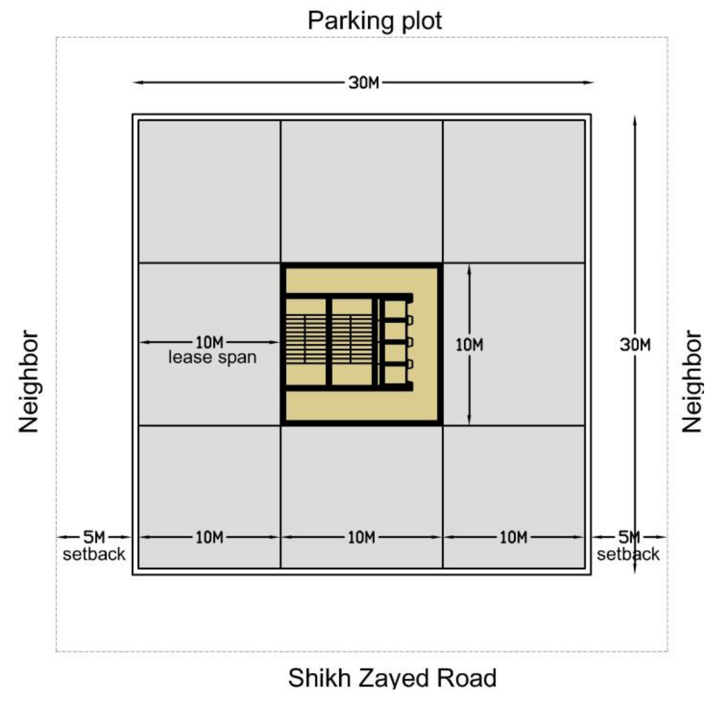


Figure 3.10 Standard office building layout plan in SZR

Generic office model dimensions and characteristics

From the previous study for SZR buildings layouts, a generic office space on SZR was created on 10M*10M*3M with the characteristics mentioned above and the settings for the different elements as highlighted below.

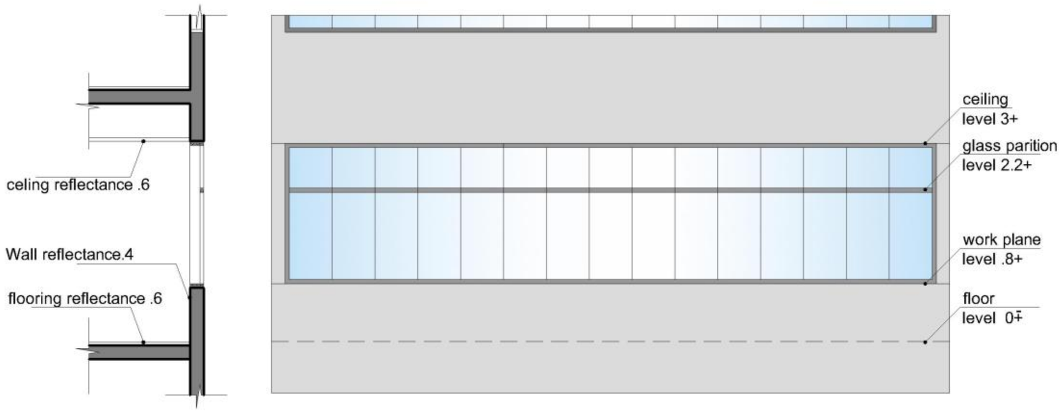


Figure 3.11 Generic office Section and window elevation.

Walls: As been recommended by Landry and Breton (2009), a wall reflectance value between 0.3-0.5 is ideal in the offices. Within this range, the wall reflectance value 0.4 is one with a diffuse off white color.

Ceiling and Flooring: The average value of ceiling reflectance will be considered as 0.6 with white diffuse color. Flooring reflectance will also be taken at a value of 0.6 with off white diffuse color and at a floor to ceiling height of 3 meters.

Window area: Vertical glazed area will be 2.2 meter in height where 0.8m under the work plane level will remain solid. Horizontally the window spreads over the office width. This maximum recommended figure was taken in view of providing as much daylight for the investigated model Glass VT is vary during simulations to test the effect of changing its values from 100%VT representing clear glass to 50%VT, which represent the dark tinted glass. Glass panels split horizontally at 2.2m height to give possibilities of giving different parameter for the upper and lower part.

Furniture: Furniture surfaces reflectance given 0.5 for the wooden desks and 0.3 for chairs and computers

This model will be simulated in terms of design parameters and materials to investigate the following variables:

- Orientation
- Glazing visible transmittance (VT)
- Sun shading alternatives, vertical and horizontal
- Office elevation i.e. ground to upper floors between buildings

3.5 Model Simulation

Producing Simulations

Whilst it will be not be necessary to explain the algorithms and scientific principles of 3D Max Design, it is important to give a quick description of how the simulations are produced and what the designer should consider when he run a simulation on the selected software . The following section will discuss briefly the methodology of how to carry out a daylight simulation analysis using 3Dmax Design.

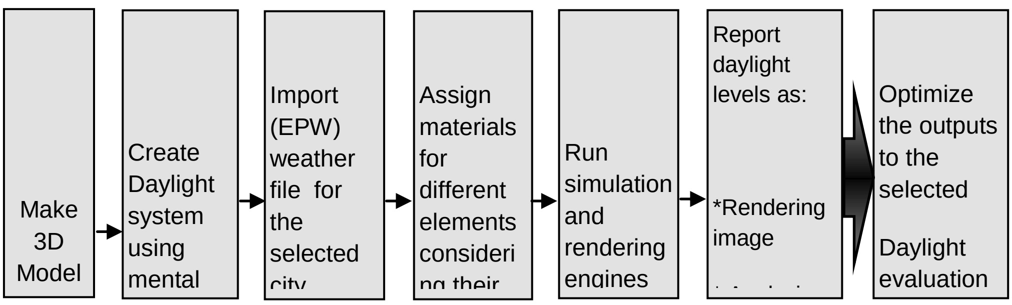


Figure 3.12 Process method for Daylight simulation using 3D Max Deign.

- **Make 3D model:** Good simulation result requires a good geometry. Creating good model does not mean modeling everything but it means that the geometry must communicate roughly to what the renderer expects. It is important to start with a clean model. According to Landry and Breton (2009: b) the margins of having modeling errors in 3D max is larger than Ecotect and Radiance, because the mental ray technology is more tolerant than Radiosity. Therefore, it is not essential to create perfect models, but models that are more accurate make simulation easier and more efficient.

- **Create Daylight system:** Once the geometry properly modeled, "Daylight System" must be created to illuminate the geometry. The daylight system in 3DMax Design models the orientation and space hemisphere under which the geometry placed.

- **Import (EPW) weather file:** 3ds Max Design has capability of loading an EnergyPlus weather file (*.EPW) files, which produce an automatic time series of HDR images and/or illuminances under multiple sky conditions. EPW files contain annual data for typical climatic conditions at a given site, including ambient temperature, relative humidity, wind speed direction, cloud coverage, and radiation data as direct or diffuse. EnergyPlus weather files for over 2000 locations worldwide can be downloaded from:

http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm.

- **Assign materials for different elements:** In order to produce accurate lighting analysis results, the importance of materials definitions come in the same consequence of light and model setup. To deal with 3D Max Design materials, the user must have enough awareness about the real material parameters. Glass is playing a major role in Daylight analysis as it is the only way to connect inside to outside. Therefore, ignoring glass parameter would affect the amount of light penetrating into the space, which would result in reflected incorrect results. A simulator should consider the amount of Glass reflection and the visible transmitting which control the amount of light will pass through the glass, also Index Of Refraction (IOR) is a major parameter as its represent the changing in sun rays angel after it hit glass Landry and Breton (2009: b).

Several glass manufacturers provide optical data to the windows provided by Lawrence Berkeley National Laboratory. This data can be exported to Radiance files (*.Rad). Good advantage of 3D Max Design its corresponds with Radiance as it accept (*.Rad) as materials .In addition walls and flooring planes must be given their accurate diffuse color and reflection amount.

- **Run simulation and rendering engines:** It's very important before running the final simulation to check the automatic error detector provided by 3D Max Design which make a quick checkup for light, modeling and material settings in order to avoid wasting the investigator’s time.

3.6 Data Collection

Reporting daylight levels over a period is the most exciting part in simulation where investigators harvesting the results. Simulation's results in 3D Max Design are retrieved in different formats as following:

1. Rendered Images: These images represent a space in the form of a photo realistic image, under given sky conditions and with real material parameters. They are the easiest way for one to appreciate actual site situations, Figure (3.13).

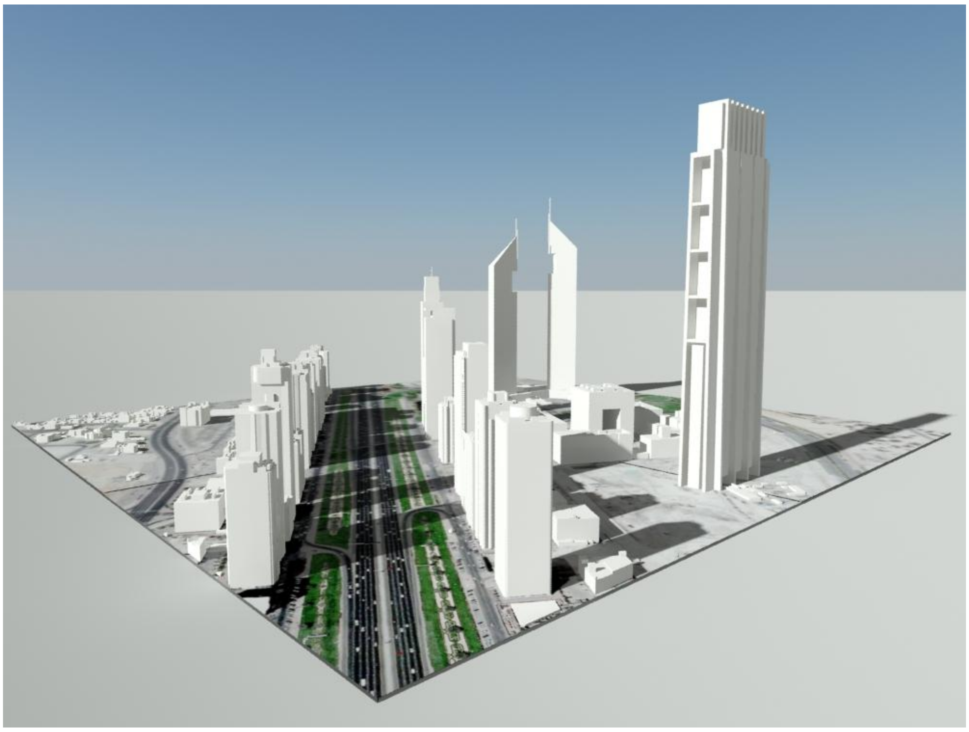


Figure 3.13 Real image render is one of simulation output formats by 3D Max Design.

2. Measurements Presentations: Figure (3.14) shows the different possibilities to present calculated measurements as render. It's possible to show calculations values as false color image ranged from blue for the lowest value to red for the highest illuminance value. Measurements could also be presented on real images as an overly grid covering the whole image or placed specifically on selected facades.

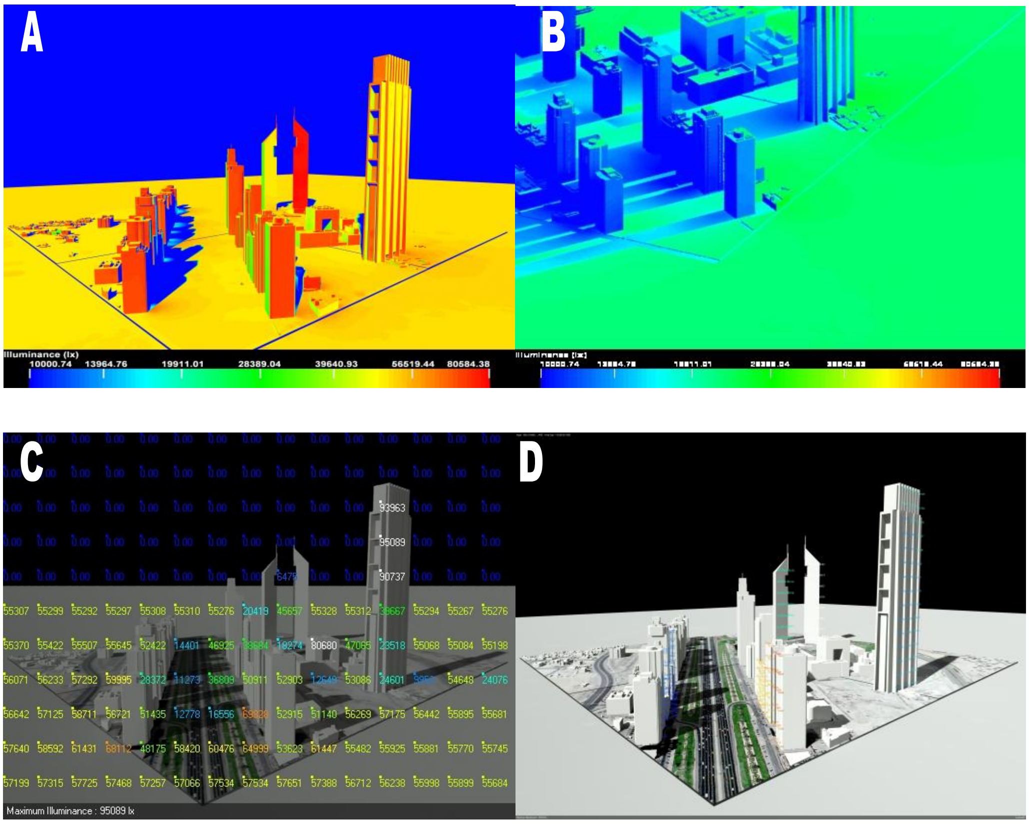


Figure 3.14 Different types of daylight measurements presentation by 3D Max Design. (figure A&B) represent data measurements for SZR as false gradient color rendering ranged from blue for the lowest value to red for the highest illuminance value, (figure C) represent overlay grid data measurements covering the whole image, (figure D) shows overlay grid data measurements on some selected surfaces in SZR model.

3. Microsoft Excel Format : After obtaining a set of Daylight System under specified Weather Data File over a period of time via the 3ds Max Design animation system (timeline), simulation can be run for the entire animation time range on a the analysis grid , Once the simulation is completed the results can be exported to (*.CSV) Microsoft excel file.

Table 3.1 shows an example of the excel sheet produced by 3D Max Design on specified light meter. As been shown in table 3.1, light meter (analysis grid) gives ID for every point on the grid ,where it gives data for every ID as time frame, location , Date, Direct Illuminance , indirect Illuminance , total Illuminance , unit of illumination , daylight factor and location of the sensor point on X ,Y ,Z axes .

Table 3.1 : partial excel sheet layout produced by 3D Max Design daylight simulation

Name	ID	Frame	Location	Date	Direct	Indirect	Total	Illum	Day	Pos	Pos Y	Pos Z	Unit	Orie	Ori	Orie
LightMete	10	323	Dubai	08:00:00 M	0	241	241	lx	0	3.7	-4.5	7.11	Centimet	0	0	1
LightMete	20	323	Dubai	08:00:00 M	0	327	327	lx	0	3.7	-3.5	7.11	Centimet	0	0	1
LightMete	30	323	Dubai	08:00:00 M	0	304	304	lx	0	3.7	-2.5	7.11	Centimet	0	0	1
LightMete	40	323	Dubai	08:00:00 M	0	266	266	lx	0	3.7	-1.5	7.11	Centimet	0	0	1
LightMete	50	323	Dubai	08:00:00 M	0	275	275	lx	0	3.7	-0.5	7.11	Centimet	0	0	1
LightMete	60	323	Dubai	08:00:00 M	0	258	258	lx	0	3.7	0.49	7.11	Centimet	0	0	1
LightMete	70	323	Dubai	08:00:00 M	0	223	223	lx	0	3.7	1.49	7.11	Centimet	0	0	1
LightMete	80	323	Dubai	08:00:00 M	0	205	205	lx	0	3.7	2.49	7.11	Centimet	0	0	1
LightMete	90	323	Dubai	08:00:00 M	0	278	278	lx	0	3.7	3.49	7.11	Centimet	0	0	1
LightMete	100	323	Dubai	08:00:00 M	0	332	332	lx	0	3.7	4.49	7.11	Centimet	0	0	1
LightMete	10	1807	Dubai	08:00:00 T	0	668	668	lx	0	3.7	-4.5	7.11	Centimet	0	0	1
LightMete	20	1807	Dubai	08:00:00 T	0	884	884	lx	0	3.7	-3.5	7.11	Centimet	0	0	1
LightMete	30	1807	Dubai	08:00:00 T	0	718	718	lx	0	3.7	-2.5	7.11	Centimet	0	0	1

In this study every point in analysis grid will be tested once every month in different timings 9am 12pm and 16pm. Every point on the analysis grid will be calculated 36 times. This study will propose a grid area of 1m². While the area of proposed generic office is 10M * 10M = 100 m² then the total number of grids will be conducted in every simulation is a 100 grid points every point will be calculated 36 time yearly. Therefore the total number of excel rows will be 3600 row in every simulation. It's evident that the output data is very huge. This is due to the dynamic nature of the sun, which requires this amount of tests in order to accurately capture it in its different locations in the hemisphere. Following section will discuss the methodology for how to deal with the given data in order to summarize the output data into a legible format.

3.7 Analysis & Discussion

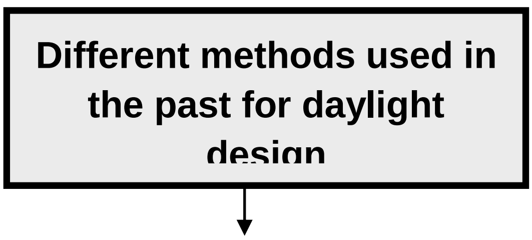
From the data collected in the tests, an analysis on the performance of different vertical facades and daylight performance in the internal office space will be conducted. Changing specifications of one or all of mentioned parameters will be studied and the effect of illumination falling on vertical facade or penetrating to the internal space will be analyzed rendered images. Tables and charts will represent the measured values. UDI (useful daylight illuminance) will be displayed as an evaluation metric for daylight performance where a simple comparison method will be done between different UDI for different offices parameter will finally leads to the optimum solution.

3.8 Summaries

In the conclusion, tables and charts presented in the analysis will be referred to , then a summary outcome of the testes will be presented to support the final conclusion . The conclusion for the UDI tables will give an indication as to where a Designer should focus on in the early stage of design. Those indications will be written as a general guidance to be useful for every one authorities ,architects ,developers or investigators.

The research will conclude with some recommendations on research direction that future investigators wishing to further extend the study may focus on. Figure 3.16 summarize research methodology stages in sequence.

Figure (3.15) summarize the maintained Research stages process:



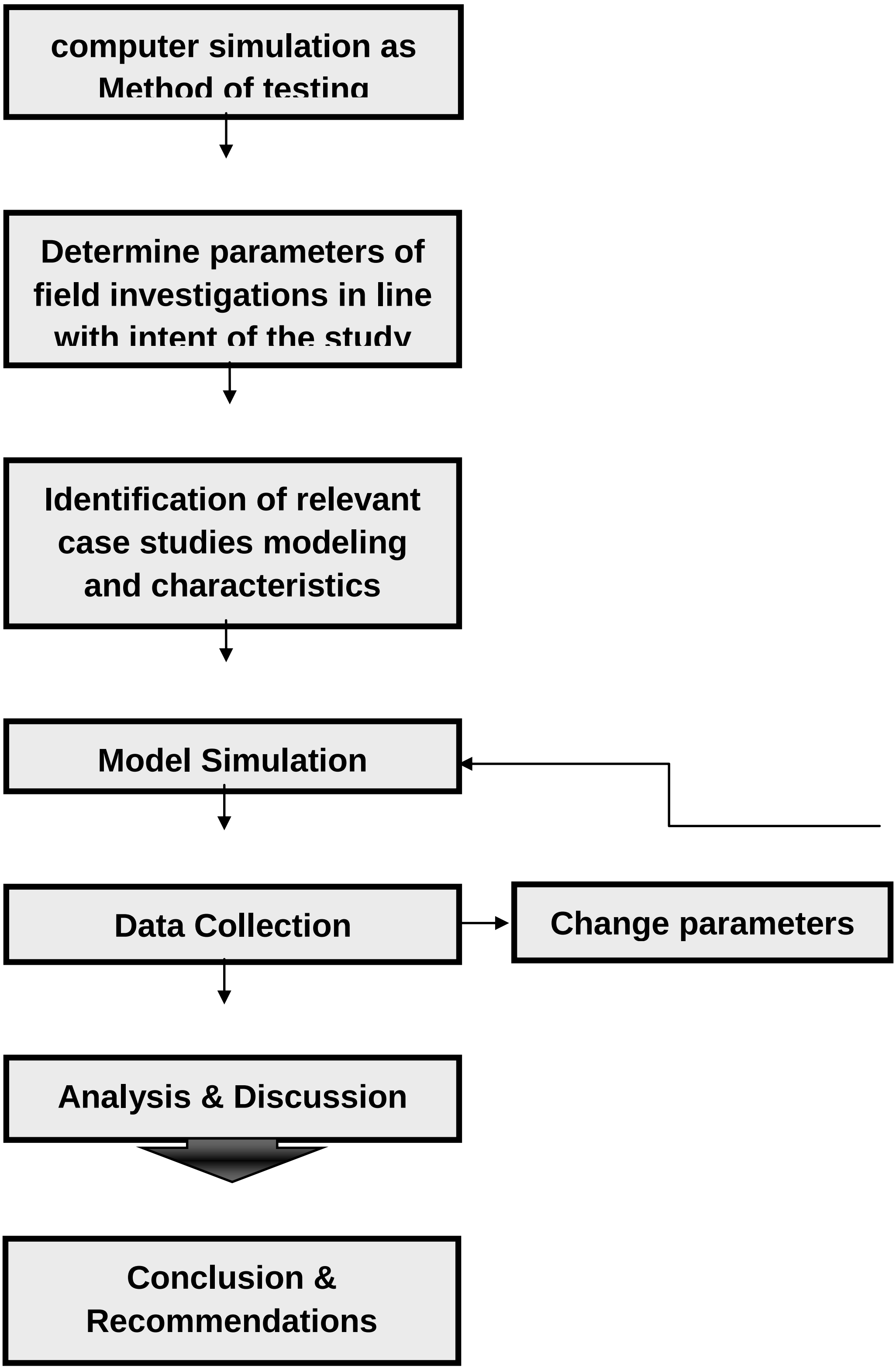


Fig 3.15 Research methodology stages

Chapter4 - Simulations and Discussion

As has been mentioned in the methodology, the 3D Max simulations have been categorized into two main sets of tests:-

- Direct and Diffuse illuminance falling on vertical external facades.
- Daylight performance of offices interiors.

