Investigating the effect of Light Pipes, as Daylight Strategy, on Employee Performance Levels in High-Rise Office Buildings in the UAE

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Abstract

Corresponding with the importance of daylighting, studies have established the non-energy related benefits of daylighting at office buildings. Quantitative studies and qualitative statements are utilized during the course of this research to study the integration of light pipes, as part of daylighting strategy in office buildings, and its effects on employee performance levels. Data compiled from books, journals and interviews as prime sources of research and analysis have provided the essential background information necessary to identify the main subjects of this research paper. Interviews conducted provided essential details related to employees perspective about bringing daylighting inside their offices.

The research takes part in two phases; the first phase involves comprehensive analysis and study of light pipes and their application in high rise office building, while the second phase involves simulation of the effect of introducing natural light on employee performance levels inside a workspace. In this research, the performance and efficiency of various sizes of light pipes inside a high rise office building is explored. Simulation models were employed to test a given office space in Dubai, and explore the integration of three main different sizes of vertical and horizontal light pipes to help achieve uniform daylighting level at the workspace during the day and thus improve employee performance levels. The literature available concludes that environmental factors have an effect on the ability of employee to perform inside an office space.

Acknowledge

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A special thanks to my husband, Payam, whose support and inspiration were compelling every step of the way during the research process.

Dedication

This research paper is dedicated especially to my late sister- Rasha, whom I unfortunately lost during the research, may her beautiful soul rest in peace.

Dedicated for my beloved parents, my dearest brother and for my handsome husband who was always supportive; I could not have done it with out them all.

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Chapter 1 Introduction

1.0 Background

‘A room is not a room without natural light. Natural light gives the time of day and the mood of the seasons to enter.’ (Louis Khan, 1971)

According to the statistics presented by the Living Planet report (2008) when humans rely on the use of daylighting inside spaces, there will be less dependence on the power and thus reducing all the related pollution that is being generated to accommodate the growing power demand by mankind. Resources are depleting and therefore mankind needs to maintain awareness and carefully use the available resources. Moreover, there is abundant supply of natural daylight from the Sun, which is a free existing source of light.

In general, the vast growing nature of cities has been translated by the increased demand for occupied space and also the increase demand for various building typologies. Not very long time ago families lived in large house at the country side and had grown crops or used to live on shacks besides fishing villages as a means of survival. At the current situation, people live beside their workspace are actually living in the business districts; the idea of zoning cities as per demand and supply. As per the Energy and Atmosphere requirements for achieving LEED (Leadership in Energy and Environmental Design) certified buildings as a credit for Daylight, Minimum Daylight Factor of 2%, meant that the light levels inside the space must be 2% minimum of the light levels outdoors, in 75% of all space occupied for critical visual tasks.

High buildings are one of the most dominant features in the skyline of cities in the 21st century. High rise office towers are the place where the working population spends more than half of their day. The intent of the research is to investigate the various effects of daylighting at high rise office buildings on employee performance levels. One of the many factors that help effectively improve employee performance levels is the scale introduced by Watson et al.

(1988) the Positive Affect Negative Affect Schedule (PANAS). The PANAS scale is a psychometric scale that was developed to help measure the positive and negative affects both on states and traits. The original scale was composed of 20 items; the scale was later developed further by Watson et al (1988) into PANAS-X scale, which is composed of 60 terms.

Past researches were mostly focussed on the overall energy savings contributed by light pipes, while this specific type of research refines the search into daylighting as part of the employee performance aspect which in turns will introduce an environment friendly space that utilises one of the abundant free resources, sunlight. Light pipes are considered a median to transport light into deep or underground spaces that do not have direct access to the outside.

1.1 Benefits of Daylighting

1. Improve performance level: Natural setting, i.e. psychological.
2. Reduce operating cost; electricity, cooling and/or heating load
3. Improved the building life cycle-cost
4. Reduce emission: reduce green house gases and fossil fuel depletion

1.2 Importance of daylight at office buildings

The utilization of daylight in the interior of high-rise office buildings can save energy and reduce pollution. Daylighting can reduce artificial lighting consumption from 50 to 80% (Bodart and Herde, 2002). The global primary energy saving will come not only from the reduction of the lighting consumption but also from the reduction of artificial lighting internal loads which could then reach up to 40%, for the type of glazing usually used in office buildings (Bodart and Herde, 2002).