4.1 Direct And Diffuse Illuminance Falling On Vertical External Facades.

4.1.1 Outline of the simulation process

The first step towards designing building that achieves daylight performance internally is to obtain information on the amount of daylight available externally. A Cumulative frequency distributions of daylight availability will be reported from Shikh Zayed offices towers in different locations and orientations. 3D Max Design simulations will be used in this research as an approach to obtain daylight levels on vertical surfaces. Measurements of direct and diffuse outdoor illuminance falling on vertical facade plane at three orientations (N, W and S) will be collected by a vertical light meter placed on each facade. Light meter is a surface of 200m² divided to 10m² grids with a sensor point on every node to detect the daylight measurements falling on that point Figure (4.1). All sensors installed on this surface are 80cm above the slab level (work plane level) and in a relatively free position from any external obstructions could affect their results. Measurements will be collected 3 times daily at 9 a.m, 12 p.m and 4 p.m.

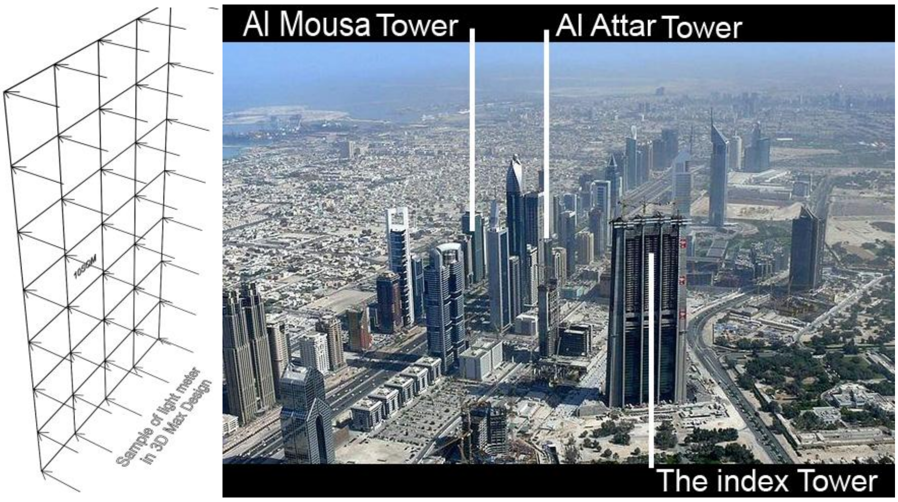


Figure 4.1 (left)four grid light meters were placed on SZR different towers.

This research used Sheikh Zayed road as case study for Dubai offices. For purposes of this simulation, the data is compiled from four light meters placed on facades of different locations and orientations as follows:-

- Two light meters are placed on The Index Tower main elevations (north &south).
- The western facade of Al Attar Tower has another light meter.
- The last light meter placed on Al Mousa Tower on the 10-meter setback side facade.

The first three light meters aims to investigate the impact of facade orientation on the amount of illuminance falling on a vertical surface. The fourth light meter aims to studies how setback can affect the amount of illuminance falling to a surface in different height levels. As mentioned before in the methodology, simulations results are represented into three ways:-

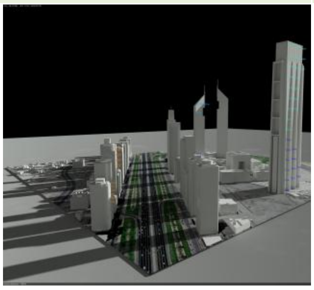
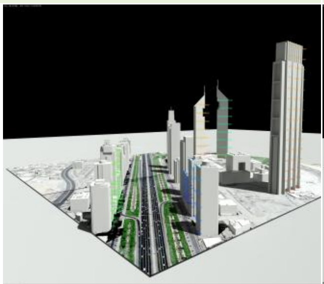
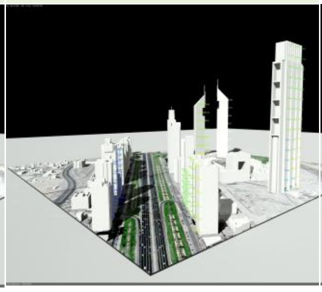
- The realistic situation on ground.
- Using pseudo gradient colors to indicate dark, light, over or underexposed surfaces
- Microsoft Excel file format classifying data collected from every node into a table. The table contents of location, Date, Direct Illuminance, indirect Illuminance, total Illuminance, unit of illumination, daylight factor and location of the ID point (sensor point) on X, Y, Z-axes.

4.1.2 Results and Analysis

Table 4.1 and 4.2 show recorded daylight illuminance readings for Sheikh Zayed road towers over the course of four seasonal months(March, June, September, December) at 9:00 am, 12:00 pm and 4:00 pm in two different output formats.

Table 4.1 shows a real 3D image renders for the current situation on Sheikh Zayed Road. Readings on light meters also are represented on the labeled images. We will refer to these readings in more details in the following section.

Table 4.1 3D images renders for current situation on Sheikh Zayed Road with three readings at 9:00am, 12:00pm and 4:00pm over four seasonal months(March, June, Sep, Dec).

	SZR at 8:00 am	**SZR at 12:00 pm**	**SZR at 4:00 pm**
March			

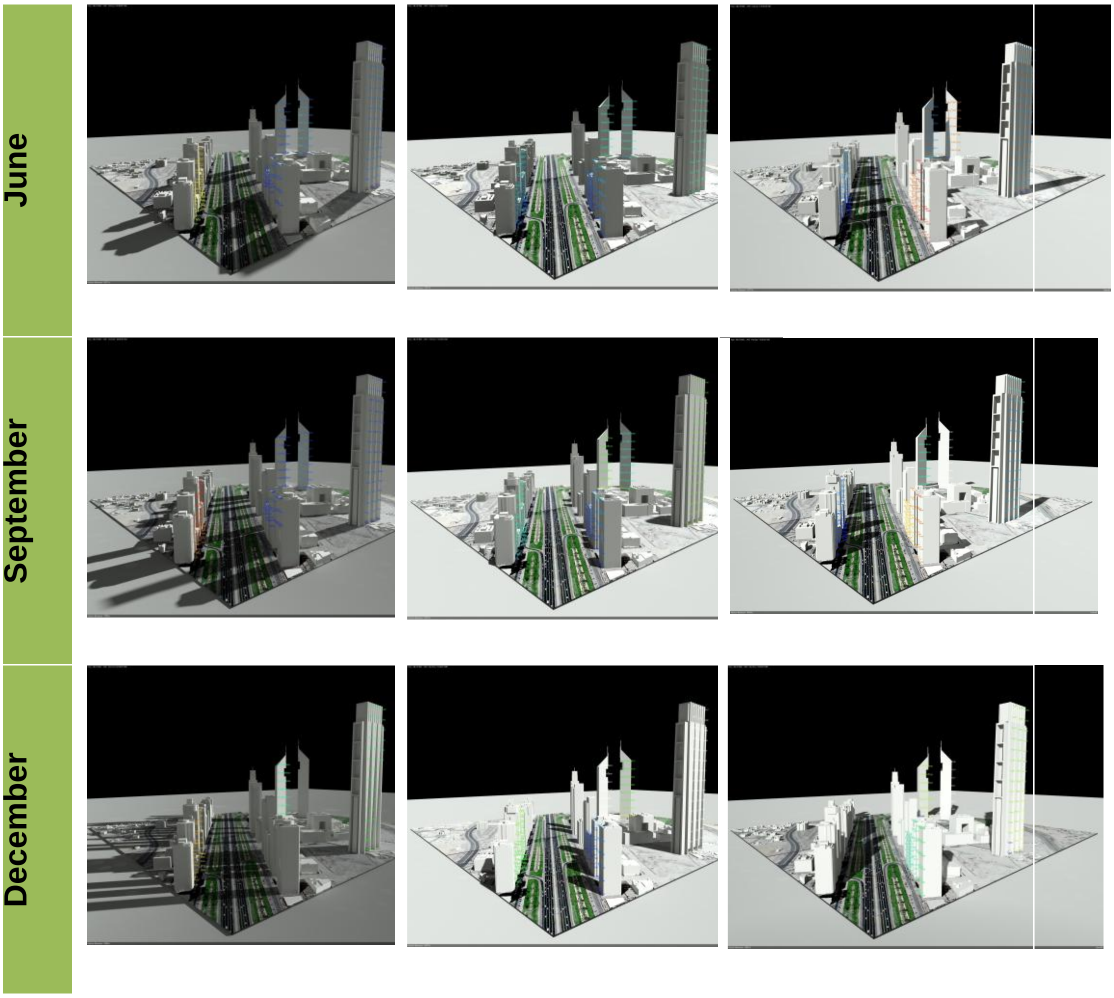
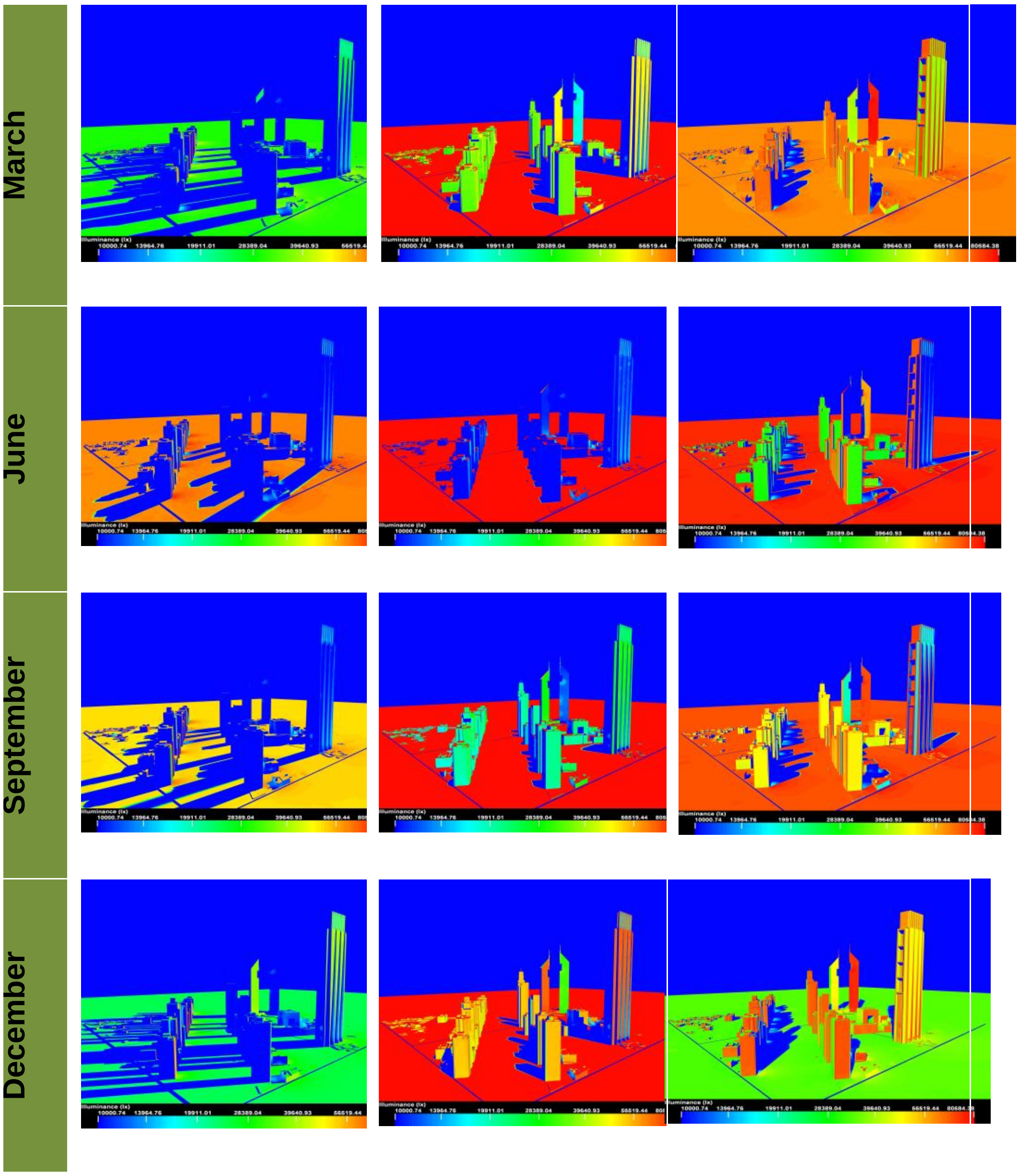


Table 4.2 Shows quantitive values of light presented by a false color analysis that uses a color scale to display values, as shown below the color scale range between 10,000 lux in blue and 80,000 lux in red.

Table 4.2 Daylight illuminance values for the same simulation are presented by false gradient colors with a scale range from 10000 lux in blue to 80000 in red.

	SZR at 9:00 am	**SZR at 12:00 pm**	**SZR at 4:00 pm**



Real render images can provide an idea about how bright or dark the simulated model is while pseudo gradient colors images can provide a rough idea about the daylight illuminance levels on all surfaces through different colors. However, data concluded from both outputs are still not enough to judge the adequacy of illuminance and hence does not represent a practical professional evaluation tool.

In contrast graphical charts representation is simple and direct approach to analyze and figure out measured illuminance data. It is also useful for comparative studies during the early building design stage. The following section summarizes by graphical charts the collected data from the 4 meters in the previous tests. Table 4.3 shows a brief description for these tests.

Table 4.3 Brief description of tests for the illuminance falling on different surfaces

Surface 1 - Illuminance falling on North facing façade (The Index Tower).	**Test N.1** North surface without shading protection.	**Test N.2** North surface with 50cm projection from slab level	
Surface 2 - Illuminance falling on South facing façade (The Index Tower).	**Test S.1** South surface without shading protection.	**Test S.2** South surface with 50cm projection from slab level.	**Test S.3** South surface with 50cm projection on 1 meter lower than slab level.
Surface 3 Illuminance falling on West facing façade (The Index Tower).**-**	**Test W.1** West surface without shading protection.		
Surface 4 Illuminance falling on Al Mousa Tower	**Test SB.1** Illuminance falling on Al Mousa Tower Side		

10 meter setback facade.	façade on the 10 meter setback.

Surface 1 - Illuminance falling on North facing façade (The Index Tower).

Test N.1 North surface without shading protection

Figure 4.2 Test N.1 daylight illuminance falling on North surface of The Index Tower without shading protections

In this test , the light meter is placed on plane north facade without having any protection treatments Figure(4.2). Figures (4.3-5) show the average illumination falling on vertical north surfaces at 3 different times 9:00 am, 12:00 pm and 04:00pm in four seasonal months (March, June, September and December). Data are separated into three groups, Direct, Indirect and Total illumination.

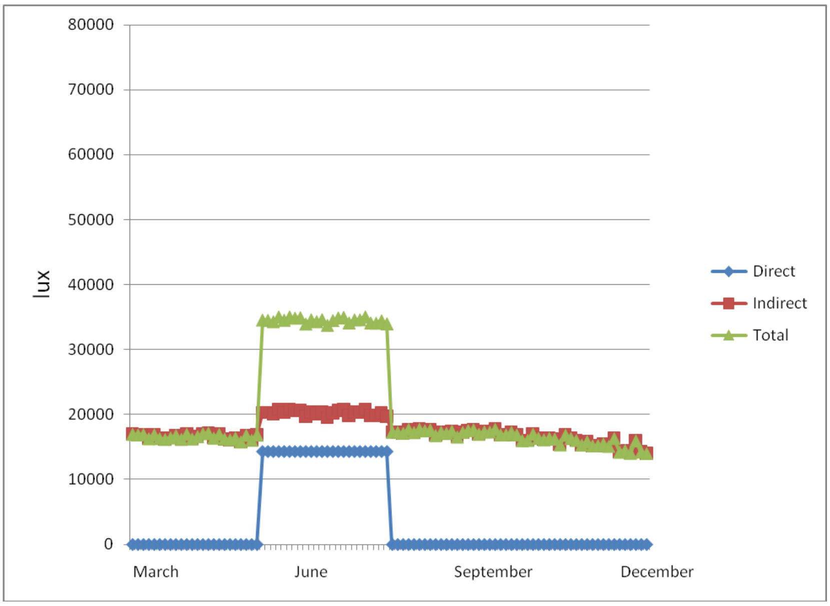


Figure 4.3 Test N.1 Vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 9:00 am)

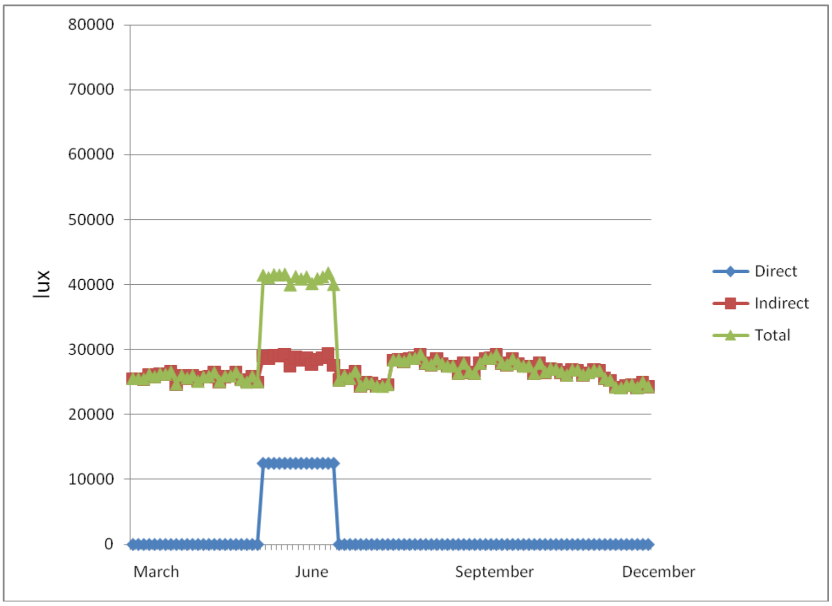


Figure 4.4 Test N.1 Vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 12:00 pm)

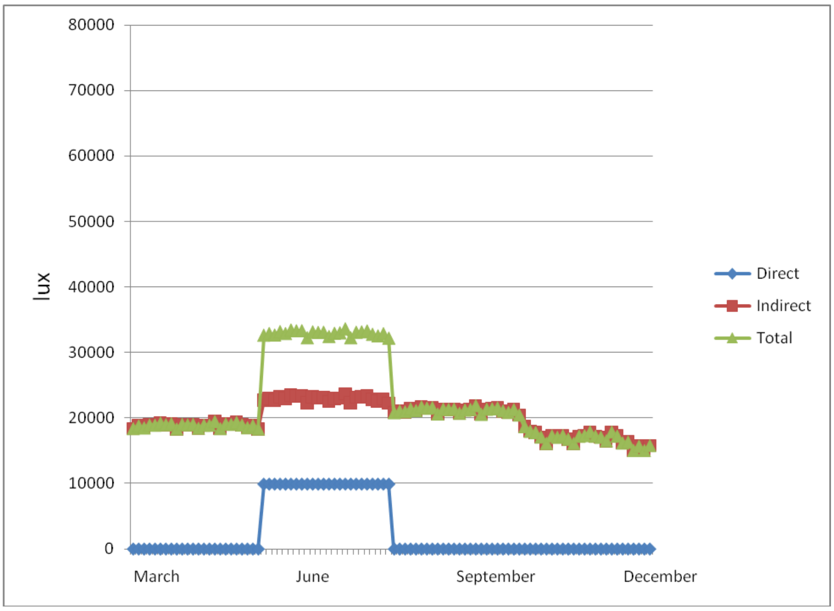


Figure 4.5 Test N.1 vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 4:00 pm)

The readings shown in the previous figures were nearly similar for most of the year (in the range of 20000 lux). Figures indicating daylight illuminance for most the nodes are almost flat line during the year. It's an important sign for having a uniformed internal environment. The only notable changes in daylight illuminance are on June where the sun gets the maximum position towards North direction Figure (4.6). Accordingly, some direct beams are penetrating in very narrow angel to the vertical surface during the whole day causing some increased lux levels.

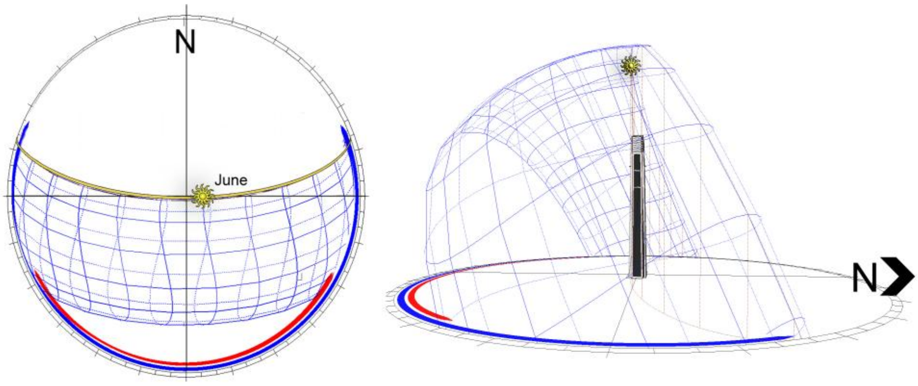


Figure 4.6 Ecotect graph represent sun path during the year. June path is yellow highlighted when the sun getting its maximum position towards North direction causing some daylight fluctuations.

Test N.2 North surface with 50cm projection from slab level

Figure 4.7 Test N.2 daylight illuminance falling on North surface of The Index Tower with 50cm projection from slab level.

logically as the horizontal angle between sun and the vertical surface can not exceed 20°, a projection on the slab level might give protection for the external facade. Acodingly the tesets is were repeated with a 50 cm projection from every slab level Figure(4.7) . The figures (4.8-10) summarize the anlyzed results.

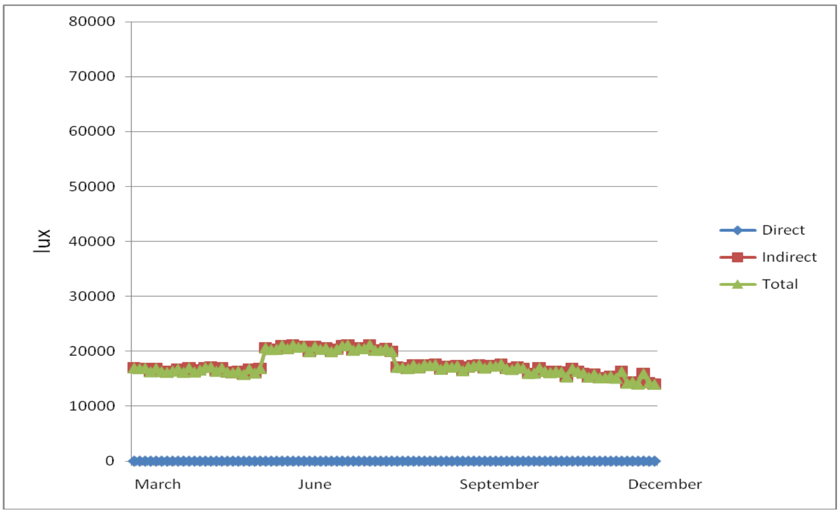


Figure 4.8 Test N.2 vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 9:00 am)

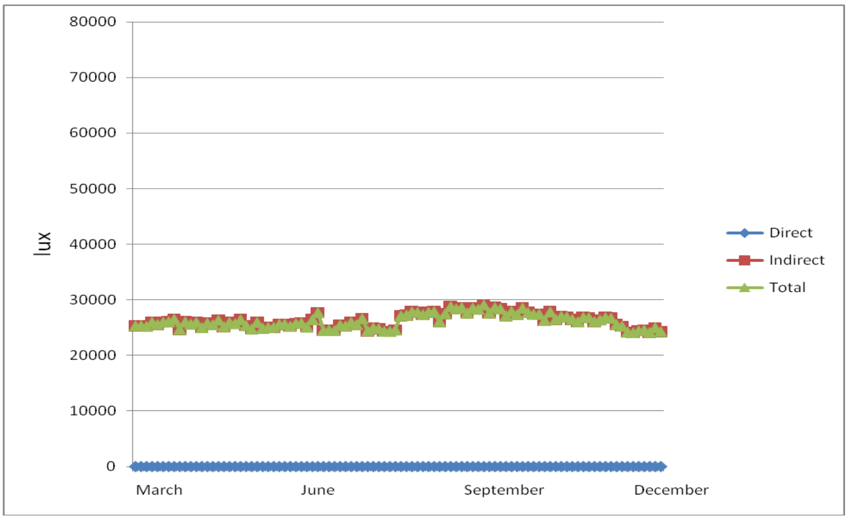


Figure 4.9 Test N.2 Vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 12:00 pm)

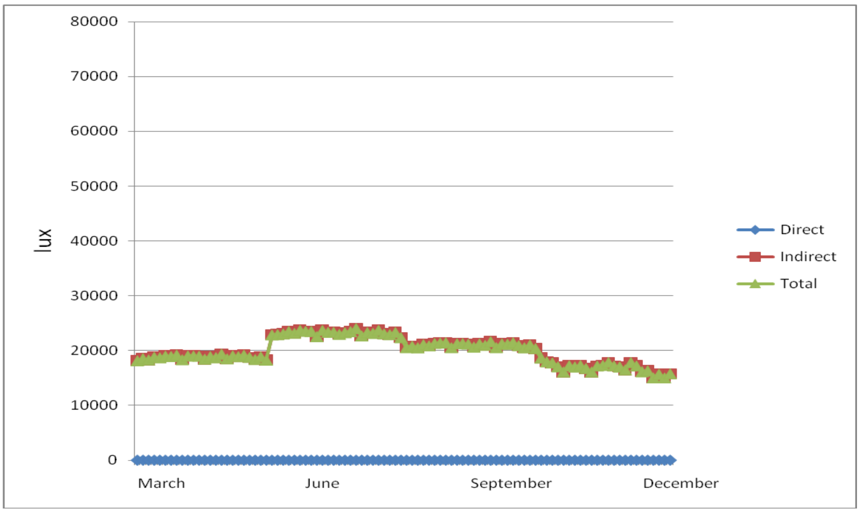


Figure 4.10 Test N.2 Vertical illumnation falling on North surfaces (The Index Tower Dubai-UAE 14:00 pm)

Significant improvements were achieved as direct illuminance falling in June were obstructed by the small projections in every slab. Figures (4.8-10) show that the total illuminance recorded became more uniform and consistent during the year.

Surface 2 Illuminance falling on South facing façade (main elevation) of The Index Tower.

Test S.1 South surface without shading protection

Figure 4.11 TestS.1 daylight illuminance falling on South surface of The Index Tower without shading protection.

This simulation is conducted on the south facade of the same tower as in the previous simulations. Data were collected from light meter and presented in the following figures:

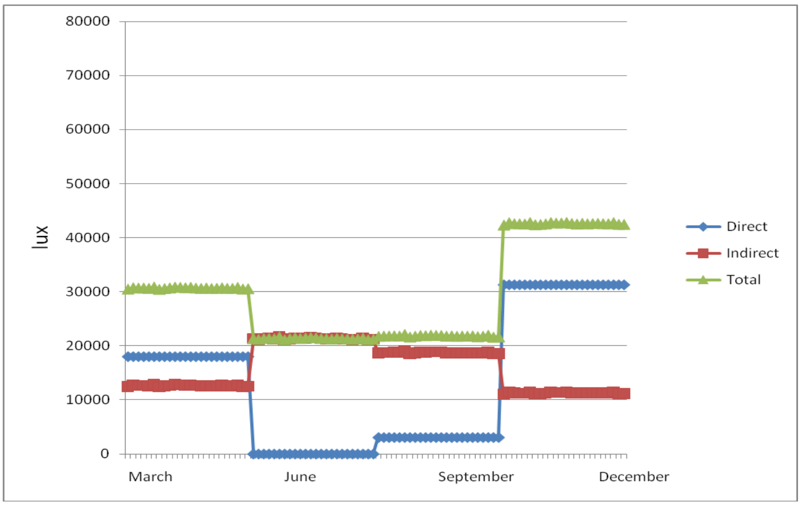


Figure 4.12 Test S.1 Vertical illumnation falling on north surfaces (The Index Tower Dubai-UAE 9:00 am)

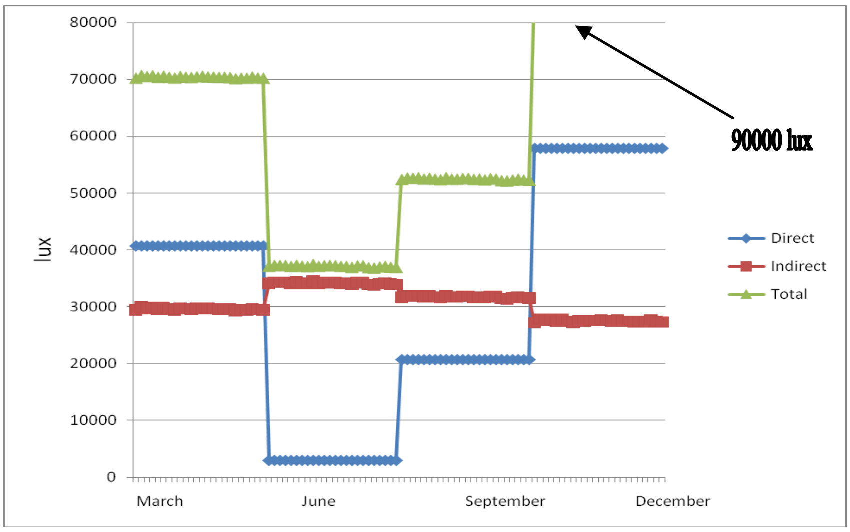


Figure 4.13 Test S.1 vertical illumnation falling on South surfaces
(The Index Tower Dubai-UAE 12:00 pm)

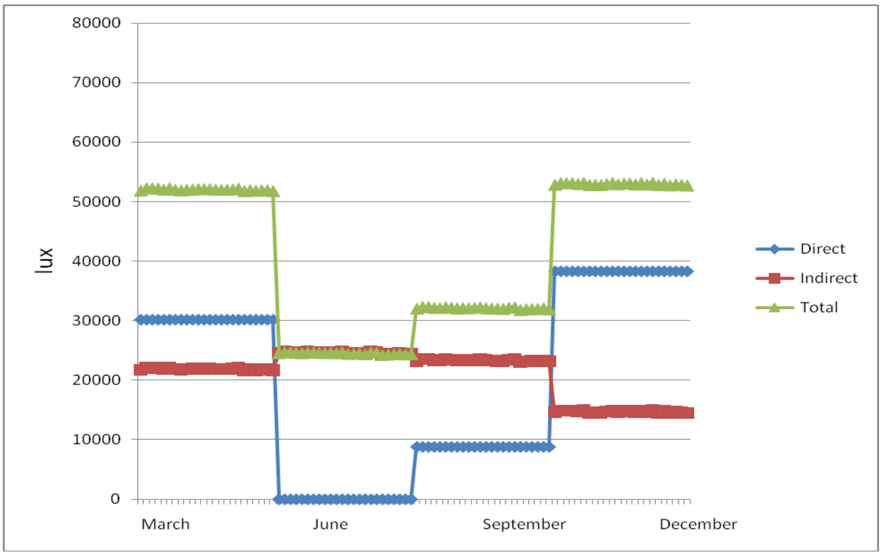


Figure 4.14 Test S.1 vertical illumnation falling on South surfaces
(The Index Tower Dubai-UAE 4:00 pm)

The Daylight illuminance values recorded were higher than those of the previous case Figures (4.12-14). The direct illuminance is significantly higher, indicating a greater occurrence of direct sunlight in the space. South facades receives direct sunlight for a longer durations specially in March(Spring) and December(Winter) when the sun is located closest to the South and taking the shortest path Figure (4.15).

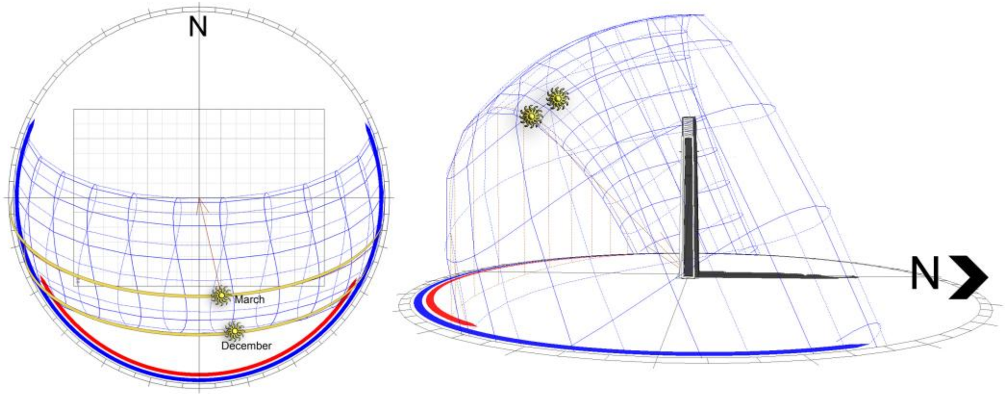


Figure 4.15 Ecotect graph represent sun path during the year .March and December paths are yellow highlighted when the sun located closest to south and taking the shortest path causing excessively high direct illuminance on south facade.

Moreover, the intensity of illuminance is nearly similar in morning and afternoon while noontime witnesses a higher intensity, which exceeds 80000 lux in some days. On the other hand, South facing facades can be shaded relatively easy compared to east or west orientations.

Test S.2 South surface with 50cm projection from slab level

Figure 4.16 Test S.2 daylight illuminance falling on South surface of The Index Tower with a 50 cm projection from slab level.

This simulation was repeated by a projection of 50cm from the slab level, results recorded from the light meter were nearly the same in first simulations .Some insignificant improvements were recorded in March while other months got nearly the same results. This promoted a change in the location of the projection as seen in the next set of tests (Test S.3)

Test S.3 South surface with 50cm projection and 1 meter lower than slab level

Vertical blinds might be the ideal solution to reduce the amount of luminance on this elevation, but it will lead to have some dark areas internally in the deep points. Increased projections do not make sense practically and economically. This simulation gives the measurements after lowering the 50cm projection height by 1 meter Figure (4.17). Accordingly shading projection will be 1.2 meter above the work plane level not in the same slab level.

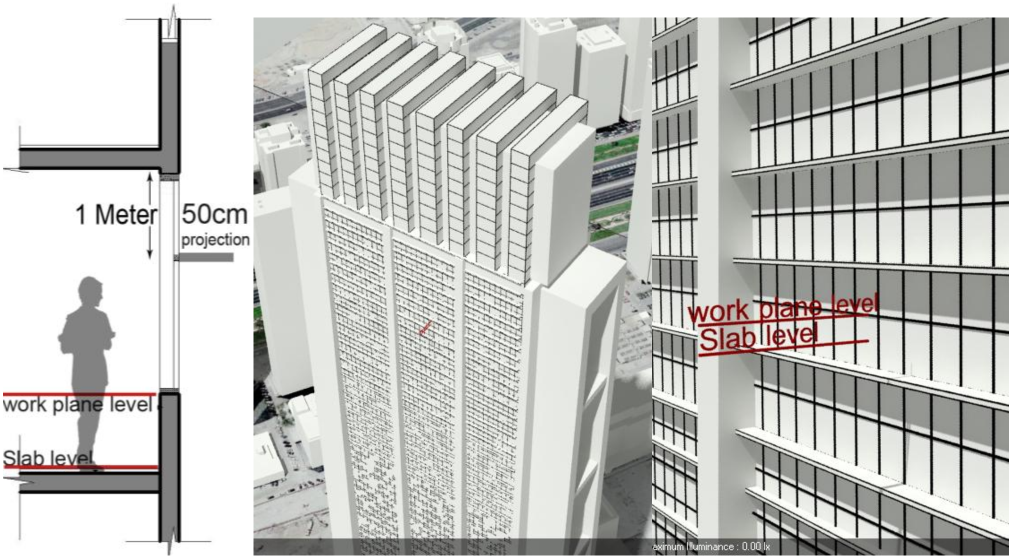


Figure 4.17 Test S.3 daylight illuminance falling on South surface of The Index Tower with a 50 cm projection 1 meter below slab level (1.2 meter above work plane level).

Figures (4.18-20) summarizes the simulation results. Daylight illuminance dropped for all times and direct illuminance is no longer being received for the majority of the year. This is due to the increased amount of time that the overhang illustrated in fig 4.17 protects the daylight window. However, with its lower winter sun angles South facade still receives direct illuminance in morning and afternoon times while noon period is fully protected. These results are highlighting the importance of shading windows for more daylight harvesting in sunnier periods.

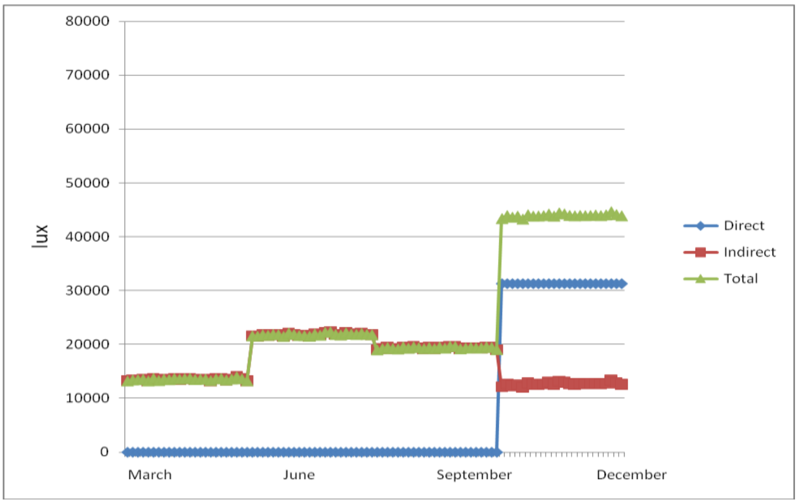


Figure 4.18 Test S.3 Vertical illumnation falling on South surfaces
(The Index Tower Dubai-UAE 9:00 am)

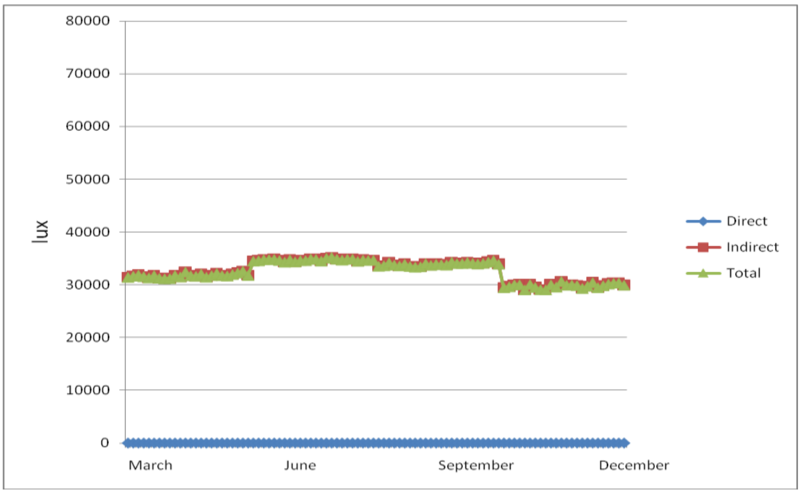


Figure 4.19 Test S.3 vertical illumnation falling on South surfaces
(The Index Tower Dubai-UAE 12:00 pm)

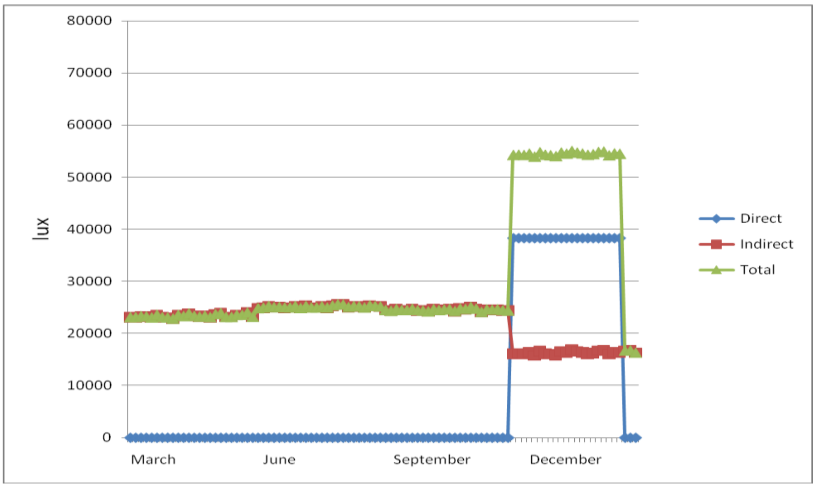


Figure 4.20 Test S.3 vertical illumnation falling on South surfaces
(The Index Tower Dubai-UAE 4:00 pm)

Surface 3 Illuminance falling on the Western facing façade (main elevation) Al Attar Tower

Test W.1 West surface without shading protections

In this simulation, a vertical light meter was applied to the West-facing facade of Al Attar Tower. Data on average illuminance was collected and the results are shown in the Figures (4.22-24).

Figure 4.21 (left) Test W.1 daylight illuminance falling on West surface of Al Attar Tower without shading protections (right) Al Attar western facade at SZR (personal archive, August 2009).

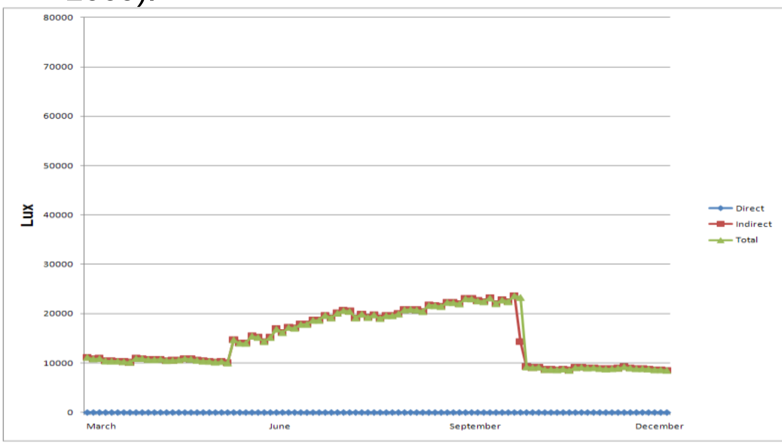


Figure 4.22 Test W.1 vertical illumnation falling on West surfaces (Al Attar Tower Tower Dubai-UAE 9:00 am)

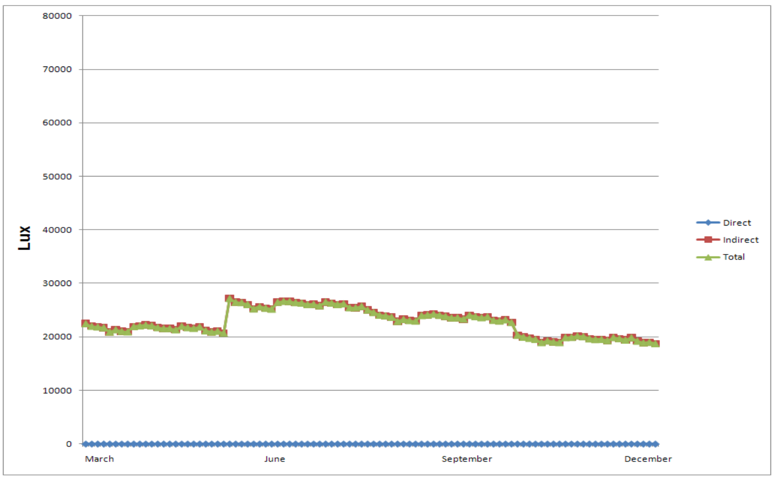


Figure 4.23 Test W.1 vertical illumnation falling on West surfaces (Al Attar Tower Dubai-UAE 12:00 pm)

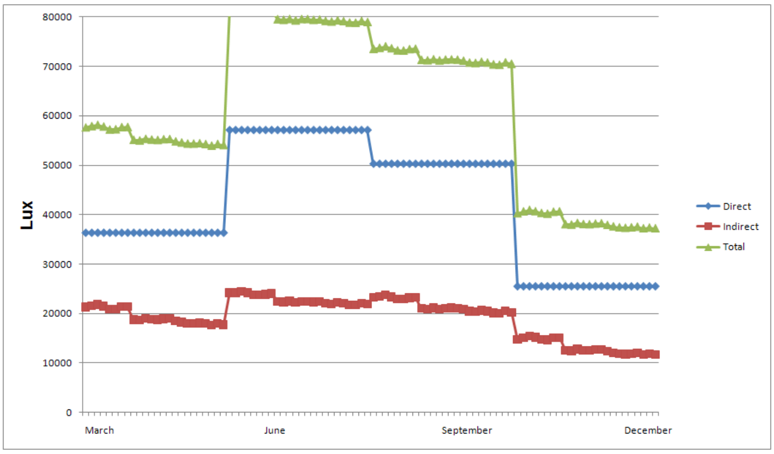


Figure 4.24 Test W.1 vertical illumination falling on West surfaces (Al Attar Tower Dubai-UAE 4:00 pm)

At 9:00am, Western facade is completely protected from direct sun light at 09:00am but illuminance levels are likely to be too low for adequate light penetration during winter months. This will be confirmed in upcoming simulation experiments for internal daylighting performance of a generic office. In addition, illuminance is not consistent through different months with illuminance falling to the West facade during March around 9,000 lux to highs of 23,000 lux during the month of September. The 12:00 pm results came also inconsistent but it performs better than that at 9:00 am, as the illuminance received is higher than 20000lux for the majority of the year. However, west-facing windows are receiving excessively high illuminance levels during the afternoon. Illuminance levels of 50,000 lux during the month of March are seen rising sharply to highs of 90000 lux on June and September. The Western façade is constantly experiencing high illuminance levels, a big indication for glare problems and heat gain.

As the sun at 4:00 pm is located at a very low angle to the horizon, West and east facing windows are the most difficult to provide exterior shading

,making horizontal shading devices is ineffective against the early morning or late afternoon sun, Figure (4.25).

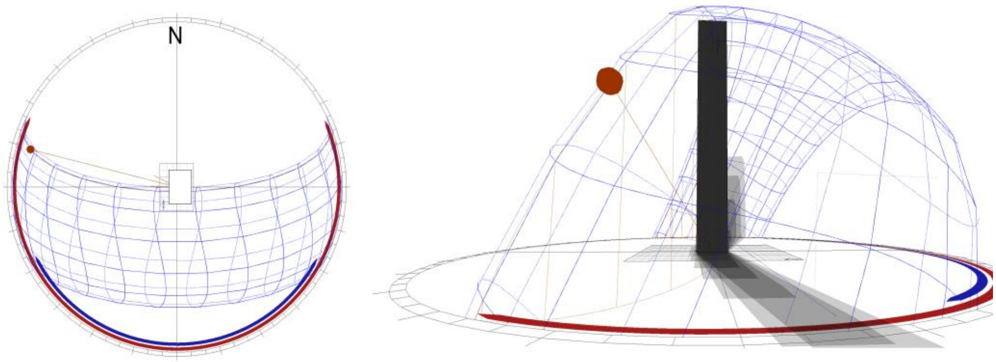


Figure 4.25 Ecotect graph represent sun path During the year . Horizontal shading devices are ineffective against the early morning or afternoon sun as the sun located at very low angel at that time.