Building Performance rating systems including LEED in the U.S, The Hong Kong BEAM, and Australian Green star, all propose guidelines for the integration of daylighting systems and promote designs that are sustainable and help to conservation of the environment. During the last few years, the authorities in Abu Dhabi, the capital of the United Arab Emirates, have launched a green rating system specific to the Middle East named as ESTIDAMA. The main concern is even with the placement of such body of guidelines and the availability of the valuable researches conducted with scientific data, we are still unable to fulfill and accommodate 'Green' buildings design as a way of life and seem unable to oppose the temptation of maximizing profits on every investment opportunity created and here lies the problem where buildings are seen as part of a success deal and not as a humane haven. The main goal is to bring together passive daylighting techniques and integrate them to achieve an energy-conscious building.

Due to the worldwide increase in the awareness of the importance for the preservation of the environment and the depleting resources, one solution would consider reducing the dependence of building systems on the artificial lighting through integrating daylight strategies into the deep office spaces. For so many employees, daylighting provided in spaces enhances their perception of correct colour levels and also the difference of light colours (Licht, 2006). The lack of daylight is considered to be as one of the main leading causes of sick building syndrome (SBS); the further the workspaces are located towards the centre of the room the more the ailments, while higher levels of daylight have shown to improve performance levels between employees (Licht, 2006).

1.3 Definition of Employee performance

The quality and quantity of work affects indirectly the quality of the personal, social and well-being (Lowe, 2000). Employee performance level is not a directly measurable concept throughout the various studies conducted in the past the main measurement and investigation methods involved various interviews and questionnaires. The main research available as part of the literature is conducted through interviews and participant observation and series of interviews conducted throughout time to find a criterion to measure job performance levels.

There are still gaps in the literature regarding the distinction between job satisfaction and the job performance levels (Wright and Doherty, 1998). While Wright, Cropanzano and Meyer (2004) established a positive link between job satisfaction and job performance levels, the research conducted mostly on linking emotions and job performance levels had been focused on how employee emotional experience has influenced their job performances (Cartwright and Cooper, 2009). For the sole purpose of this research, employee performance is defined as the amount of work and quality of work being achieved throughout a time period. The performance level is studied as an individual not as a group.

1.4 The effects of daylighting on employee well being

There is a growing body of literature indicating that the effect of light on circadian regulation is capable of affecting the employee productivity levels as well as their health. Seasonal affective disorder (SAD), or the “winter blues,” is recognized by the medical community as a psychiatric disorder. As a matter of fact, seasonal reductions are defined as the amount of daylight available in the winter at extreme northern and southern latitudes which can provoke depression (Rosenthal et al., 1990). Light treatment, typically provided with bright light from electric lighting systems, is recognized by the medical community as the preferred method of treating SAD (Rosenthal et al., 1985).

The evaluation of visual comfort and energy efficiency due to daylighting requires an accurate measure of the amount of daylight for any point within the internal space. The sun is the main supplier or the main source of natural daylight, and to some extent by the moon and the stars. This continuous source of solar energy could be utilized and brought into office buildings to help reduce the energy loads in the high rise towers and also to improve employee productivity. Investigations in health of employees and the office settings were exclusively chosen for this review and are presented separately.

1.5 Lighting levels at Office interior

In Dubai, the average working hours vary between 8 to 9 hour long days. The different private companies require certain working hours sometimes the day starts from some working people at 7 am while other start around 9 am, and work 8 or 9 hours accordingly. Therefore some employees arrive earlier at work and experience sometimes the early rays of daylight inside the office space. The amount of daylight varies as the sun moves higher up the sky, therefore it is critical to understand the location of the sun during those peak morning hours when the employee first starts the day.

Generally, inside office workspaces with integrated daylighting, sufficient light is available from the windows. American scientists have found that an illumination levels above 2000 lux may be the cause to suppress the secretion of melatonin – sleeping hormones, while an illumination of 500 lux, Table 1, commonly found in offices and is the healthy lighting level (Licht, 2006). Furthermore, daylight is preferred by most people because of the spectral composition, and the visual contact with the outside world that is provided by windows. On the other hand, glare and heat gains during the hot season should be avoided. This can be achieved only by careful control of the admitted solar radiation. As a rule, direct sunlight inside the building should be avoided, at least during the hot season (Ne'eman and Shrifteilig, 1982).

As a rule of thumb, the natural daylight level inside an office space is an average of 500 lux on a workspace depending on the type of activity. Ambient illuminance throughout the office space should not exceed 500 lux or 50 foot candle (IESNA lighting handbook, 2000). The light levels inside an office space should help provide a healthy and comfortable working environment.

Table 1: Recommended lighting levels, ASHRAE (1997)

Office Activities	**W/m^2**	**met[a]**
Reading, seated	55	0.9
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking around	100	1.7
Lifting packing	120	2.1

Light pipes, that deliver natural daylighting into deep spaces, are known to have a beneficial health effect for office employees when compared to fluorescent lighting (Monodraught, 2008). One of the main advantages that light pipes have is that the daylighting delivered does not have reflection on visual display unit (VDU) screens. Monodraught (2008) advises that their light pipes have a noticeable effect on the reduction of Sick Building Syndrome (SBS) and eliminates the glare at office environment.

1.6 Quantifying the advantages of introducing light pipes (cost and energy reduction)s

Light pipes do acquire a large part from the budget of a project but in the long term, light pipes can help reduce the overall dependency on artificial lighting and thus help decrease the running costs. The consciousness to the necessity of the energy consumptions of a building system and the considerations regarding the total primary energy consumed by a building is very important to understand how to save energy and where to start making environmental friendly decisions (Rossi et al., 2004).

Due to longer hours of usage and higher nominal illumination most of the fossil fuel is required for electricity to power artificial lighting as part of the building energy used for the different systems. All usable office floor spaces should receive sufficient amount of daylighting, ideally the daylight factor, the ratio of the outside illuminance over the inside illuminance in percentage, should be more than 30 percent, and the highest proportion of the office floor plan should be daylight oriented (Licht, 2006). Compaq Computer's facilities manager saved the company about $1 million a year by cutting back on energy sue. By increasing daylighting in the building along with other improvements, worker productivity increased by 55% in just one year (Sustainable Development International Corp, 2002).

1.7 Challenge: Introducing light pipe into high rise buildings

The research is divided into three main areas of study. The first part is an investigation into daylighting and the qualities of light. The second part is analysis of light pipes and its application in office buildings, while the third part is a literature review about the employee performance levels and how it is affected by daylighting.

An existing office building is chosen for the purpose of this research. The office building currently lacks efficient amount of daylight inside the office space. The office space on the 2nd and 27th floor was surveyed for duration of 3 months using a lux meter and the findings reveal the deficiency in the lux levels that are required for a workspace. The research proposes a daylighting strategy to help improve the employee performance levels inside this specific office building. The light pipes are explored in relation to their location and the amount of total natural light achieved. There are several ways to introduce daylighting into deep high rise office spaces. Designing the building in such a way as to provide deeper penetration from the East façade will help bring more natural daylight inside the office space. Integrating louvers into the façade of the office tower could help bring more light inside. Light reflects and refracts into the office space and penetrates deeper into the office space. The main limitation would be the overall concept and design of the exterior of the building. Covering the whole elevation with louvers would provide dark areas at certain times of the working day

This research paper investigates methods of increasing employee performance levels by introducing daylight into deep, high rise office offices in Dubai through investigating the various sizes of light pipes for an optimal design. The main method of investigation is through survey and simulation, which have been the common methods used for similar type of researches. Light pipes deliver natural daylight into unreachable places and help improve the interior environment without generating excessive heat (Oakley et al., 2000). Light pipes project daylight towards the floor of a room (usually of low reflectance) and this could possibly reflect numerous times off the floor and ceiling before reaching the walls.

The various research papers regarding the efficiency of light pipes and the measure of employee productivity employ different methods for investigation. While calculation method and literature review research paper do provide in depth analysis of the quality and technology of light pipes; simulation models and surveys conducted in various research papers have proven to be the most efficient technique best suitable for this kind of research. Interviews have the potential to create concepts, and help broaden the understanding of the general population being sampled (Knight and Ruddock, 2008).