The next set of simulations for the internal generic office will try to propose some solutions to reducing the negative effects of illuminance falling on the eastern elevations.

Surface 4 Illuminance falling on Al Mousa Tower Side façade on the 10 meter setback.

This test will explore the amount of illuminance received by vertically obstructed surface. In this test, light meter was applied on Al Attar building side elevation. This façade is 10meters away from the neighboring building facade Figure (4.26). The purpose of this simulation is to demonstrate the daylight levels in low levels between two buildings. Whilst the existence of direct sunlight is very rare only at noon times when the sun is located high in the sky, therefore only diffuse daylight illuminance will be considered while direct illuminance will be ignored so as not to adversely affect the average illuminance.

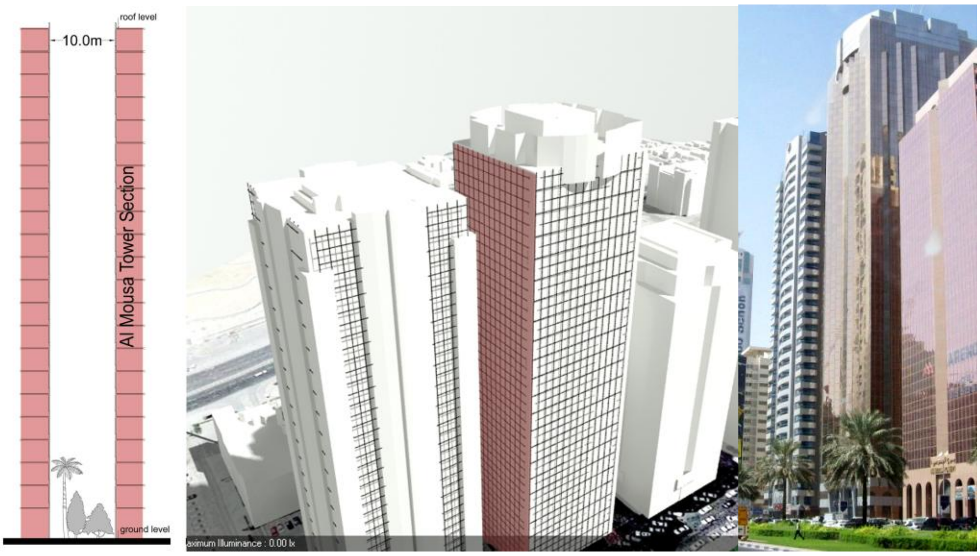
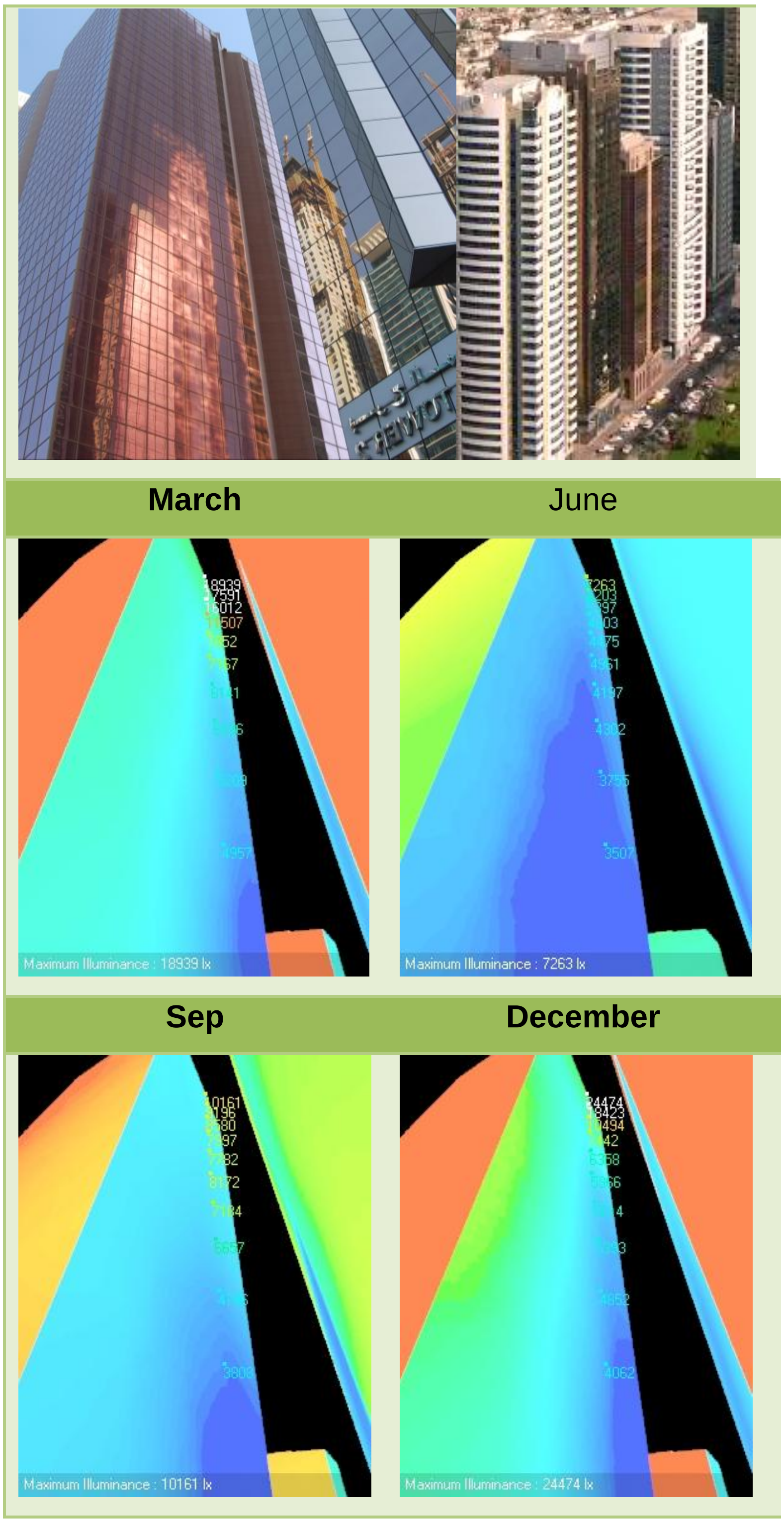


Figure 4.26 (left) Test SB.1 daylight illuminance falling on Side facade of Al Mousa Tower on the 10-meter setback surface, (right) Al Mousa Tower at SZR (www.dubai.ae).

Table (4.4) shows upside view for the simulated surface in gradient color in four seasonal months (March, June, Sep and Dec). Light meter provides also numeric readings in every level. These readings are summarized in figure (4.27).

Table 4.4 Upside view for Al Mousa Tower side surface. Result values were presented on the surface in four seasonal months (March, June, Sep and Dec). Gradient color ranges from 3000 lux in blue to 30000 in red. Light meter results were shown as numbers on each figure.



As indicated in Figure (4.35), the total illuminance falls sharply at the lower levels. Surface observes a low of only 3700 lux in the lower levels and this steadily increases as one goes to higher floors. These illuminance levels are likely to be too low for adequate light penetration into internal office spaces. This will be confirmed in upcoming simulation experiments for internal day lighting performance of a generic office.

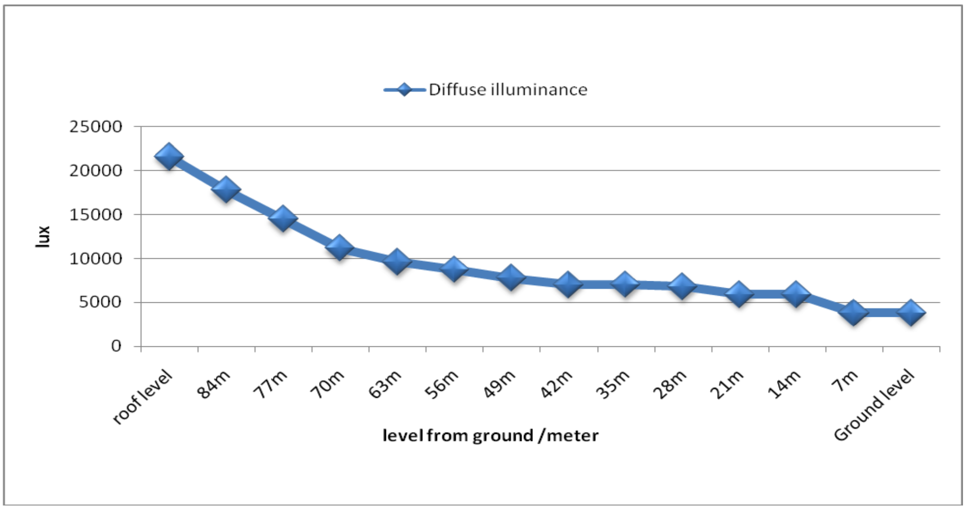


Figure 4.27 Yearly average diffuse illuminance falling to Al Mousa Tower on the 10-meter setback side facade, from roof to ground level.

4.1.3 Summary of results and findings for external facades tests

- Daylight illuminace falling on the north facade is uniform at the same time during the year.
- Problems of glare can accrue in the north direction only on June and July when the path of sun is located at the nearest point to north.
- Simple solution of small projection can provide proper protection for windows in north direction.
- South direction experiencing direct sun penetration during the day getting deeper in winter .
- South facing windows can be shaded relatively easy compared to east or west orientations.
- Horizontal shading can contribute to reduce the direct illuminance but does not provide full protection especially from the winter sun.

- Western elevation experience greater illumination levels up to 90000 lux in the afternoon hours throughout the entire year.
- The sun is located very low in the sky during the afternoon hours, which complicates shading solutions and makes horizontal shadings ineffective as protection method.
- Western facades receive relatively low illuminance levels on morning times especially in winter when the illuminance level lows below 5000lux in some days.
- Daylight illuminance falling to vertical surface recorded very low values in the lower floor levels between two buildings has a separation distance of 10 meter.

4.2 Simulations for internal daylight level in a generic office

This set of simulations will focus on the internal daylight performance for a generic office. The office model was constructed by 3D Max Design. As been presented in methodology office model had dimensions of 10X10 meter and a clear height of 3 meter. Office characteristics and parameters were mentioned previously in Chapter3.

results for the first set of simulations will be discussed into detail and focus on the main problems facing every orientation then the different solutions for every direction will be displayed after introducing UDI evaluation metric to clarify the measurements outcome in figures to be absorbed by anyone and summarize the huge excel data file into small chart.

As been discussed in the previous section, noontime does not make big challenge for all directions as sun is usually high in the sky and simple horizontal projection can always succeed to protect facade at this time. Since interior simulations consuming relatively more time than the external one because of the complicated calculations caused by surfaces reflections and glass refraction. Hence, this set of simulations will consider two timings only 9:00 am and 4:00 pm while 12:00 pm calculations was neglected.

The general hints given by the previous section about daylight light behavior on external facades is been reinforced and detailed here by internal office simulations.

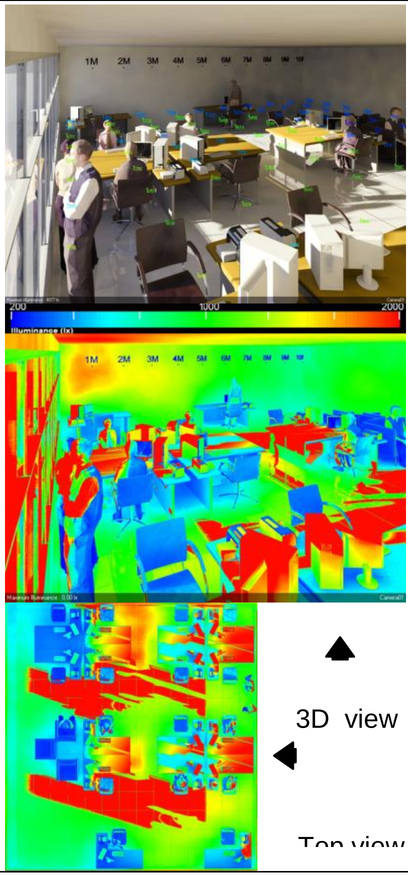
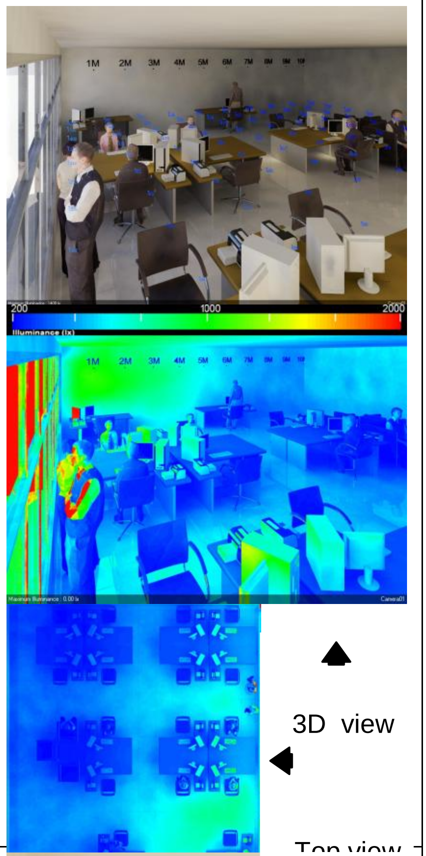
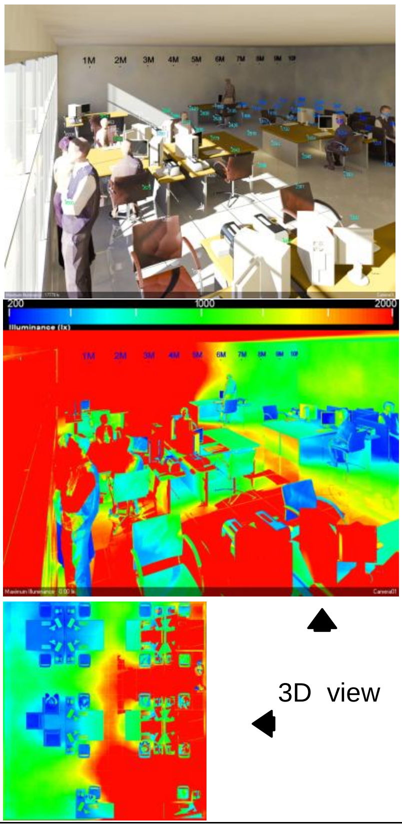
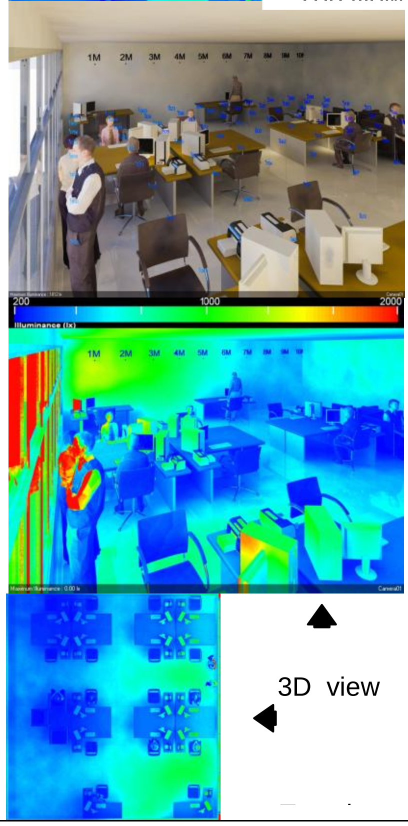
Following Table(4.5) summarizes the daylight demeanor in the west direction. Every cell in the table presents three images. First image shows a real time render with daylight values on the work plane (80cm height), the other two images give a pseudo gradient color for daylight values where the scale presented as 200 lux for the blue color and 2000 lux for the red color.

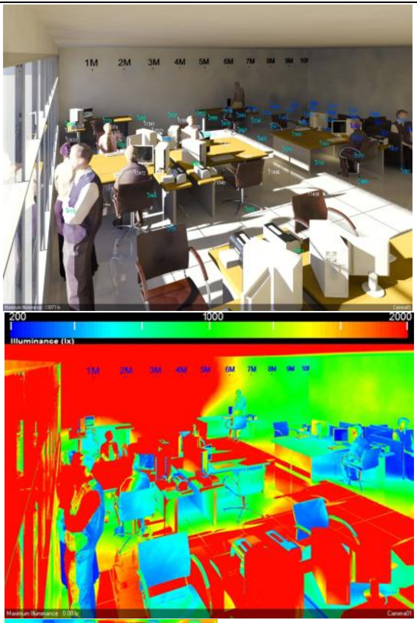
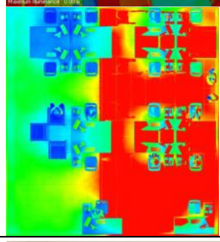
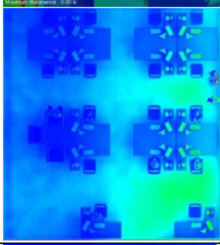
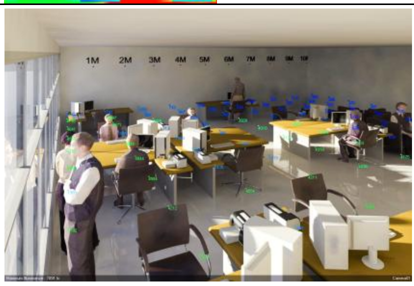
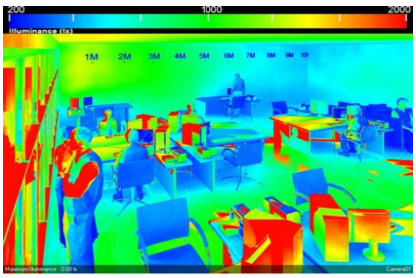
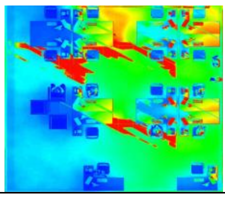
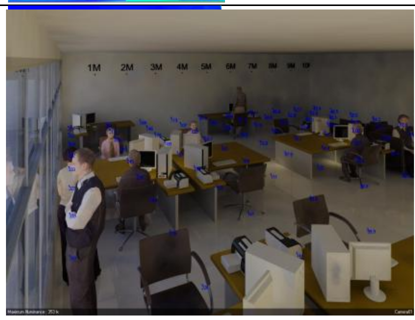
Studying Table 4.5 Reveals the following main issues:

- At 4:00 pm, West office space experiences excessive daylight illuminance especially in summer where the images are too bright (over exposed) and red color is covering the most of office area. Winter is less exposed and gradient colors look more to green and blue ,however the low sun angle in winter cause deeply penetrating for sun beams to inside office , as a result we can notice many red spots spread all over the room which is an important indication for glare .
- At 9:00 am West office look more stable from the afternoon time as there is no red spots. However, the office space look dark specially in the deep parts where it's blue most of the year. In winter the office look very gloomy and dark particularly in December.

Table 4.5 Internal simulations by 3Dmax Design for West oriented office on for seasonal months (March, June, September, December) at two times 9:00am and 4:00pm .

	Western Office at 4:00 pm	Western Office at 9:00 am

<table>
<tr><td>March</td><td>
</td><td>
</td></tr>
<tr><td>June</td><td>
</td><td>
</td></tr>
</table>

September	  3D view	  3D view
December	   3D view	  3D view

Simulations results came out also as Excel file format presenting a monthly based data. Following 300 rows table shows sample of Data been collected on March only from a Western oriented office.

Table 4.6 Partial excels sheet represent a measurements been collected from work plane level on March only.