There are different types of interview and for this specific type of research the evaluation interview was found as the most useful type. The evaluation type interviews examine new programmes and propose improvements, and this research examines the lighting inside an office space and interviews the employees and light pipes are investigated. Taking into consideration the climate of Dubai and addressing the office requirements in such an environment is quite a challenge. Making good use of the abundant daylight during the working hours of the day would be best through channelling the sunlight into deep office spaces. The wide growing commercial market in Dubai provides an investment full zone where every square meter counts towards a heavy rent. Light pipes along with environmental friendly design will bring together a better awareness to the growing need for efficient use of resources.

Chapter 2 Literature Review

2.1 Daylighting

2.1.1 The ergonomic (physics) of daylight

Daylighting is an important issue in modern architecture. Daylight is also an essential part of the solar spectrum, since it is the band of sun's energy that helps us relate with the day and night (Muneer, 2004). Muneer(2004) states in the book 'Solar radiation and Daylight models', the importance of being able to understand the physics of solar radiation and daylight. The comprehension and application of these concepts has transformed the design process and also changed the geometry of buildings, such as the introduction of atriums and large windows. Natural sunlight has a much better light to heat ratio when compared with any type of artificial or electric lights (Wulfinghoff, 2000).

There is an important difference between sunlight and daylight and it is very essential to understand the main distinction being the fact that sunlight contributes to sometimes excessive heat and thus causing thermal discomfort at certain locations (Kwok and Grondzik, 2007). Kwok and Grondzik acknowledge that daylighting is fundamental as good energy performance solution and also to achieve occupant satisfaction. The daylight factor at any point inside a space depends on various design factor including aspects such as the overall room geometry, the relative location of the point to the nearest opening and the location of the space globally and within the context of the existing climatic conditions. The LEED new construction 2.1 system requires a minimum daylight factor of 2 percent for daylight credit.

Light is a range of electromagnetic radiation that is visible to the human perception. Light is produced by one of two methods Incandescence is the emission of light from hot matter and Luminescence is the emission of light when excited electrons fall to lower energy levels. Figure 2.1 demonstrates the various wavelength of light and explains that visible light is at the range of

400 to 700 nm. Waves at low wavelength have more energy than waves that have longer wavelength. Radio waves have wavelength up to 100 meters and have less energy than X-rays that have shorter wavelength.

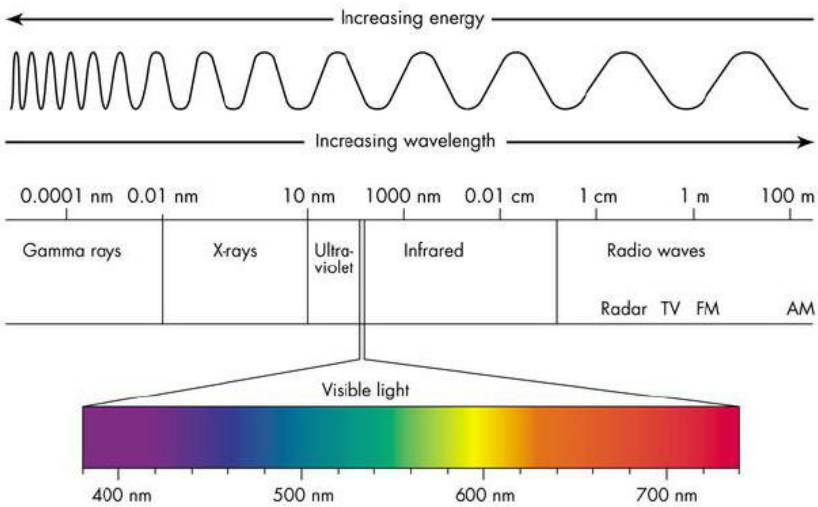


Figure 2.1 Light spectrum and wavelength
(http://www.antonine education.co.uk/physics_gcse/Unit_1/Topic_5/em_spectrum.jpg)

Before the 1940's, daylight was the primary light source in buildings and artificial lighting was just supplementing the natural light. In the span of almost 20 years, electric lighting transformed the workplace by meeting most of the occupants' lighting requirements (Wulfinghoff, 2000). During the past few years, energy and environmental concerns have made daylighting a rediscovered aspect of building lighting design. The physics of daylighting at interiors has not changed since its original use, but the building design adapting to its use has changed. Office spaces are designed to house the working population that are occupied with multi tasks throughout the average 8 hour working day; therefore lighting inside the office space should enhance employees to perform more efficiently (Wulfinghoff, 2000).

2.1.2 The history of daylighting in buildings

Since the early 20th century there has been increasing dependence on artificial lighting and a progressive abandoning of methods and technologies used in the preceding centuries, concerning the treatment and exploitation of daylighting. This movement was accompanied by various restraints in the research and innovation sector. The majority of commercial facilities work during the daylight hours, allowing them to take advantage of an abundant natural light. Work places aimed to provide constant means of light into spaces for longer hours and maintain consistent levels hence artificial lighting was favoured on natural daylight which is mainly available at different levels during a day.

One of the main setbacks of designing with daylight earlier was the heat that was exerted into the space accompanying the light. Sunlight can cause thermal discomfort as the amount of the heat directly accessing the space through the apertures was reflected and diffused into the space. Lighting represents a major energy user in commercial buildings, and a large amount of energy can be saved by integrating well designed lighting controls that take advantage of the freely available natural daylight. There is a vital need for a comprehensive understanding of the employees' needs in day lit spaces (Galasiu and Veitch, 2006). As mentioned at the reference book published by IESNA (Illuminating Engineering Society of North America, 2000) during the working hours of the day, with proper controls, daylight can replace some electric lighting. The reference book also states the vital importance of having visual access of the employee to the outside through windows. A view to the exterior provides the eyes of the employee with some relaxing time by focusing on distant objects outside.

Gregg Ander (1995) defines daylighting as dynamic lighting technology involving consideration of heat gain, glare, and variations in light availability and sunlight penetration into a space. By optimizing the potential of daylight the energy for lighting the buildings would be drastically reduced, especially in office buildings since they are mainly used during the day. Daylight uses in buildings require daylight admission and distribution inside of office buildings. Shallow buildings are most preferable, window design and size are important and solar control and shading systems are essential. The European reference book for daylighting in architecture (2001) describes the various office typologies as large, intermediate and small offices with mainly four different types; linear, nuclear, perimeter and radial. The reference book highlights that mainly high rise office towers accommodate the nuclear types (2001).

The disproportionate use of artificial lighting may lead to preventable effects both from the end user which is the employee at the office building, and furthermore from an energy conservation standpoint. The energy that is utilized from electric lighting is documented with 13% of domestic energy consumption in 2000 being attributed to electric lighting/appliances (this compared to 7% in 1970) (Jenkins and Muneer, 2003). This is the equivalent to 6.5 million tonnes of oil in terms of the energy used to. In the industrial sector, 47 million tonnes of oil equivalent is attributed to electric lighting/appliances (Jenkins and Muneer, 2003). While electric lighting is necessary during evening hours, most of the time the energy is wasted when it is use during the day time. This is typically the result of unfortunate building design and lack of window openings especially at high rise tower buildings. Light pipes are just one solution to this, permitting daylight into buildings without generating excessive glare and heat loss or gain issues (Jenkins and Muneer, 2003).

2.1.3 The energy conscious daylighting design

Daylighting is often integrated into a building as an architectural statement and for energy savings. However, benefits from daylighting extend beyond architecture and energy concepts. The psychological and physiological aspects of natural daylight should also be taken into considered. The comforting space and connection to the environment provided to building occupants grant benefits as significant as the energy savings to building owners and managers. Field monitoring studies and simulation models have found out that daylighting controls can help lighting energy savings of 30% to 77 % (Krarti et al., 2009). Krarti (2009) mentioned that positive affects of daylighting on the indoor environment and that it can foster high productivity levels. Daylighting strategies should take into account the uniform distribution of light and also glare aspects. Glare is usually avoided by taking into consideration the distance between the light source and the window system. The daylight outdoors is a measure of the direct and the indirect sunlight. In a clear sky the outdoor sunlight could measure up to about 60,000 lux most of that amount is directly from the sun.