Name	ID	Frame	Indirect	Direct	Total	Illum. Unit	Daylight F	Pos X	Pos Y	Pos Z	LightMeter	107	1	2515	1737	4252	lx	0	0.77	5.55	2.02
LightMeter	1	1	0	0	0	lx	0	-5.62	-4.57	2.02	LightMeter	108	1	2647	1737	4383	lx	0	1.84	5.55	2.02
LightMeter	2	1	69.7	0	69.7	lx	0	-4.55	-4.57	2.02	LightMeter	109	1	3060	1737	4797	lx	0	2.9	5.55	2.02
LightMeter	3	1	202	0	202	lx	0	-3.49	-4.57	2.02	LightMeter	110	1	3540	1737	5277	lx	0	3.97	5.55	2.02
LightMeter	4	1	209	0	209	lx	0	-2.42	-4.57	2.02	LightMeter	1	9	0	0	0	lx	0	-5.62	-4.57	2.02
LightMeter	5	1	234	0	234	lx	0	-1.36	-4.57	2.02	LightMeter	2	9	1.58	0	1.58	lx	0	-4.55	-4.57	2.02
LightMeter	6	1	244	0	244	lx	0	-0.29	-4.57	2.02	LightMeter	3	9	68.7	0	68.7	lx	0	-3.49	-4.57	2.02
LightMeter	7	1	271	0	271	lx	0	0.77	-4.57	2.02	LightMeter	4	9	80.2	0	80.2	lx	0	-2.42	-4.57	2.02
LightMeter	8	1	274	0	274	lx	0	1.84	-4.57	2.02	LightMeter	5	9	89.2	0	89.2	lx	0	-1.36	-4.57	2.02
LightMeter	9	1	282	0	282	lx	0	2.9	-4.57	2.02	LightMeter	6	9	104	0	104	lx	0	-0.29	-4.57	2.02
LightMeter	10	1	289	0	289	lx	0	3.97	-4.57	2.02	LightMeter	7	9	109	0	109	lx	0	0.77	-4.57	2.02
LightMeter	11	1	298	0	298	lx	0	-5.62	-3.56	2.02	LightMeter	8	9	121	0	121	lx	0	1.84	-4.57	2.02
LightMeter	12	1	303	0	303	lx	0	-4.55	-3.56	2.02	LightMeter	9	9	122	0	122	lx	0	2.9	-4.57	2.02
LightMeter	13	1	303	0	303	lx	0	-3.49	-3.56	2.02	LightMeter	10	9	123	0	123	lx	0	3.97	-4.57	2.02
LightMeter	14	1	314	0	314	lx	0	-2.42	-3.56	2.02	LightMeter	11	9	127	0	127	lx	0	-5.62	-3.56	2.02
LightMeter	15	1	314	0	314	lx	0	-1.36	-3.56	2.02	LightMeter	12	9	134	0	134	lx	0	-4.55	-3.56	2.02
LightMeter	16	1	332	0	332	lx	0	-0.29	-3.56	2.02	LightMeter	13	9	135	0	135	lx	0	-3.49	-3.56	2.02
LightMeter	17	1	338	0	338	lx	0	0.77	-3.56	2.02	LightMeter	14	9	137	0	137	lx	0	-2.42	-3.56	2.02
LightMeter	18	1	342	0	342	lx	0	1.84	-3.56	2.02	LightMeter	15	9	140	0	140	lx	0	-1.36	-3.56	2.02
LightMeter	19	1	349	0	349	lx	0	2.9	-3.56	2.02	LightMeter	16	9	140	0	140	lx	0	-0.29	-3.56	2.02
LightMeter	20	1	354	0	354	lx	0	3.97	-3.56	2.02	LightMeter	17	9	142	0	142	lx	0	0.77	-3.56	2.02
LightMeter	21	1	390	0	390	lx	0	-5.62	-2.55	2.02	LightMeter	18	9	155	0	155	lx	0	1.84	-3.56	2.02
LightMeter	22	1	395	0	395	lx	0	-4.55	-2.55	2.02	LightMeter	19	9	155	0	155	lx	0	2.9	-3.56	2.02
LightMeter	23	1	396	0	396	lx	0	-3.49	-2.55	2.02	LightMeter	20	9	159	0	159	lx	0	3.97	-3.56	2.02
LightMeter	24	1	399	0	399	lx	0	-2.42	-2.55	2.02	LightMeter	21	9	165	0	165	lx	0	-5.62	-2.55	2.02
LightMeter	25	1	433	0	433	lx	0	-1.36	-2.55	2.02	LightMeter	22	9	167	0	167	lx	0	-4.55	-2.55	2.02
LightMeter	26	1	442	0	442	lx	0	-0.29	-2.55	2.02	LightMeter	23	9	170	0	170	lx	0	-3.49	-2.55	2.02
LightMeter	27	1	461	0	461	lx	0	0.77	-2.55	2.02	LightMeter	24	9	172	0	172	lx	0	-2.42	-2.55	2.02
LightMeter	28	1	474	0	474	lx	0	1.84	-2.55	2.02	LightMeter	25	9	173	0	173	lx	0	-1.36	-2.55	2.02
LightMeter	29	1	487	1737	2223	lx	0	2.9	-2.55	2.02	LightMeter	26	9	177	0	177	lx	0	-0.29	-2.55	2.02
LightMeter	30	1	490	0	490	lx	0	3.97	-2.55	2.02	LightMeter	27	9	177	0	177	lx	0	0.77	-2.55	2.02
LightMeter	31	1	491	0	491	lx	0	-5.62	-1.54	2.02	LightMeter	28	9	183	0	183	lx	0	1.84	-2.55	2.02
LightMeter	32	1	503	0	503	lx	0	-4.55	-1.54	2.02	LightMeter	29	9	189	0	189	lx	0	2.9	-2.55	2.02
LightMeter	33	1	504	0	504	lx	0	-3.49	-1.54	2.02	LightMeter	30	9	192	0	192	lx	0	3.97	-2.55	2.02
LightMeter	34	1	512	0	512	lx	0	-2.42	-1.54	2.02	LightMeter	31	9	198	0	198	lx	0	-5.62	-1.54	2.02
LightMeter	35	1	515	0	515	lx	0	-1.36	-1.54	2.02	LightMeter	32	9	200	0	200	lx	0	-4.55	-1.54	2.02
LightMeter	36	1	529	0	529	lx	0	-0.29	-1.54	2.02	LightMeter	33	9	203	0	203	lx	0	-3.49	-1.54	2.02
LightMeter	37	1	541	0	541	lx	0	0.77	-1.54	2.02	LightMeter	34	9	203	0	203	lx	0	-2.42	-1.54	2.02
LightMeter	38	1	558	1737	2295	lx	0	1.84	-1.54	2.02	LightMeter	35	9	204	0	204	lx	0	-1.36	-1.54	2.02
LightMeter	39	1	560	0	560	lx	0	2.9	-1.54	2.02	LightMeter	36	9	204	0	204	lx	0	-0.29	-1.54	2.02
LightMeter	40	1	570	1737	2306	lx	0	3.97	-1.54	2.02	LightMeter	37	9	206	0	206	lx	0	0.77	-1.54	2.02
LightMeter	41	1	572	0	572	lx	0	-5.62	-0.53	2.02	LightMeter	38	9	207	0	207	lx	0	1.84	-1.54	2.02
LightMeter	42	1	578	0	578	lx	0	-4.55	-0.53	2.02	LightMeter	39	9	211	0	211	lx	0	2.9	-1.54	2.02
LightMeter	43	1	579	0	579	lx	0	-3.49	-0.53	2.02	LightMeter	40	9	217	0	217	lx	0	3.97	-1.54	2.02
LightMeter	44	1	606	0	606	lx	0	-2.42	-0.53	2.02	LightMeter	41	9	220	0	220	lx	0	-5.62	-0.53	2.02
LightMeter	45	1	608	0	608	lx	0	-1.36	-0.53	2.02	LightMeter	42	9	221	0	221	lx	0	-4.55	-0.53	2.02
LightMeter	46	1	615	0	615	lx	0	-0.29	-0.53	2.02	LightMeter	43	9	233	0	233	lx	0	-3.49	-0.53	2.02
LightMeter	47	1	621	1737	2358	lx	0	0.77	-0.53	2.02	LightMeter	44	9	233	0	233	lx	0	-2.42	-0.53	2.02
LightMeter	48	1	627	1737	2363	lx	0	1.84	-0.53	2.02	LightMeter	45	9	243	0	243	lx	0	-1.36	-0.53	2.02
LightMeter	49	1	645	1737	2382	lx	0	2.9	-0.53	2.02	LightMeter	46	9	247	0	247	lx	0	-0.29	-0.53	2.02
LightMeter	50	1	648	0	648	lx	0	3.97	-0.53	2.02	LightMeter	47	9	249	0	249	lx	0	0.77	-0.53	2.02
LightMeter	51	1	691	0	691	lx	0	-5.62	0.49	2.02	LightMeter	48	9	249	0	249	lx	0	1.84	-0.53	2.02
LightMeter	52	1	698	0	698	lx	0	-4.55	0.49	2.02	LightMeter	49	9	259	0	259	lx	0	2.9	-0.53	2.02
LightMeter	53	1	699	0	699	lx	0	-3.49	0.49	2.02	LightMeter	50	9	259	0	259	lx	0	3.97	-0.53	2.02
LightMeter	54	1	701	1737	2437	lx	0	-2.42	0.49	2.02	LightMeter	51	9	262	0	262	lx	0	-5.62	0.49	2.02
LightMeter	55	1	705	1737	2442	lx	0	-1.36	0.49	2.02	LightMeter	52	9	265	0	265	lx	0	-4.55	0.49	2.02
LightMeter	56	1	706	0	706	lx	0	-0.29	0.49	2.02	LightMeter	53	9	266	0	266	lx	0	-3.49	0.49	2.02
LightMeter	57	1	721	1737	2458	lx	0	0.77	0.49	2.02	LightMeter	54	9	269	0	269	lx	0	-2.42	0.49	2.02
LightMeter	58	1	734	0	734	lx	0	1.84	0.49	2.02	LightMeter	55	9	276	0	276	lx	0	-1.36	0.49	2.02
LightMeter	59	1	750	0	750	lx	0	2.9	0.49	2.02	LightMeter	56	9	279	0	279	lx	0	-0.29	0.49	2.02
LightMeter	60	1	763	0	763	lx	0	3.97	0.49	2.02	LightMeter	57	9	288	0	288	lx	0	0.77	0.49	2.02
LightMeter	61	1	767	0	767	lx	0	-5.62	1.5	2.02	LightMeter	58	9	290	0	290	lx	0	1.84	0.49	2.02
LightMeter	62	1	768	0	768	lx	0	-4.55	1.5	2.02	LightMeter	59	9	296	0	296	lx	0	2.9	0.49	2.02
LightMeter	63	1	771	1737	2508	lx	0	-3.49	1.5	2.02	LightMeter	60	9	296	0	296	lx	0	3.97	0.49	2.02
LightMeter	64	1	808	1737	2545	lx	0	-2.42	1.5	2.02	LightMeter	61	9	298	0	298	lx	0	-5.62	1.5	2.02
LightMeter	65	1	815	1737	2552	lx	0	-1.36	1.5	2.02	LightMeter	62	9	303	0	303	lx	0	-4.55	1.5	2.02
LightMeter	66	1	827	1737	2564	lx	0	-0.29	1.5	2.02	LightMeter	63	9	306	0	306	lx	0	-3.49	1.5	2.02
LightMeter	67	1	837	0	837	lx	0	0.77	1.5	2.02	LightMeter	64	9	318	0	318	lx	0	-2.42	1.5	2.02
LightMeter	68	1	866	1737	2603	lx	0	1.84	1.5	2.02	LightMeter	65	9	319	0	319	lx	0	-1.36	1.5	2.02
LightMeter	69	1	932	0	932	lx	0	2.9	1.5	2.02	LightMeter	66	9	324	0	324	lx	0	-0.29	1.5	2.02
LightMeter	70	1	937	1737	2674	lx	0	3.97	1.5	2.02	LightMeter	67	9	324	0	324	lx	0	0.77	1.5	2.02
LightMeter	71	1	972	1737	2709	lx	0	-5.62	2.51	2.02	LightMeter	68	9	329	0	329	lx	0	1.84	1.5	2.02
LightMeter	72	1	974	1737	2711	lx	0	-4.55	2.51	2.02	LightMeter	69	9	337	0	337	lx	0	2.9	1.5	2.02
LightMeter	73	1	975	0	975	lx	0	-3.49	2.51	2.02	LightMeter	70	9	338	0	338	lx	0	3.97	1.5	2.02
LightMeter	74	1	983	1737	2720	lx	0	-2.42	2.51	2.02	LightMeter	71	9	344	0	344	lx	0	-5.62	2.51	2.02
LightMeter	75	1	987	0	987	lx	0	-1.36	2.51	2.02	LightMeter	72	9	359	0	359	lx	0	-4.55	2.51	2.02
LightMeter	76	1	991	1737	2728	lx	0	-0.29	2.51	2.02	LightMeter	73	9	361	0	361	lx	0	-3.49	2.51	2.02
LightMeter	77	1	1005	1737	2742	lx	0	0.77	2.51	2.02	LightMeter	74	9	367	0	367	lx	0	-2.42	2.51	2.02
LightMeter	78	1	1019	0	1019	lx	0	1.84	2.51	2.02	LightMeter	75	9	369	0	369	lx	0	-1.36	2.51	2.02
LightMeter	79	1	1027	0	1027	lx	0	2.9	2.51	2.02	LightMeter	76	9	388	0	388	lx	0	-0.29	2.51	2.02
LightMeter	80	1	1038	1737	2774	lx	0	3.97	2.51	2.02	LightMeter	77	9	392	0	392	lx	0	0.77	2.51	2.02
LightMeter	81	1	1069	1737	2806	lx	0	-5.62	3.52	2.02	LightMeter	78	9	395	0	395	lx	0	1.84	2.51	2.02
LightMeter	82	1	1133	1737	2869	lx	0	-4.55	3.52	2.02	LightMeter	79	9	410	0	410	lx	0	2.9	2.51	2.02
LightMeter	83	1	1137	1737	2873	lx	0	-3.49	3.52	2.02	LightMeter	80	9	411	0	411	lx	0	3.97	2.51	2.02
LightMeter	84	1	1152	1737	2889	lx	0	-2.42	3.52	2.02	LightMeter	81	9	412	0	412	lx	0	-5.62	3.52	2.02
LightMeter	85	1	1189	1737	2926	lx	0	-1.36	3.52	2.02	LightMeter	82	9	422	0	422	lx	0	-4.55	3.52	2.02
LightMeter	86	1	1197	0	1197	lx	0	-0.29	3.52	2.02	LightMeter	83	9	447	0	447	lx	0	-3.49	3.52	2.02
LightMeter	87	1	1222	1737	2959	lx	0	0.77	3.52	2.02	LightMeter	84	9	454	0	454	lx	0	-2.42	3.52	2.02
LightMeter	88	1	1229	0	1229	lx	0	1.84	3.52	2.02	LightMeter	85	9	463	0	463	lx	0	-1.36	3.52	2.02
LightMeter	89	1	1256	1737	2993	lx	0	2.9	3.52	2.02	LightMeter	86	9	484	0	484	lx	0	-0.29	3.52	2.02
LightMeter	90	1	1273	1737	3010	lx	0	3.97	3.52	2.02	LightMeter	87	9	503	0	503	lx	0	0.77	3.52	2.02
LightMeter	91	1	1280	1737	3017	lx	0	-5.62	4.53	2.02	LightMeter	88	9	512	0	512	lx	0	1.84	3.52	2.02
LightMeter	92	1	1325	0	1325	lx	0	-4.55	4.53	2.02	LightMeter	89	9	536	0	536	lx	0	2.9	3.52	2.02
LightMeter	93	1	1352	1737	3089	lx	0	-3.49	4.53	2.02	LightMeter	90	9	540	0	540	lx	0	3.97	3.52	2.02
LightMeter	94	1	1479	0	1479	lx	0	-2.42	4.53	2.02	LightMeter	91	9	605	0	605	lx	0	-5.62	4.53	2.02
LightMeter	95	1	1492	0	1492	lx	0	-1.36	4.53	2.02	LightMeter	92	9	610	0	610	lx	0	-4.55	4.53	2.02
LightMeter	96	1	1526	1737	3263	lx	0	-0.29	4.53	2.02	LightMeter	93	9	620	0	620	lx	0	-3.49	4.53	2.02
LightMeter	97	1	1540	1737	3277	lx	0	0.77	4.53	2.02	LightMeter	94	9	637	0	637	lx	0	-2.42	4.53	2.02
LightMeter	98	1	1567	1737	3304	lx	0	1.84	4.53	2.02	LightMeter	95	9	638	0	638	lx	0	-1.36	4.53	2.02
LightMeter	99	1	1575	0	1575	lx	0	2.9	4.53	2.02	LightMeter	96	9	638	0	638	lx	0	-0.29	4.53	2.02
LightMeter	100	1	1610	1737	3347	lx	0	3.97	4.53	2.02	LightMeter	97	9	648	0	648	lx	0	0.77	4.53	2.02
LightMeter	101	1	1704	1737	3441	lx	0	-5.62	5.55	2.02	LightMeter	98	9	648	0	648	lx	0	1.84	4.53	2.02
LightMeter	102	1	1897	1737	3633	lx	0	-4.55	5.55	2.02	LightMeter	99	9	685	0	685	lx	0	2.9	4.53	2.02
LightMeter	103	1	2103	1737	3840	lx	0	-3.49	5.55	2.02	LightMeter	100	9	688	0	688	lx	0	3.97	4.53	2.02
LightMeter	104	1	2224	0	2224	lx	0	-2.42	5.55	2.02	LightMeter	101	9	698	0	698	lx	0	-5.62	5.55	2.02
LightMeter	105	1	2307	1737	4044	lx	0	-1.36	5.55	2.02	LightMeter	102	9	824	0	824	lx	0	-4.55	5.55	2.02
LightMeter	106	1	2335	0	2335	lx	0	-0.29	5.55	2.02	LightMeter	103	9	825	0	825	lx	0	-3.49	5.55	2.02

Full year data measurements requires 12 tables like that shown in Table(4.6). 3600 rows of measurements are representing one simulation over the course of one year for. Therefore, using the measurements as its in current situation defiantly is ineffective to make evaluation for office daylight performance. For that reason, Excel data should be simplified to be effectively used for different comparison tests. The following section is discussing how Excel data going to be presented as UDI charts in order to simplify the complicated characteristics of climate-based analyses in brief and clear comprehensible form.

4.3 Useful daylight illumination (UDI) as evaluation metric

As been noted by Nabil and Mardaljevic (2006), UDI provides a convenient method of assessing daylight and solar penetration by using dynamic climate-based conditions that change across various locations and orientations. The aims of this study is to demonstrate how the UDI metric can be constructed from the huge excel measurements in order to be used as fast evaluating metric for different design solutions. The UDI scheme is both richly informative and extremely simple. It would give a designer of a space quick indication of likely tendency for discomfort, potential high or low levels of illumination and solar gains for a space given its specific characteristics. In addition, UDI gives an idea about daylight distribution and space uniformity.

UDI metric criteria

As been discussed in the literature review there has been disagreement among the few investigators who have used UDI as evaluation metric primarily on an acceptable upper UDI limit for human comfort. As this study is based in Dubai, the heating gain factor of daylighting has to be considered in the metric criteria. This study will adopt (Li, 2007) scale taking 1000 lux as the upper illuminance level. Note, however, 2000 lux is also considered acceptable value for human eye but it would lead to heat gain, which is not acceptable for the hot UAE climate.

UDI ranges is summarized as follows:

- Low Daylight Illuminance (LDI) when daylight illuminance less than 200 lux .

- Useful Daylight Illuminance(UDI) when daylight illuminance in the range 200–1000 lux .
- High Daylight Illuminance (HDI) when Daylight illuminance in exceeds 1000 lux .

A light meter grid with 100 measurement points (10X10) was uniformly distributed on plan across the workplane (height 0.8 m) above the ground level inside the generic office model Figure (4.28). The average illuminances levels were recorded at each of these points at (9:00am & 4:00pm) one day per month over the course of one year. The total number of illuminance values computed in every simulation therefore was (2X100 points X12 months) = 2400 values.

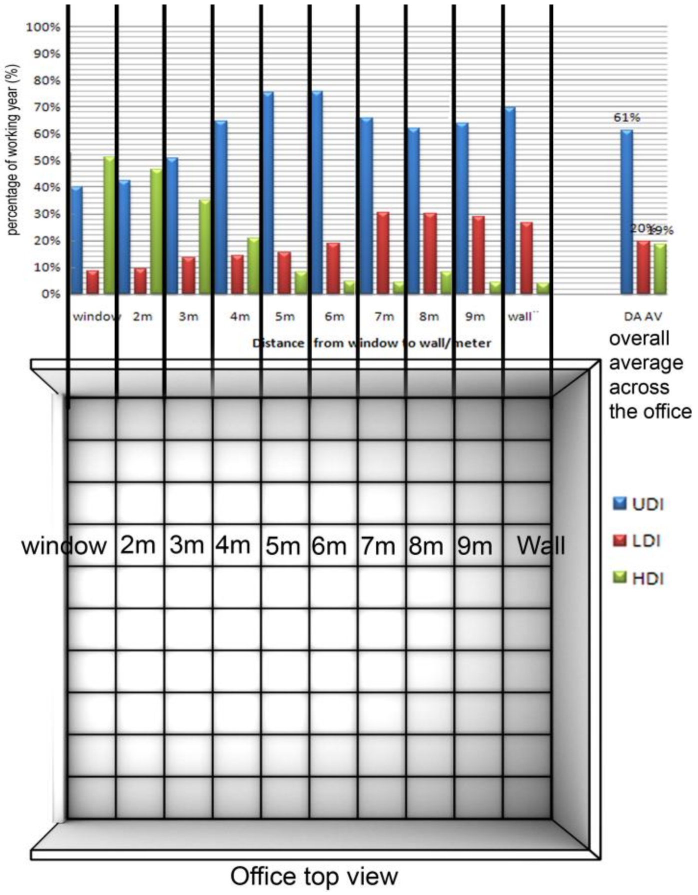


Figure 4.28 UDI metric graph example giving data about the percentage of year that every meter in the office achieving UDI,HDI and LDI.

Figure (4.28) shows final UDI metric graph. it's been described as following :

- The 2400 measurements were grouped into 10 bins of columns representing the office depth measured from window wall (meter #1) to internal wall (meter #10).
- Every group of bars in the graph contains three UDI metrics (UDI in blue, LDI in red and HDI in green).
- The value at each light meter grid node on the office plan is classified under one of these three mentioned categories. For example when the value is less than 200 lux the point will be determined as LDI(red), when the illuminance detected falls between 200 to 1000 its classified as UDI(blue) and if detected illuminance at the point exceeds1000 lux it is classified as HDI(green).
- The final results are represented as a percentage of the working year (%)
- There are additional group of columns on the right showing the UDI average for the whole office space.

Examples for graph description:

Ex1. The workspaces within the first 1 meter (adjacent to window) achieve UDI (200-1000lux) for 40% of the year, while workspaces within 9 -10 meters from the window (adjacent to internal wall) achieve UDI for up to 70% of the working year.

Ex1. The workspaces within the first 1 meter (adjacent to window) get over exposed for up to 50% of the year with illuminance exceeding 1000lux.This percentage of HDI start falling to below 5% as one moves further away from the window.

Ex3. The percentage of the time in the working year when UDI was achieved in the whole office is 61%; it means that this office can be lit using daylight only for more than 60% of the working year.

In General UDI levels between 80%-100% represent excellent daylight designs parameters, while good daylighting designs could fall to a range 60%-80% UDI average range. 60% UDI average and below indicating for low daylight design performance, CHPS (2006).

Based on the UDI graph readings, investigator can be with ease evaluate the space performance and pin out day lighting problems either to do with high levels of illumination associated with discomfort and solar gains or low illuminated areas.

(UDI) Tests for Different office parameters, levels and orientations

To determine the suitable benchmark levels that define good daylighting in office using UDI evaluation metric discussed above, series of tests were conducted and the UDI metric were calculated for each test. Some parameters such as office dimension (10mX10mX3m) and workplane level (80cm from FFL) were held constant throughout the different tests. Other parameters however were altered. These are, changes to:-

- External Glass Visible Transmittance (VT),
- Orientation
- Vertical obstructions and office level
- Shading treatments

This has been carried out so that investigator may test how one or a group of these parameters can affect daylight performance.

The following sections present series of tests, each test will be summarized by a UDI graph. First three sets of tests will investigate the UDI for different orientations and parameters, while the last two sets of simulations will focus on how UDI change with different levels and building separations (setback). Table 4.7 classifies the different tests in the following section.

Table 4.7 General description and classification for UDI simulations

glass VT and shading treatments						
	4.3.1	**Test N.1**	**Test N.2**	**Test N.3**	**Test N.4**	
	North oriented office	North oriented office flushed glazing and glass VT of 70%	North oriented office with 40 cm recess glaze glass VT of 70%	North oriented office 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part	North oriented office with 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading	
	4.3.2	**Test S.1**	**Test S.2**	**Test S.3**	**Test S.4**	**Test S.5**
	South oriented office	South oriented office flushed glazing and glass VT of 70%	South oriented office 40 cm recessed glaze VT 70% in the low part &clear glass in the	South oriented office with 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading projection of 50cm	South oriented office with 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading projection of 50cm to outside and 50 cm to inside	South oriented office with 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading projection of 50cm and 50cm vertical projections.
	4.3.3	**Test W.1**	**Test W.2**	**Test W.3**	**Test W.4**	**Test W.5**
	West orient	West oriented	West oriented	West oriented	West oriented	West oriented

	ed office	office flushed glazing and glass VT of 70%.	office 40 cm recessed glaze VT 70% in the low part &clear glass in the.	office 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading projection	office 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with shading projection rotated towards east.	office 40 cm recessed glaze VT 70% in the low part &clear glass in the upper part with dynamic vertical shadings.
Tests for offices in different buildings forms ,	4.3.4.1 Square building layout	**Test SQ.1** square plan in high level with 10 meter setback from neighbor glass VT 70%.	**Test SQ.2** square plan in a intermediate level with 10 meter setback from neighbor glass VT 70%.	**Test SQ.3** square plan in a low level with 10 meter setback from neighbor glass VT 70%.	**Test SQ.4** square plan in a low level with 10 meter setback from neighbor clear glass.	