Over the past decades, the statement of the so-called “energy-conscious architecture” has shaped the development of new planning methodologies. In addition to the techniques of solar-heating, daylighting rational exploitation is crucial; for this purpose, sophisticated systems and techniques of daylighting have been studied and developed to control the intensity of the solar radiation, the internal distribution as well as the energy gains and losses, improving at the same time, the comfort and the visual performances of the environments (Canziani, Peron and Rossi, 2004).

Simon Burton (2001) states in the book ‘Energy efficient office refurbishment’, that office building have one of the highest levels of energy consumption when compared with the energy consumption of other building typologies. The annual energy consumption in office buildings varies between 100 and 1000kWh per square meter, depending on geographic location, use and type of office equipment, and type of lighting among other variables. Burton (2001) mentions that using natural sources such as daylighting is one of the main approaches to achieve good internal office conditions.

2.1.4 The application of daylighting at offices in Dubai

This research is based on a specific location and a very concise climatic context; the climate of Dubai. Dubai, one of the seven emirates that compose the United Arab Emirates, is a vibrant city that is located strategically linking the continents of Asia, Africa and Europe together. The climate of Dubai is summarized to a category named Desert Climate, coined after the Köppen climate classification introduced by Wladimir Köppen in 1884. Desert climates are ones that witness moderate temperatures and low rainfall levels which make vegetation very scary. Dubai is located at the Arabian Desert; topographically known for sandy desert; this type of sand supports the growth of one main plant which is found abundantly in Dubai, the palm tree. Dubai has clear sunny skies for almost all year round; this qualifies the city to make best use of this abundant available sunlight in a productive manner to contribute to the well being of the city and its inhabitants.

The behaviour of humans is driven by an internal clock synchronized to the solar light-dark cycle. The circadian system considers biological rhythms that recur at around 24-hour intervals. Sunlight is the principal stimulus to the human internal clock. The circadian system regulates day to day patterns of behaviours such as activity and rest, but also adjusts our bodies at the cellular level, regulating functions such as the cell cycle (Moore, 1997).

The respected studies of daylighting by Heschong - Mahone Group (California Energy Commission's Public Interest Energy Research, 2003) discovered that office workers perform 10%-25% better on tests of mental function and memory recall, and call centre workers processed calls approximately 6%-12% faster than regular times.

Studies conducted found several physical conditions that were significantly associated with worker performance. Having a better view out of a window, gauged primarily by the size of the view and secondarily by greater vegetation content, was every time associated with better worker performance in six out of eight outcomes considered. Office workers were found to perform 10% to

25% better on tests of mental function and memory recall when they had the best achievable view versus those with no view. Furthermore, office worker self reports of better health conditions were strongly associated with better views. Reports of increased fatigue were most strongly linked with a lack of view.

The depth that daylight will penetrate is dependant on the ceiling height relative to the top of the window. The depth of the office room has direct effect on the intensity of illumination. Lighting deep interior spaces require special treatments. The main challenge is to achieve evenly distributed light with out creating glare. This actually means that the light opening has to be either on opposite walls of the space or in the roof. The daylight factor must be at least 3 percent for the entire office space and it should be evenly distributed. (Licht, pg 27) As per IESNA lighting handbook (2000) reference guide daylighting apertures can have both a positive and a negative effect on the general energy performance of the building. Integrating daylight into the design of the office space can help reduce the need for the artificial lighting during the day time while maintaining the required illuminance levels.

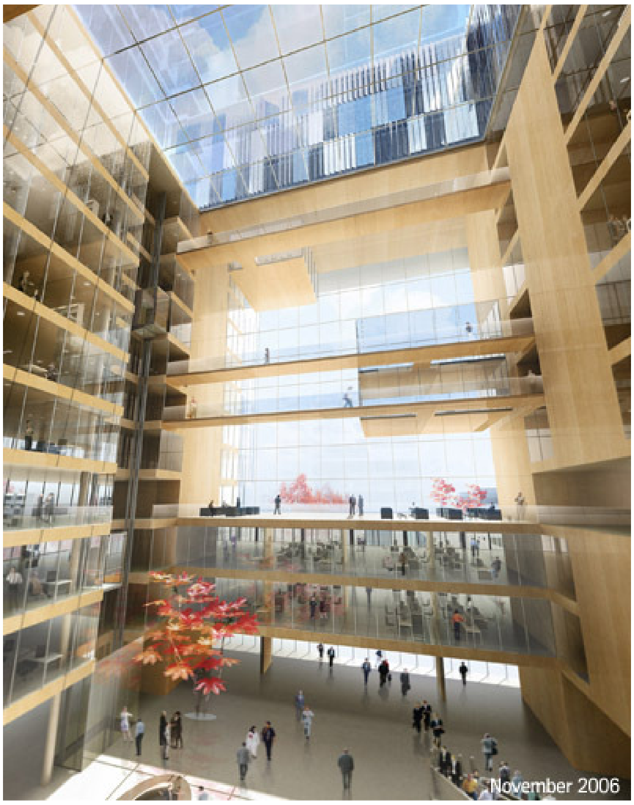


Figure 2.2 Atrium space,
(www.thyssenkrupp.com)

Designing atriums and skylights in to office towers can help bring light into the building from the core, as presented for reference in figure 2.2. Sloped or horizontal skylights admit light but are often problematic because of unwanted seasonal overheating and radiant heat loss. Atriums provide indirect lighting from the sky by penetrating the building volume through a defined path. The main challenge with skylights is that they produce high variable amount of brightness.

The high levels of brightness would cause glare (IESNA lighting handbook, 2000) since atriums are vertical, tall open spaces inside the building, they behaviour just like solar chimneys, such that they create an updraft effect which can help ventilate the whole building. An issue regarding atriums and skylights is that they both require a lot of the built up area which is a problem regarding the usable office space. The floor plan in this case would be reduced thus making the lease able area minimized. Marc Fontoynont (1999) mentions the sizing of the openings is important since the larger the window area in the facade of the building the higher the risk that employees will be exposed to glare and over heating in the summer. Shading devices on the façade play a vital role in situations where glare could create an issue. South facing windows should have large overhangs to reduce the penetration of direct light from the sky.

2.2 Daylighting and Employee Performance levels

2.2.1 Employee Comfort

Humans are affected both physiologically and psychologically with the various spectrums achieved by the different types of light. Those are the effects that are the less quantifiable and simply overlooked benefits of daylighting (Robbins 1986). Daylighting has been linked with improved mood, enhanced morale, lower fatigue, and reduced eyestrain. One of the most important psychological aspects from daylighting is meeting the need for contact with the outside living environment (Robbins 1986).

The main success of any company is based on the company's financial performance and also on the ability to provide high quality of services throughout time. This financial performance is dependent on the organization and its employees to work efficiently. The physical health is mainly determined by psychological, social and biological factor (Cartwright and Cooper, 2009). Cartwright (2009) explains the individual well being is the outcome of an intricate interaction between personal variables, job characteristics and the wider organizational factors.

Based on Edwards (2002) literature review, the body of human beings is affected psychologically by the various spectrums from different types of light. Edwards (2002) stated that improved mood, lower fatigue, and enhanced morale are all associated with the presence of daylighting. As part of the literature review research conducted, Edwards (2002) mentioned the record of increased well- being of the occupants working in a day lit space. The paper discusses the studies performed linking daylighting with employee productivity levels. Edwards (2002) accomplished studies that started off on silk weavers during the 1920s to establish a relationship between daylighting and worker productivity levels.

To obtain an understanding on the requirements of an office employee a psychometric chart was used. The psychometric chart, figure 2.3, describes the comfort levels of an individual in relation with the different climatic conditions. The results obtained from the psychometric chart where for an office worker dressed in a business suit and is undertaking low amount of activity which is considered mainly sitting behind the computer. The body generates heat by converting food and water to mechanical energy and other bodily processes, through metabolic processes.