	4.3.4.2 Rectangular building layout	**Test RE.1** Rectangular plan in a high level with 25 meter setback from neighbor glass VT 70%.	**Test RE.2** Rectangular plan in a intermediate level with 25 meter setback from neighbor glass VT 70%.	**Test RE.3** Rectangular plan in a low level with 25 meter setback from neighbor glass VT 70%.	**Test RE.4** Rectangular plan in a low level with 25 meter setback from neighbor Clear glass.

4.3.1 UDI for North facing Offices

Offices receive indirect Daylight through north facing windows, this orientation receiving fewer possibilities for glare problems. This set of simulations evaluates UDI for a generic office with a northern facade.

Test N.1

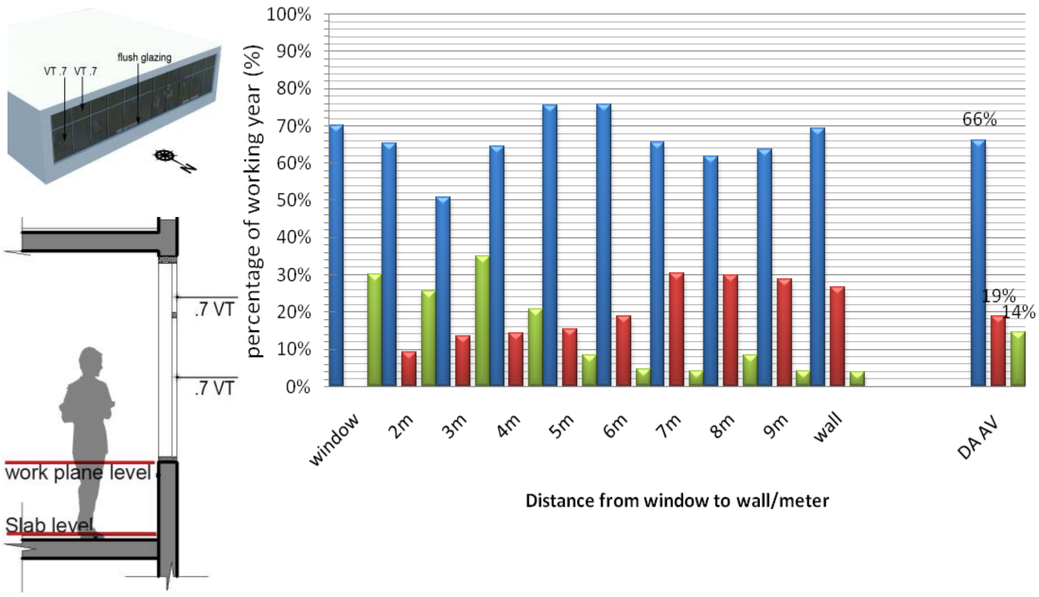


Figure 4.29 UDI for North oriented office and flush glazing facade with glass VT 70%.

Figure (4.29) shows UDI chart for North oriented office with a flush glazing facade and a glass VT of 70%. The UDI total average recorded as 66% indicates good daylight performance .However, workspaces nearer to the window receiving high luminance values for around 30% of the year, while workspaces areas deeper inside the office (beyond 4 meters from the window) are fairly dark as LDI reaches highs of 30% of the working year. The sun hits the north office facade at a very narrow angle causing this high illuminance values. The next test will investigate this by use of a redesigned glass facade that will be recessed by 40cm in order to give some protection from the high illuminance daylight values on June and July.

Test N.2

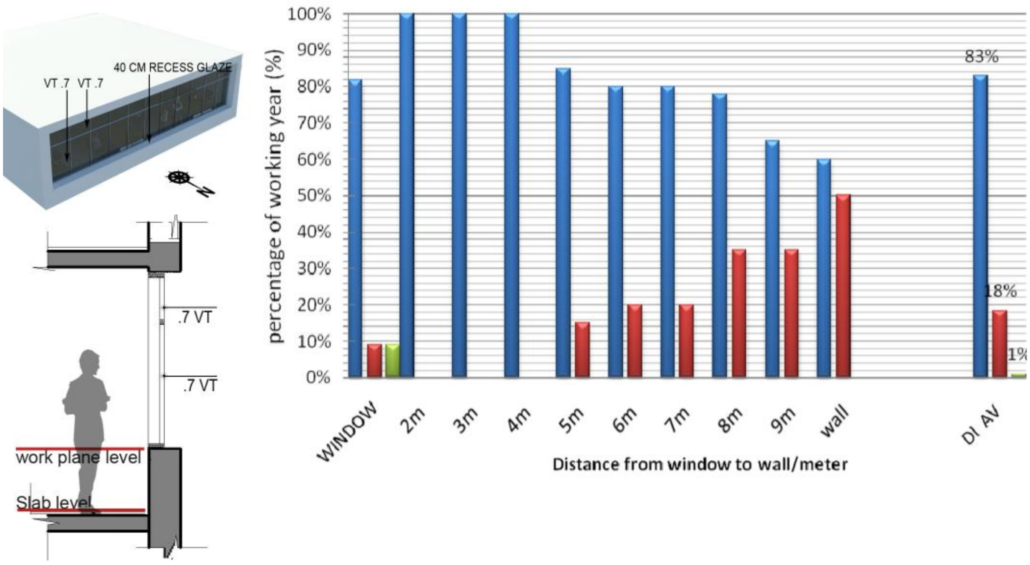


Figure 4.30 UDI for North oriented office, 40cm recessed glass and glass VT 70%

Figure (4.30) shows UDI chart for North oriented office with window recessed by 40cm recessed facade and with a glass VT of 70%. Results indicate daylight performance has raised significantly, with UDI at 83% for the year. For worktop areas within 1 to 4 meters from the window wall, a very desirable UDI of 100% of the working year is achieved. The LDI average is nearly similar to the previous test but the distribution is different . The deeper work areas record higher values of LDI than in the previous test while the areas closer to the windows have 0% LDI. A small percentage (10%) of LDI and HDI is recorded adjacent to the window.

The next test will retain the recessed window but change the VT value for the glass, in an attempt to let more light penetration to the deep points inside the office.

Test N.3

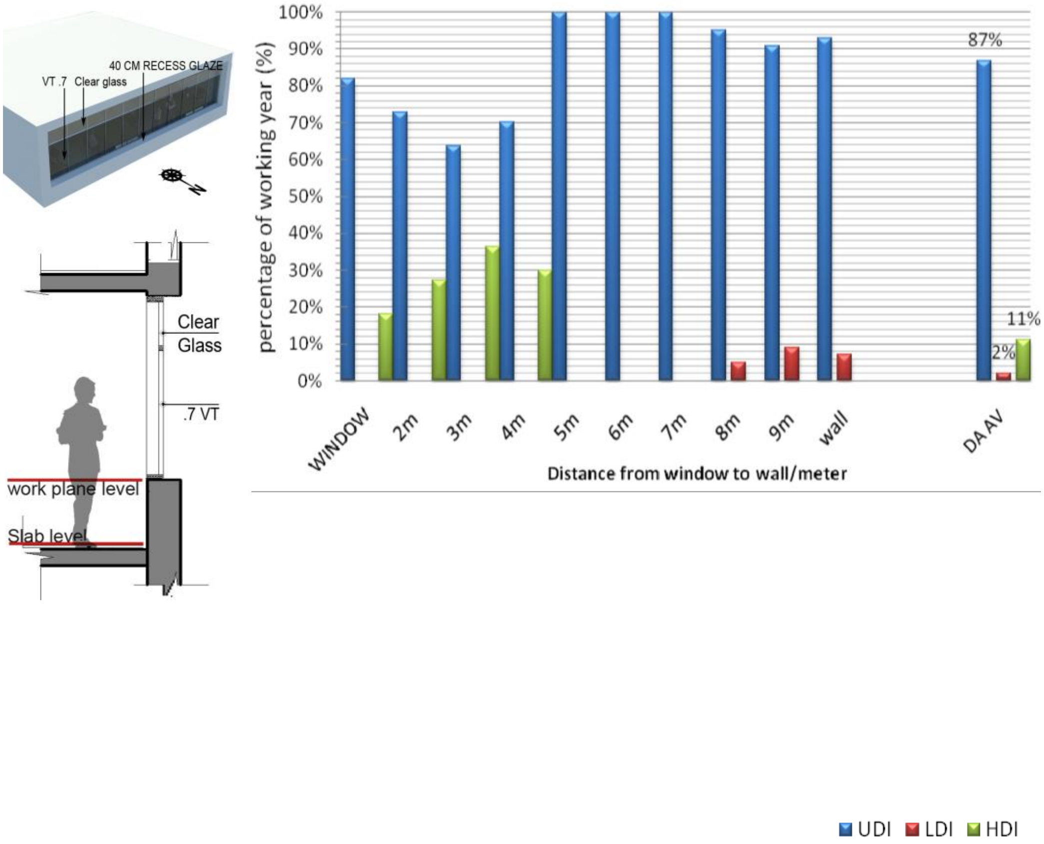


Figure 4.31 UDI for North oriented office, 40cm recessed glass and glass VT 70% for the lower panel and clear glass for the upper part.

A separate test was carried out before this one with the entire glazing panel replaced with a clear glass with a VT of 100%. The initial results indicated a rise in HDI to 70% hence this option was not investigated further. This experiment has therefore been set up with the upper panel of glazing as clear glass to let in more daylight to internal spaces and lower panel with a VT of 70% to protect space adjacent to the window. Figure (4.31) shows UDI chart for North Oriented office with a 40cm recessed façade, a glass VT of 70% for lower panels of window opening and clear glass with a VT of 100% in the upper part. In this test UDI average came more with 87% indicating for excellent design parameters. Worktops deeper into the space have quite comfortable illuminance level for most of the year. In spite of this HDI has occurred again 4 meters from the window wall. The next test will try to sustain the low LDI records achieved in this test but also reduce HDI that has been recorded within the office spaces nearer the window wall.

Test N.4

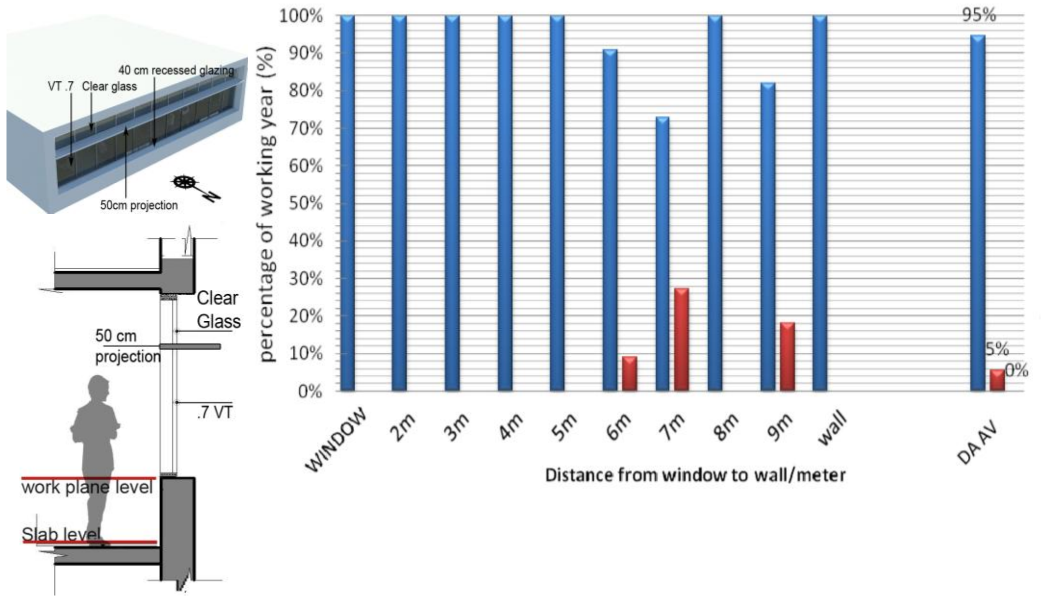


Figure 4.32 UDI for North oriented office, 40cm recessed glass and glass VT 70% for the lower panel and clear glass for the upper part with 40 prjection fitted along the glazing partition.

UDI LDI HDI

Figure (4.32) shows UDI chart for North oriented office with a 40cm recessed glazed façade, with a lower glass planes with VT of 70% and clear upper glass planes with VT 100% in the upper part and a horizontal projection of 40 cm fitted along the glazing partition between the upper and the lower panels of glass. UDI average is much more ideal with averaging at 95% of the working year. Workspaces within the first 5metres from the window record an average UDI of 100% of the working year. The deeper areas in the office also recorded average UDI of 100% while some intermediate minimal areas still have some LDI values. This result demonstrates the multiple roles that projection play, as shading device for the workspaces adjacent to the window wall and as a sunlight reflector shelf for deeper workspaces.

4.3.2 UDI for South facing Office

As noted earlier in the first set of simulations for external surfaces, South facing facades in the UAE have the probability of experiencing direct solar penetration during day. We also noted earlier that South facing windows could be protected from extreme direct sunlight at noon when the sun is located high in the sky by use of horizontal shading devices while vertical protection might be required during the morning and afternoon hours. As in the previous set of tests, the following tests will investigate UDI for south oriented office with parameters progressively altered to create maximum UDI for the internal space. From the external tests, we can expect that this orientation will be relatively easy compared to east or west orientations. Also, the direct sun incident on a south fenestration can also be reflected into the building with light shelves as has been indicated for North oriented spaces which would provide for deeper light penetration and more diffused daylight.

Test S.1

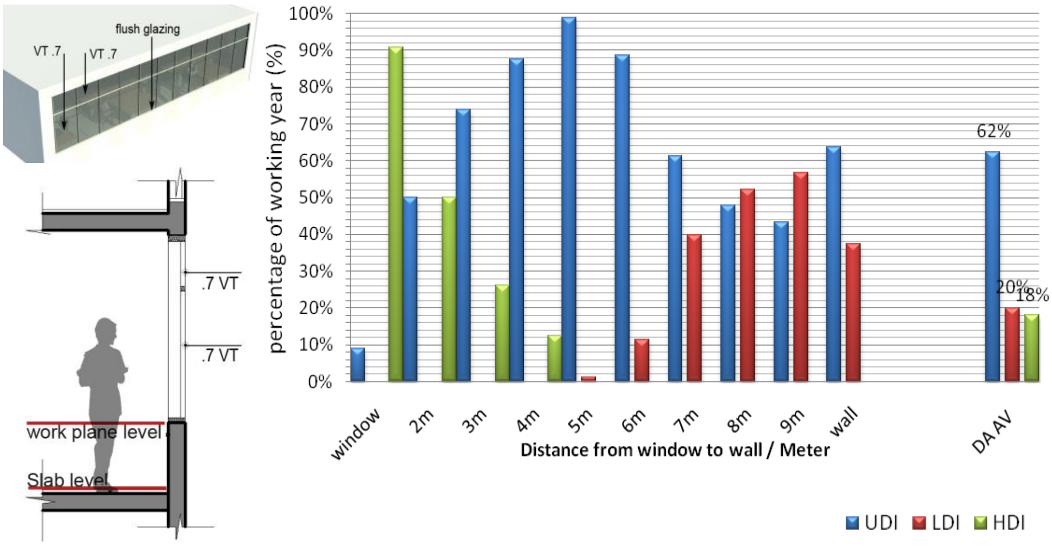


Figure 4.33 UDI for South oriented office . Flush glazing facade with Glass VT 70%.

Figure (4.33) shows UDI chart for South oriented office with glazing fixed flush with slab level and glass VT of 70%. This office achieves a useful daylight illuminance on average 62% of the year. This indicates relatively less performance for offices in South orientation compared to the same parameters for offices in North orientation. The HDI average is 18% but because the sun is at a high altitude, the high illuminance values are dominant nearer the window wall (exposed for 90% of the year) and in contrast, the deeper office spaces receive unfavorable LDI of up to 60% of the working year. It is evident that the office space requires some protective treatment that does not adversely affect the already reduced UDI in the deeper spaces.

Test S.2

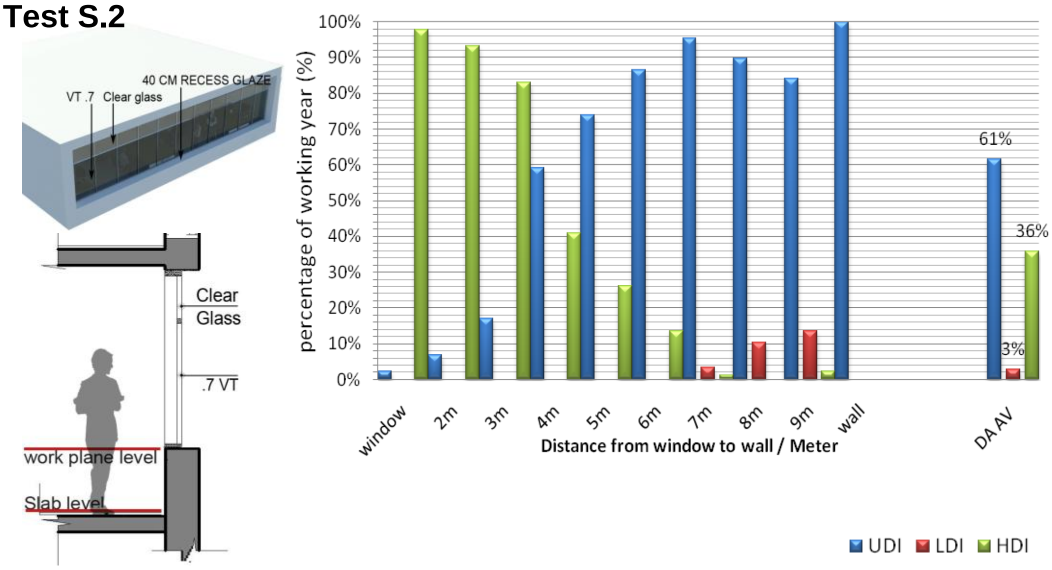


Figure 4.34 UDI for South oriented and 40cm recessed glass .Glass VT is 70% in the lower panel, and upper panel is clear glass panel.

Figure (4.34) shows UDI chart for South Oriented office with a 40 cm recessed glazing, a lower panel glass with VT of 70%, and upper panel is clear glass panel. The UDI average remained nearly the same at 61% and the deeper areas performing very well with LDI averaging 3%. However, changing the upper glass unit to clear glass has further negatively affected the front office as HDI have increased to an unacceptable 99%. The next test will provide the same office with horizontal shading protection and test its effect on this high HDI.

Test S.3

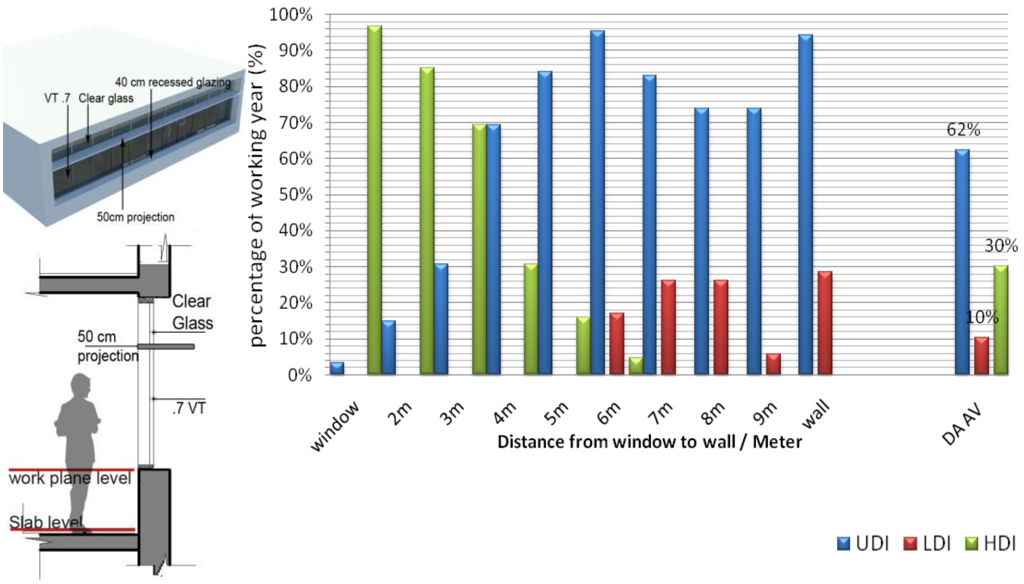


Figure 4.35 UDI for South oriented office, 40cm recessed glass with glass VT 70% for the lower panel and clear glass for the upper part .50cm projction fitted along the glazing partition.

Figure (4.35) shows UDI chart for South Oriented office have the same parameters of the previous test but this time a horizontal projection of

50cm is been provided in the partition area between clear glass and the 70% VT glass. UDI average was not affected in this test. However, horizontal shading device gave very limited improvements to HDI levels while it affected deep points negatively as LDI is raised next test will duplicate the horizontal shading device size to be 1 meter.

Test S.4

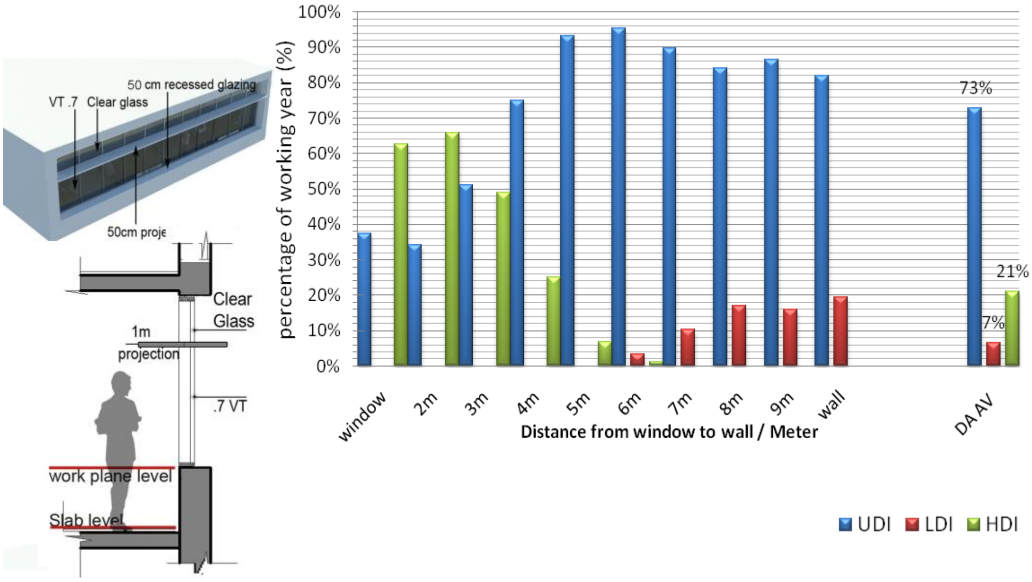


Figure 4.36 UDI for South oriented office, 40cm recessed glass with glass VT 70% for the lower panel and clear glass for the upper part with 50cm projection fitted to outside and 50 cm projection to inside the office.

In Figure (4.36) simulation was conducted for the same previous office parameters, but horizontal shading size is been increased to 1meter. The 50 cm additive part projected to internal side office in trial to work as light shelf reflecting illuminance into the office, providing deeper penetration and more diffused daylight in the deep points.UDI average shows good improvements as it jumped to 73%. The intermediate spaces are now performing well as they have around 90% UDI. However still front areas are over exposed with around 65% HDI. Excel file is been checked back to point out the reason for high illuminance parts. It's been found that winter months is behind high illuminance values when the sun is relatively low in the sky. Increasing shading size again is ineffective as its not protecting the space from side sunbeams. Next set will add some vertical shadings to check how they affect UDI performance.

Test S.5

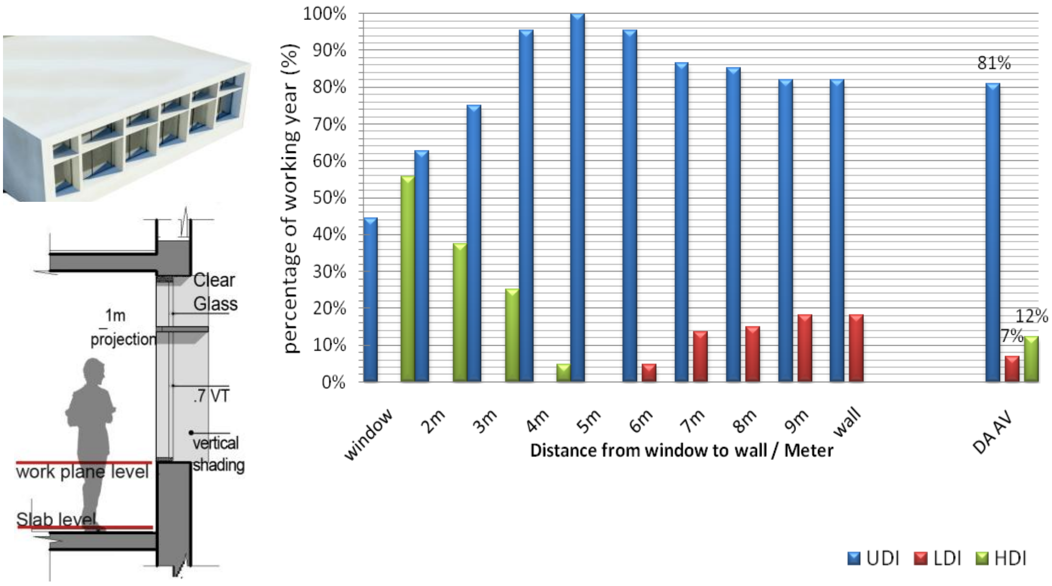


Figure 4.37 UDI for North oriented office, 40cm recessed glass and glass VT 70% for the lower panel and clear glass for the upper part with 50 prjection fitted along the glazing partition and serious of 50cm vertical shadings.

Figure (4.37) shows how the UDI is been affected after adding 4 vertical shadings (50cm each). Significant improvements have been achieved as UDI average raised to 81%. Still there is some high illuminance parts came in very low angel in December and January. These office parameters are forming relatively excellent design parameters for South oriented office. Moreover, there is still a possibility to increase UDI by increasing the vertical shading depth.

4.3.3 UDI for West facing Office

With reference to external facade tests, east and West facing windows are the most difficult to provide exterior shading for because sun is located very low in the sky making horizontal shades ineffective against the morning and afternoon times. West facing windows receive more direct illuminance and solar radiation, usually that leading to glare and overheating problems. Having ideal western office is nearly impossible. This series of tests will try to reduce the negative impacts of the direct sun illuminance in order to achieve higher UDI percentage.

Test W.1

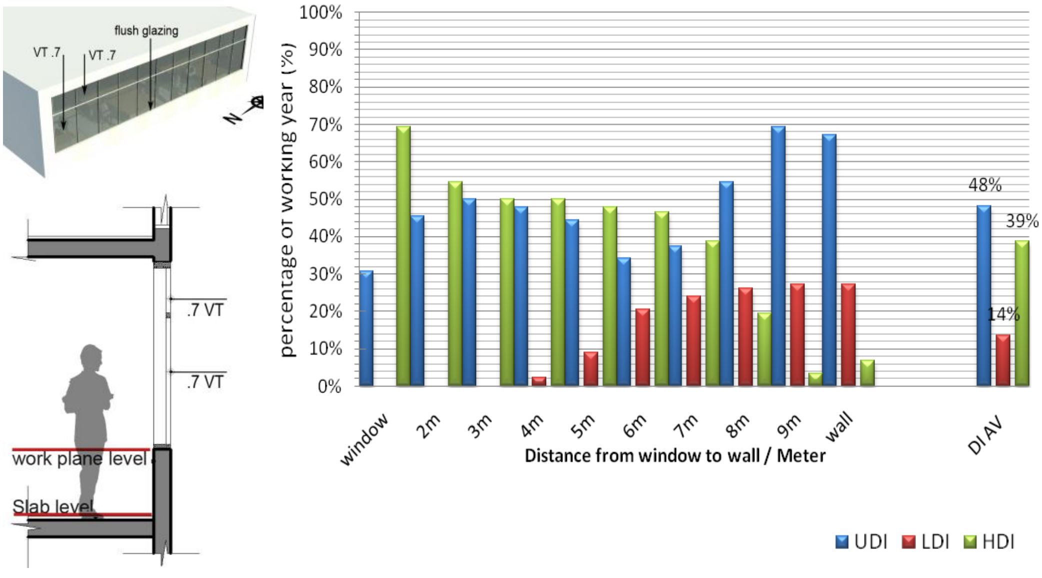


Figure 4.38 UDI for West oriented office. Flush glazing facade with Glass VT 70%.

Figure (4.38) represent UDI values for west oriented office having glazing fixed flush with slab level and glass VT of 70%. Compared to a (66%)UDI average in north and (61%) in south orientation . UDI average here came relatively very low with (48%) for the same office parameters . As the sun low angle allow illuminance to penetrate deeply inside the space, this chart represent high values of HDI as far as 8 meters deep inside the office. LDI also seems to be high in the last five meters. There is clear intersection between HDI and LDI values in meter number 6,7,8,9 and 10. These intersections are reinforcing our previous tests results for illuminance falling on external facade where those results recorded big differentiations between illuminance values falling to the west vertical surface in morning and afternoon times. Accordingly, mission is quiet complicated as the same space gets two extreme daylight statuses, dark in the morning and overexposed afternoon.

Test W.2

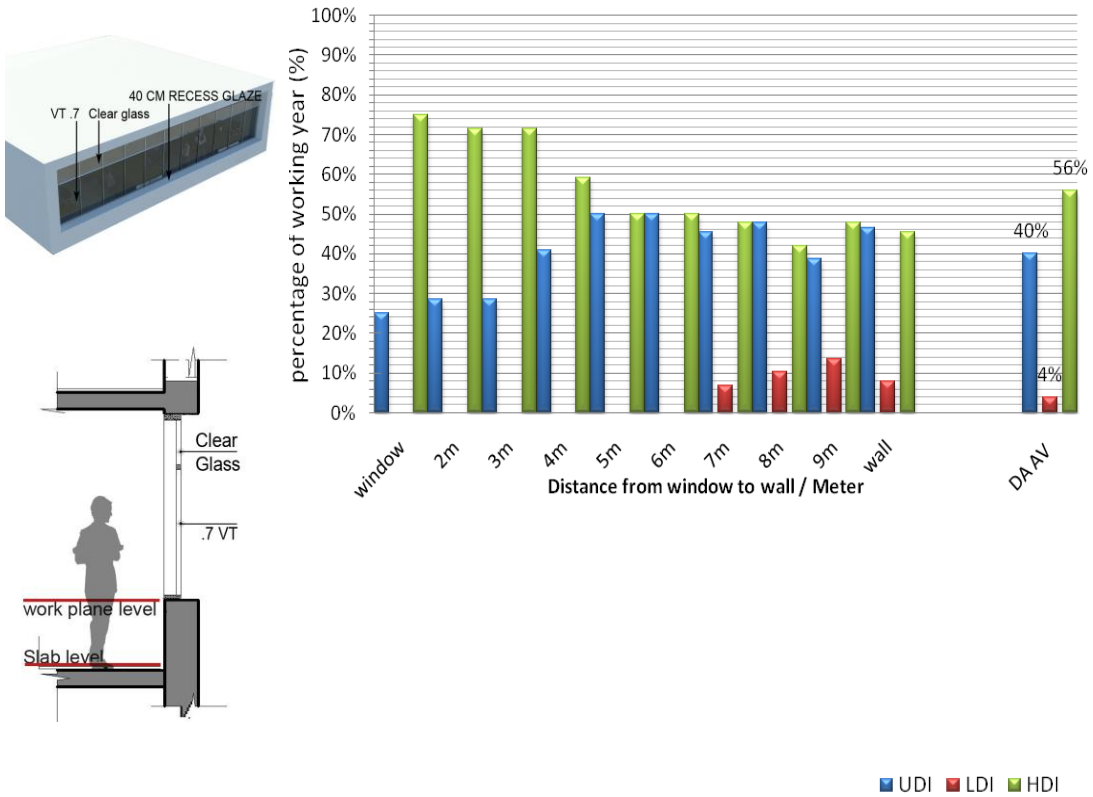


Figure 4.39 UDI for West oriented office , VT 70% for lower panel glass, and upper panel is clear glass panel.

This test is a trail to reduce the dark areas inside the office. Figure (4.39) represent UDI values for west oriented office having40cm recessed glazing with glass VT of 70% in low portion and clear glass in the upper one. LDI shows significant reduction in the backside. However, adding clear glass had driven HDI to rise sharply to 56%. Most of the areas in this test are getting high illuminance values until the last meter near the wall where it's still receiving 48%.

Test W.3

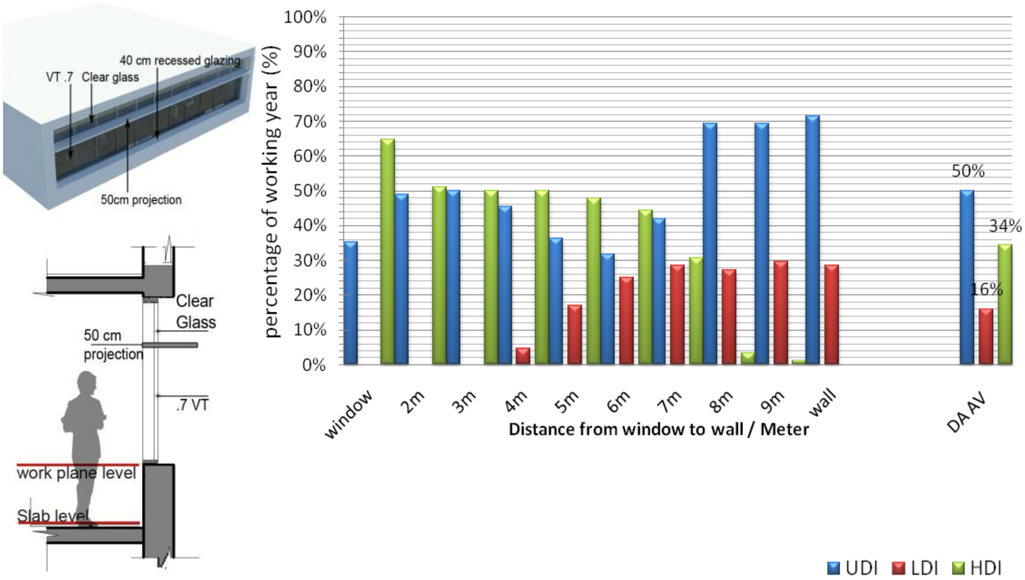


Figure 4.40 UDI for West oriented office , VT 70% for lower panel glass, and upper panel is clear glass panel with 50cm projection.

Figure (4.40) shows the results for test W.3 as horizontal 50cm projection is been added to the previous office parameters. UDI average shows some improvements compared to test W.2 but UDI average came similar to test W.1(48%). However this test shows a better separation between HDI and LDI columns compared to first test. Office still receiving high illuminance values deeply. The only way to provide protection for this office is to add vertical shading elements covering glazing facade .this vertical elements should be slightly rotated toward north in order to keep the opining away from the direct sun path Figure (4.41).

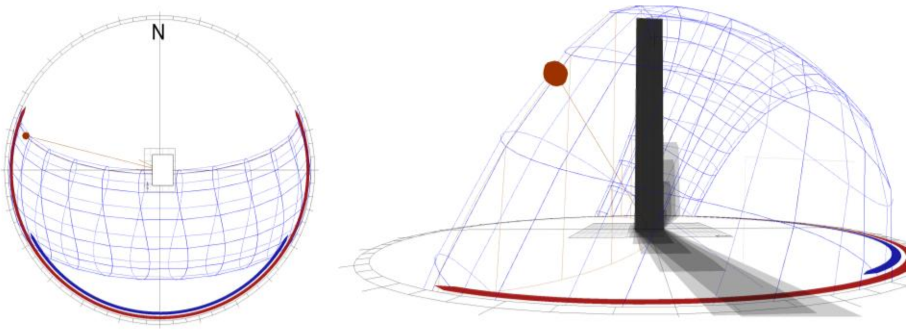


Figure 4.41 Ecotect graph shows sun path during the year. Horizontal shading devices are useless against the morning or afternoon sun as the sun located at very low angel at that time.

Test W.4

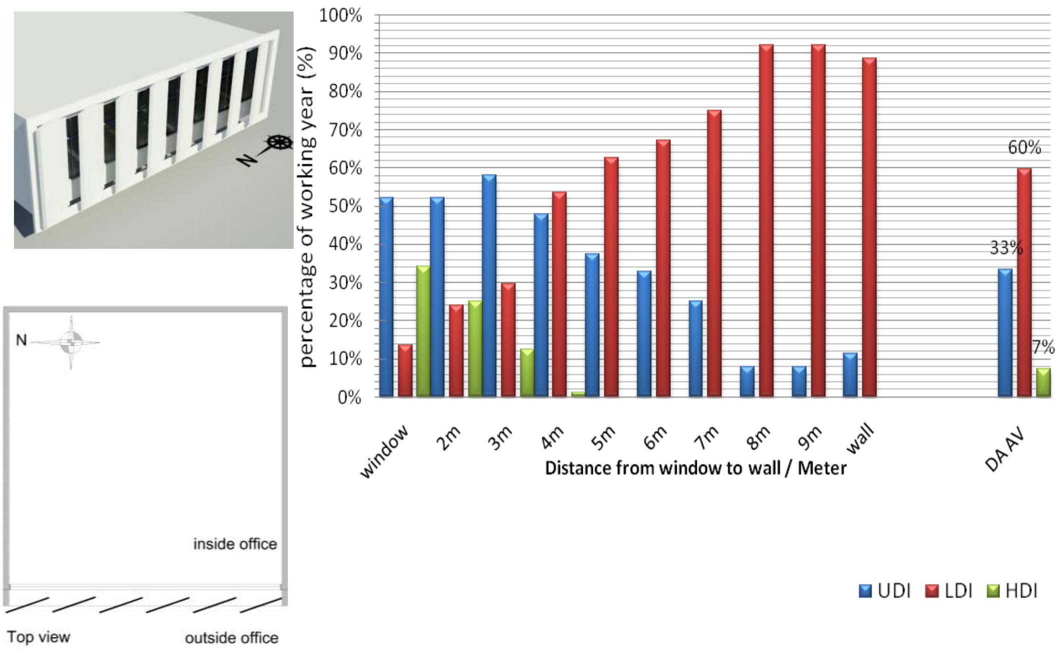
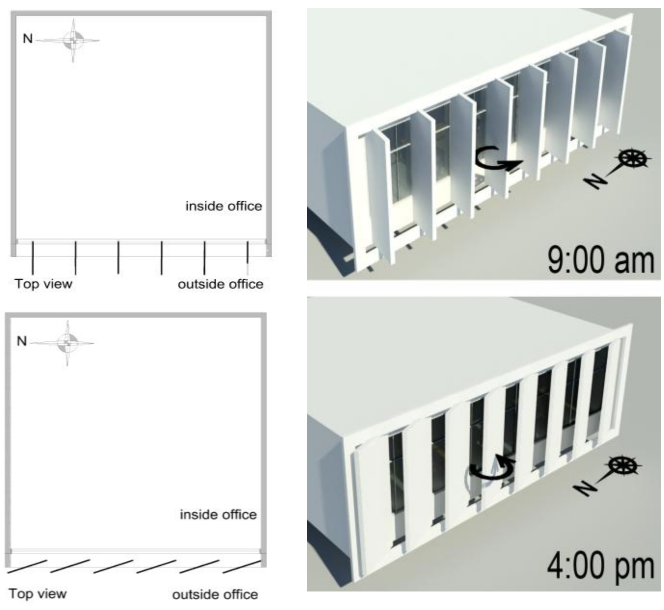


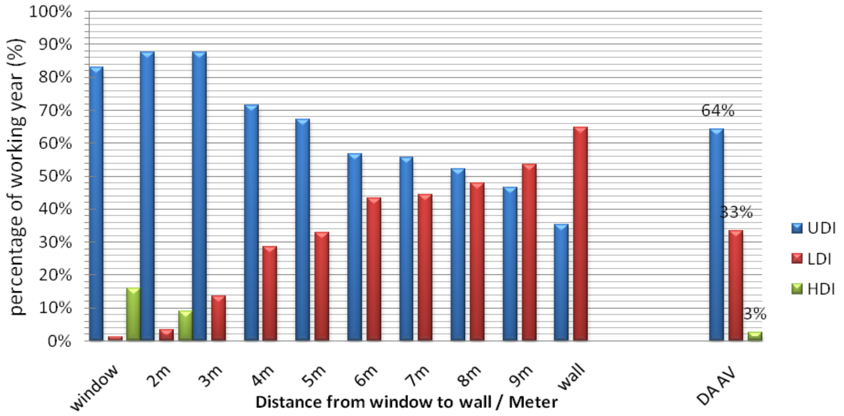
Figure 4.42 UDI for West oriented office , VT 70% for lower panel glass, and upper panel is clear glass panel with vertical shading rotated towards north direction.

Figure (4.42) shows UDI records for the same previous office with vertical shading rotated towards north direction. UDI average got reduction to 33% as LDI raised sharply in the whole office specially the deepest areas in the office. Excel file for this test is been reviewed to point out the causes of this darkness. Having this type of projections blocking the western facade is performing very well in the afternoon times when the sun is located low in the sky, while this projections are reducing the illuminace levels to the minimum in the morning times causing this high percentage of LDI. From the previous discussion we can conclude that having fixed shading device is not the ideal solution for west and east facade as the level of illuminanc is extremely different between morning and afternoon times. Accordingly, next test will try to conduct a test for dynamic shading system.

Test W.5



Figure



4.43 UDI for West oriented office , VT 70% for lower panel glass, and upper panel is clear glass panel with dynamic movable vertical shading system open at morning times and close afternoon.

This test is a repetition for Test W.4 but the vertical shading system is movable now as they are oriented vertically to the window in the morning times to let more daylight penetrating deeply in the office while they rotating toward north by afternoon in order to give protection from direct illuminance. Figure (4.43) shows the UDI results for test W.5. The UDI average achieved significant improvements to (64%). HDI areas are nearly disappeared while there is still dark areas in the office depth need to be sort out.

Since most of the dark areas resulted in the previous figure were during the morning times, there is still possibilities to achieve higher UDI percentage by adding more dynamic variables like glass VT Where in the morning glass VT increases to 100% (clear glass) letting more light penetrating to the internal space. In after noon VT back to 70% by applying simple screen tinting panel. However, 64% of the year that

Daylight alone can light the internal office space is good achievement relatively for this direction.

4.3.4 Summary of results and findings for UDI tests in different orientations

- North directions presented the best performance compared to the other directions where it can achieve good UDI values without having any protection on facade.

- Recessing glass window 40cm to inside in North office gave additional improvements, while adding shading protection give the extreme office performance with UDI highs to 95%.

- UDI for south oriented office came acceptable as 62% for standard office without protections.

- The best UDI achievements for South oriented office came after several tests to highs of 81% after adding vertical and horizontal 50cm over hangs and changing glass VT in the upper portion to 100%.

- West oriented standard office started with UDI average of 48% only because the whole office receiving excessively high HDI percentage deeply in afternoon time while the back areas got a big percentage of LDI particularly in the morning times when the sun located exactly on the opposite direction.

- Because of the big differentiations of illuminance levels recorded internally between morning and afternoon in West oriented office, UDI improvements were very limited when static shading solutions was applied.

- A dynamic movable vertical device that open in the morning times and rotate vertically to north in afternoon gave some good improvements to UDI values as it highs to 64% where these results can be higher by adding more dynamic variables.

4.3.5 UDI for offices in different buildings shapes in different levels within setback

In this sets of tests, study is focusing on how UDI affected by various offices levels within existence of near vertical obstruction. First set of tests will take the most common building plan layout in Shikh Zayed Road (square 30X30 meter) and a setback of 10 meters from neighbor. UDI for offices in different levels in this plan layout will be measured and evaluated. The second part will evaluate UDI for a proposed plan layout that providing the same built-up area and maximizing setback to 25 meter.

4.3.5.1 UDI for offices in standard square building layout (30X30m) at SZR

As been noted in chapter 3, the survey conducted Shikh Zayed Road Buildings plans geometries concluded that plots along SZR road are predominantly equally rectangular divided with majority of the plots measuring 40 meter in width (road elevation) and 90 meter in length. In spite of this rectangular plot shapes, 78% of SZR towers have square plan layout (30X30m), 12% were rectangular, 6% were circular and 4% were triangular. The popularity of square plan shape referred to structural and economical reasons. Moreover, designers and owners are preferring to use the maximum plot width facing SZR in order to get the maximum view to this prestigious road. Choosing a square plan layout is giving only 5-meter setback from the neighbor side, and is consuming the whole built-up area in the front part, while a 60 meter in the backside will remain unconstructed to be used as parking lots or facilities areas Figure (4.44).

Figure 4.44 Rectangular plots of SZR (40mx90m) use front 30X30m as tower and leave only 10 meter as separation distance to neighbor. While 60 meter in the backside usually used as parking lots or facilities areas.

Following three simulations are giving UDI performance for offices located in different levels in the 10-meter setback area.

Test SQ.1

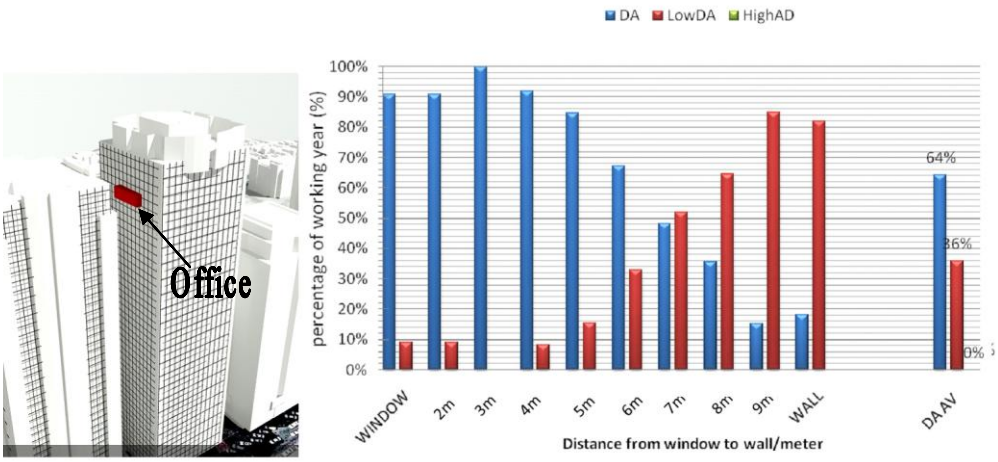


Figure 4.45 Standard office is placed in Al Mousa Tower Side elevation in high floor level and UDI results are represnted in the chart.

In this test, office was located in Al Mousa Tower in a high floor level with a glass VT of 70%. Figure (4.45) shows UDI average of 64% was achieved, which is indicating for acceptance UDI percentage in this level. However LDI is increasing as deep as we go inside until it reaches to 82% exactly next to the wall.

Test SQ.2

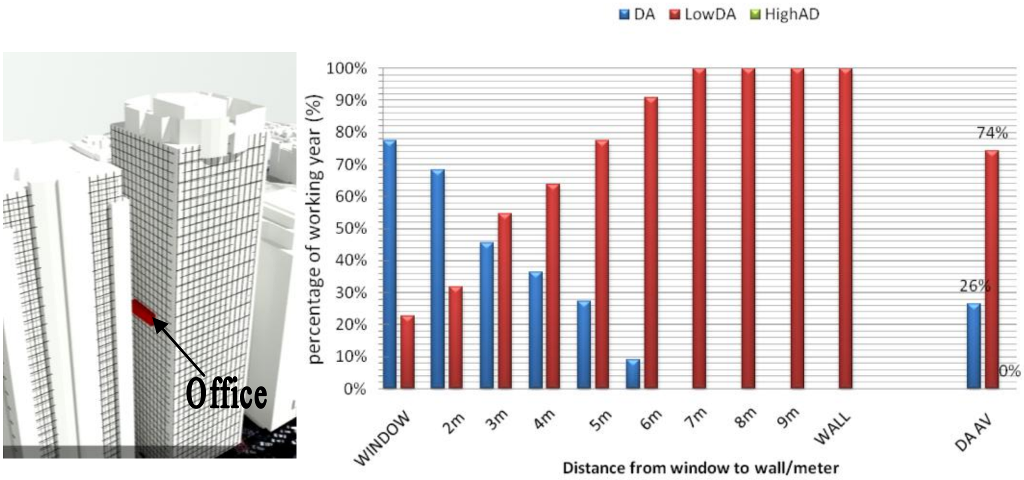


Figure 4.46 Standard office is placed in Al Mousa Tower Side elevation in intermeadiate floor level and UDI results are represnted in the chart.

The same office is been tested in an intermediate level. Figure (4.46) shows UDI graph for the measured points. UDI average has sharply dropped to 26% compared to 64% in test SQ.1. Technically last four meters in this office, can't achieve 200lux during the whole year in any point. UDI dropped down more than 60% between high and intermediate level .This falling is predicting for worse case in the lower level testing.

Test SQ.3

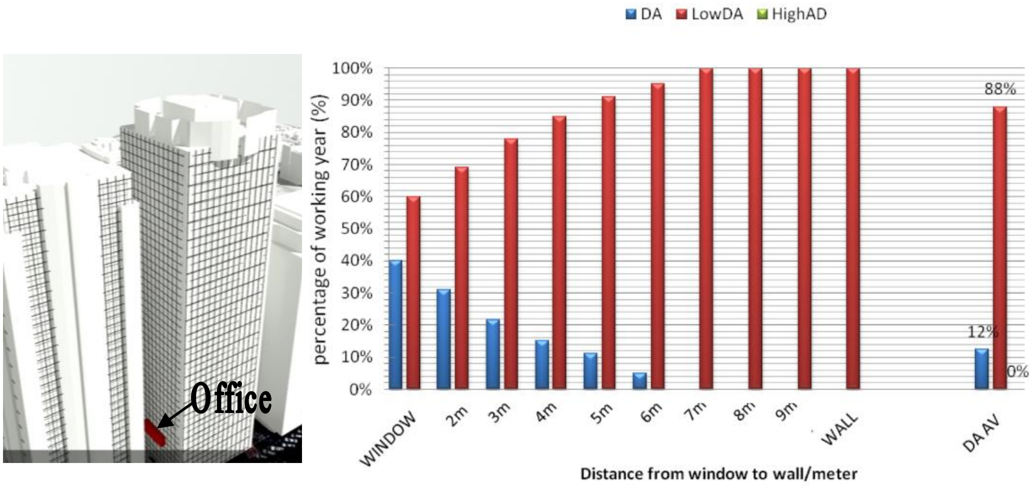


Figure 4.47 Standard office is placed in Al Mousa Tower Side elevation in low floor level and UDI results are represnted in the chart.

As been excepted UDI is badly affected by changing floor heights. Figure (4.55) shows another 50% reduction in UDI average to 12% as the LDI has raised to 88%. That is mean for this office test, electrical light should be turned on for a minimum of 88% of the working year. The next test will attempt to find the maximum UDI can be achieved by office in very low level by providing full clear glazing for the whole facade.

Test SQ.4

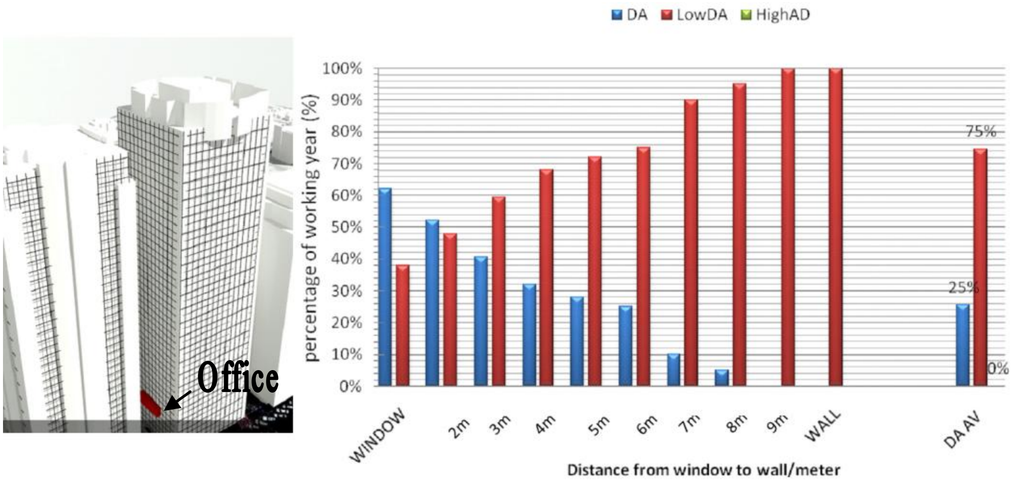


Figure 4.48 Standard office is placed in Al Mousa Tower Side elevation with full clear glass facade in low floor level and UDI results are represnted in the chart.

Figure (4.48) shows some improvements to UDI as it raise to 25% by increasing glass VT to 100 %(clear glass). This result represents the maximum UDI that office in this level can achieve, as the whole office facade is clear glass with no recess or shading protections, unless other complicated solutions like having big reflectors or mirrors to reflect lights deeply to lower floors.

4.3.5.2 UDI for offices in proposed rectangular building layout (15X60M) at SZR

As we noted in previous section, flexible plot sizes in SZR (40X90) can give many possibilities for different plans layouts. This test is sustaining the previous built-up area (30X30=900m²) but plan layout dimensions was modified to have a rectangular plan of (15mX60m=900m²). This plan width is giving 12.5 meter setback from every side. That is a total of 25 meter separation distance between two buildings. Next set of tests will determine the effect of changing building layout on UDI percentage in different floor levels.

Test RE.1

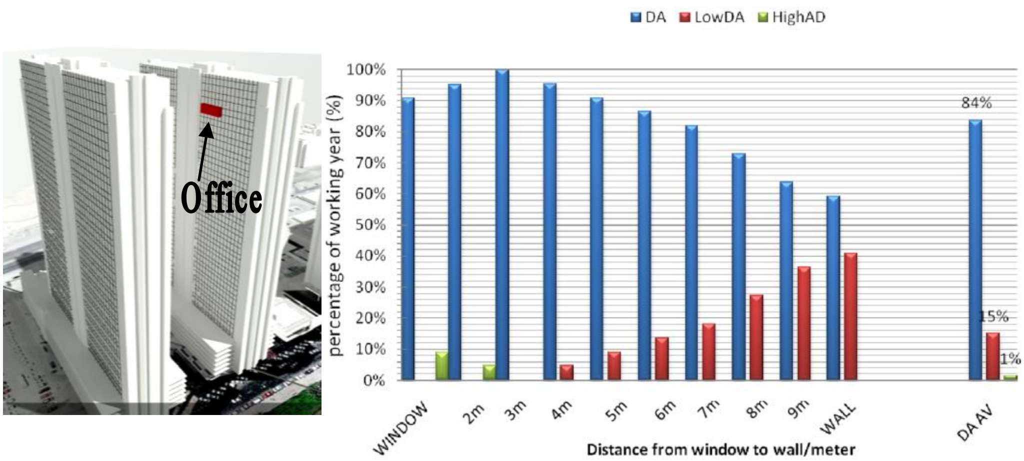


Figure 4.49 Standard office is placed in proposed rectangular Tower layout in Side elevation in high floor level and UDI results are represnted in the chart.

Same office parameters is been placed inside the proposed plan layout in high floor level with a glass VT of 70%. Figure (4.49) shows excellent UDI performance at this level as 84% compared to 64% for the same office in square building layout. LDI areas can be treated by the same methods been tested in the previous section, but this simulations are aiming to compare the performance between two buildings plans only.

Test RE.2

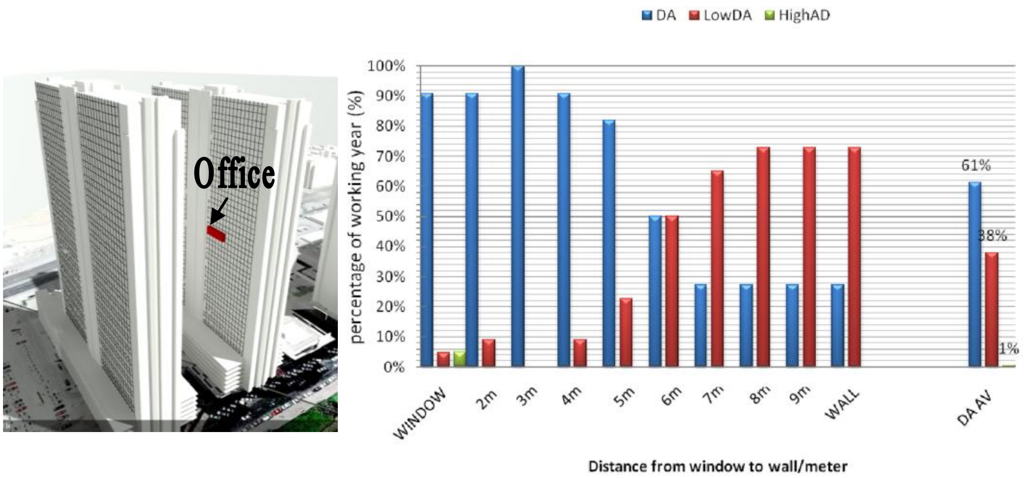


Figure 4.50 Standard office is placed in proposed rectangular Tower layout in Side elevation in intermediate floor level and UDI results are represnted in the chart.

Test is been repeated but in intermediate level. Figure (4.50) shows a UDI average of 61% in this level compared to UDI of 26% for the same office in a square building layout. UDI average in this test have lost only 25% compared to previous UDI value in high level floor level (84%). LDI is also lows to 38% compare to 74% for the square plan layout.

Test .RE3

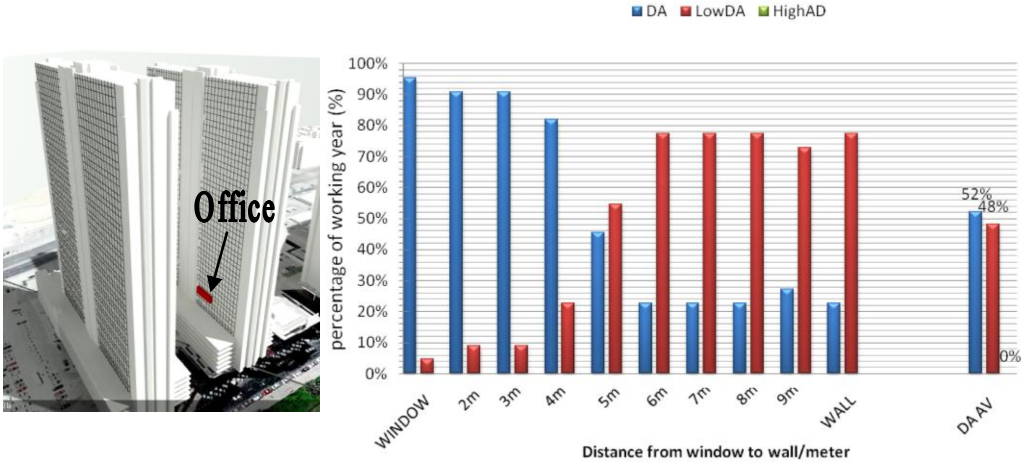


Figure 4.51 Standard office is placed in proposed rectangular Tower layout in Side elevation in low floor level and UDI results are represnted in the chart.

Figure (4.51) shows test's results in low floor level. UDI average recorded as 52% compared to 12% only in square plan tests. Next test will replace 70% VT glass by clear glass to find out the maximum UDI can be achieved by this plan layout.

Test .RE4

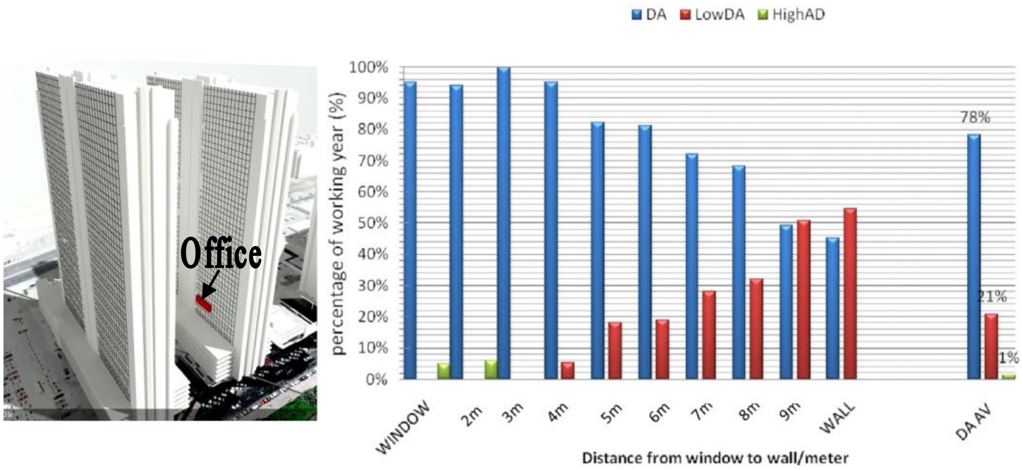


Figure 4.52 Standard office is placed in proposed rectangular Tower layout on Side elevation in lowe floor level and clear glass seleation . UDI results are represnted in the chart.

Figure (4.52) shows how UDI is been affected after 70% glass VT is been replaced by clear glass. Very major improvements are achieved in this test as the UDI average jumped to 78% indicating for relatively excellent performance for office in a low floor level.

4.3.6 Summary of results and findings for UDI tests for office in different building geometries and setbacks

- Buildings separations is strongly affecting daylight performance for internal offices.

- Similar built-up area can be achieved by different plans layouts and changing building geometry is changing setback distance between buildings.
- UDI Results for square plan layout was indicating for a real lighting problem facing this type of plans particularly for the lower floors level where the UDI recorded as 12% only.

- Rectangular plan achieved significantly better UDI results as UDI recorded in the high levels was 84% and 52% in the lower floors.

- Changing glass VT in the same facade between different levels is strongly affecting UDI achievements.

- Clear glass(VT100%) is been applied to the lower parts of the square plan layout and UDI rose accordingly to 25% after 12% only in the 70% VT test.

- Clear glass (VT100%) is been applied to the lower parts of the rectangular layout and UDI showed good improvements that highs to 78% indicating for high office performance.

Chapter5 - Conclusion and Recommendations

This research has presented some office design solutions that can be adopted to utilize daylight within office buildings in Dubai in more a sustainable manner. Various solutions were proposed and evaluated by using of UDI evaluation metric for office spaces while considering varying design parameters such as orientations, glazing specifications, floor levels vis a vis building setbacks and building layout shape.

The literature review discussed different metrics used to evaluate daylight performance and evaluated merits and demerits of the two variants, Static metrics and Dynamic metrics. It was demonstrated that static metrics has been more commonly used in the past despite the inaccuracy of data collected as it is based on a single sky condition with the results of daylight factor being equal on all four facades. However, it was noted that UDI metric was the best evaluation method as it considers the different types of skies and also because of accuracy in capturing the under or over exposed areas. A variety of testing methods were investigated such as manual tools, mathematical method, scaled model method and simulation. Simulation method was selected to be the testing method for this research because of its affordability and flexibility in changing one or group test parameters. By using 3D Max as a simulation tool, different types of results were obtained from two categories of tests:

- Tests for illuminance falling on vertical facades tests
- Daylight levels for generic offices interiors.

The interior simulation results were summarized to UDI simple graphs, which gives informative and extremely simple method that summarizing the massive excels data into small chart. Discussed below are the final results outcome for different tests and conclusions drawn from each.

5.1 Conclusions of illuminance falling on vertical external facades tests

The first step towards designing an office that utilizes daylight for illuminating its interior is to acquire information on the amount of daylight available in surroundings. This series of simulations tested the amount of direct and diffuse illuminace values falling to external facades on different orientations, levels and locations by using 3D Max Design as simulation tool. For purposes of this study, a simple model for Sheikh Zayed Road was constructed and data of external daylight illuminance was collected from different facades in different times during the course of one year.

It was noted that the daylight illuminace falling on the north facade was consistent throughout the course of the year, that is, it doesn't change much over the different seasons. These results provide a general idea about how one experiences the internal space over the duration of the year depending on the orientation of the office space with the more consistent North as opposed to the soon to be seen more variable West elevation. The North facing façade experiences high illuminance values only in June and July when the sun is at its highest altitude in the sky. The experiment further illustrated simple solutions that successfully solve this problem.

In contrast, South facing facades in UAE do experience direct solar penetration during day with direct illuminace values rising in the south facade to 80000lux at noon times. Tests conducted on this facade concluded that South facing windows could be protected from extreme direct sunlight at noon when the sun is located high in the sky by use of horizontal shading devices. Vertical protection might be required during the morning and afternoon hours particularly in winter when the sun located in the shortest path from southwest to south east.

The daylight illuminance on the western facade on the other hand differs from month to month in values with the western elevation experiencing greater illumination in afternoon hrs throughout the entire year when the sun is at a low altitude. The direct illuminance at such times can potentially causing glare and heat gain problems. However western facing building facade recorded low illuminance values in the morning time with low illuminance in office spaces further away from the window wall.

The last test indicated very undesirable illuminance levels results for the lower floors of build due to the effect of a vertical obstruction, in this case, an adjacent building within 10 meters from external facade. The upcoming segment of the study will try to evaluate those problems internally by providing an evaluation metric for daylight performance within a generic office space on Sheikh Zayed road.

5.2 Conclusions of Daylight levels for a generic offices interiors tests

The model generic office space on Sheikh Zayed road developed for purposes of the study was based on the “typical” development dominating the site based on current site layouts. The model office underwent several sets of simulations in different orientations with recorded data for a period of one year. The outcome was three main output types of data, real image, gradient color and Excel measurements. The data was very rich and informative, ideal for evaluating office performance for one or two cases but would be cumbersome/ inefficient as a comparison method between many different simulation cases with every case having 3600 rows of data. This justified progression to the next step which was to adopt the excel data and summarize it to useful daylight illuminance evaluation metric (UDI).

5.3 Conclusions of UDI evaluation metric for internal office performance

Useful Daylight Illuminance metric is been certified as evaluation metric for different design solutions. The UDI scheme is both richly informative and extremely simple method that summarizing the massive excels data into small chart. UDI would give the designer of a space quick indication of likely tendency for discomfort, potential high or low levels of illumination and solar gains for a space given its specific characteristics. In addition, UDI gives an idea about daylight distribution and space uniformity.

The generic office design tests represented several different office types and both good and bad daylighting performed offices. A wide range of different tests was reviewed in previous section illustrating the ability of the UDI evaluation metric to adequately quantify the quality of daylight in a given test. Also it represents the abilities of this metric to identify the areas responsible for LDI and HDI problems in order to take the suitable action for reducing their negative impact on daylight performance.

It's been verified that having a UDI levels between 80% to 100% represent some excellent daylight designs parameters, while good daylighting designs could fall to a range of 60% to 80% UDI range. 60% UDI and below indicating for low daylight design performance.

A serious of tests were conducted in this section in different orientations and parameters. North direction presented the best performance compared to the other directions. The North can achieve good UDI values without having any protection on facade. however the addition of overhangs on the north facades and recessing glass window 40cm to inside gave additional improvements to office performance where UDI highs to 95% indicating for a nearly perfect design performance . UDI for south oriented office came acceptable as 62% for standard office without protections, while this percentage rose to highs of 81% after adding vertical and horizontal 50cm over hangs and changing glass VT in the upper portion to 100%. UDI results for west oriented standard office started with UDI average of 48% only as the whole office receiving excessively high HDI percentage in afternoon time while the back areas got a big amount of LDI particularly in the morning times. The big differentiations of daylight levels between morning and afternoon times formed a challenging case in order to increase western office performance. Static design solutions failed to achieve significant improvements because providing a proper protection from afternoon low sun angle was leading to high values of LDI in the early morning time. A dynamic movable vertical device that open in the morning times and rotate vertically to north in afternoon gave some good improvements to UDI values as it highs to 64%.

The next set of tests in this section were to determine how building geometry and setback distance affecting daylight performance. It's been found that buildings setbacks strongly affect daylight performance for internal offices. Office footprints are mostly determined by developers' requirements for certain built-up area yet similar built-up area can be achieved by use different plans layouts that could possibly give a better day lighting performance. Altering the building geometry is also changing setback distance between buildings. As highlighted, simulations on the common square plan (30X30m) of SZR with a separation distance of 10 meters from neighboring building was tested at different levels with the results indicating very low LDI particularly for the lower floors level. The UDI recorded on lower floors as low as 12%. Simulations of a rectangular floor plan of similar usable space with separation distance of 25 meters from neighboring building when tested at the lower floors indicated significantly better UDI results. These tests indicated recorded UDI levels in the higher floors of 84% and 52% in the lower floors. Note however that these results were for unified glass VT. In addition, even better UDI levels can be achieved if the designer specified glass with higher VT to upper floors of the office tower and for the lower floors of the tower specify clear glass (VT100%). This simulation indicated greatly improved UDI values of 78% on lower floors indicating high office performance.

UDI is a relatively new concept and more studies need to be carried out to link more external parameters with the same metric like electrical consuming, heat load or HVAC In order to expand its evaluations spots. Daylight Factor metric has been the most dominant evaluation metric for a long time, mainly because of its inherent straightforwardness rather than its realism. In spite of evidence of daylight factor's lack of reality, most investigators still prefer it as the easiest and simplest way to evaluate their designs. As highlighted many building evaluation system like LEED and ASHARE are framed only in term of daylight factor. The UDI method can offer simplified characteristics of climate-based analyses in brief and clear comprehensible form. The holistic scheme of UDI gives many Promises for this metric to have strongly potential for replacing the static daylight factor metric.

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