There must be heat balance which means that the heat produced in the body must be equivalent to the heat lost from the body. A person's thermal comfort is affected by the following six parameters:

- Air Temperature
- Relative Humidity
- Air speed near body
- Mean radiant temperature
- Clothing level
- Activity level

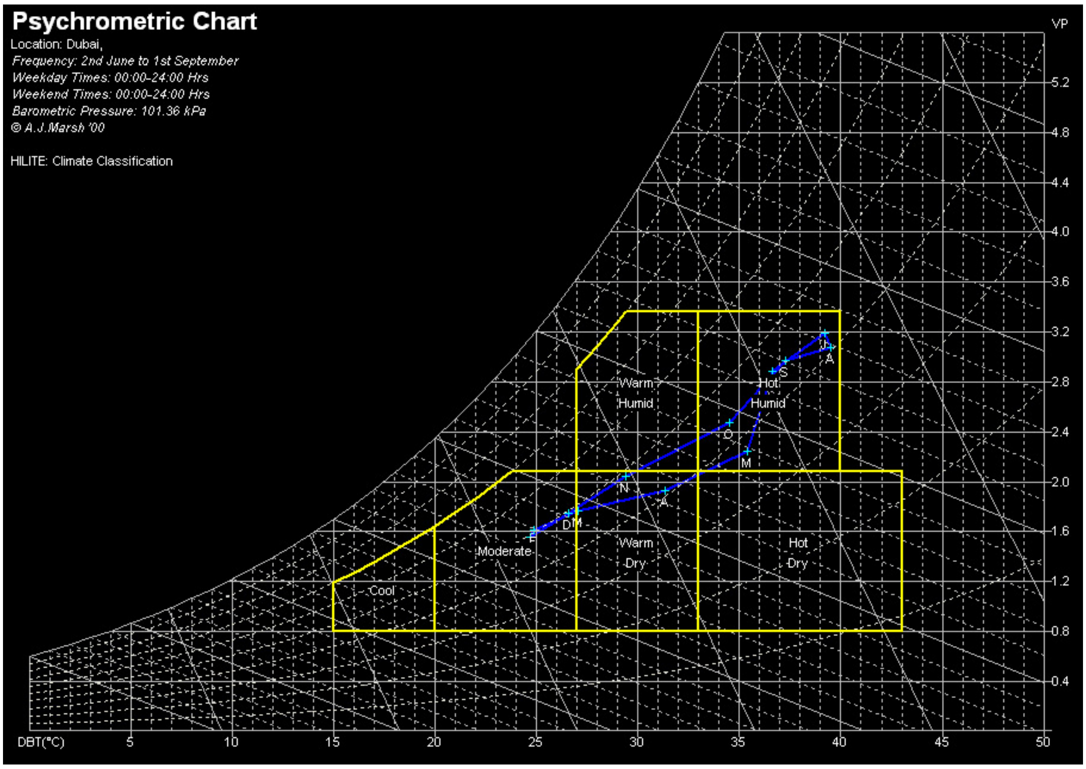


Figure 2.3 Psychometric Chart for an office employee

Leather et al., (1998) found that sunlight penetration had positive effects on workers. Improvements in productivity, a decrease in working accidents, an increased level of mental performance, improvements in sleep quality, and an increase in morale among night shift workers have been attributed to better lighting conditions (Luo, 1998).

On e of the main conclusions produced by Begemann et al., (1996), was that daylighting affects employee productivity. The research paper was focused on daylight, artificial light and people in an office environment overview of visual and biological responses. Lighting systems in working environments should meet the requirements of light and also meet the needs for biological stimulation which Begemann (1996) calls 'light vitamins'. Lack of light negatively influences the alertness, performance levels, sleep quality and the degree of discomfort and well being in a human

2.2.1.2 Seasonal affective disorder

SAD is a type of depression whose symptoms become evident during the winter months and disappears in the summer when the days become longer. Reports suggest that anything from 0.4% to 9.7% of the working population could suffer from SAD, with up to three times that number having various signs of the affliction without being classified as major depression (Rosenthal et al., 1985). The symptoms are of feeling low, lack of energy and fatigue, low levels on interest and concentration. They may also include a desire for sleep, and consume foods, with carbohydrate cravings leading to increased weight. The suggestion that short winter days and lack of light exposure is behind SAD led to the use of light as a treatment for this depression (T.A, Wehr, 1991).

Begemann et al., (1996) mentioned that on average employees add 800 lux artificial light to the daylight level on the desk space the full range of daylight desk illumination levels. The main objectives of Begemann et al., (1996) were the search for biological stimulation effects. Begemann et al., (1996) coins the term 'ill-lighting syndrome' for sub-syndromes, which is caused by poor lighting. Creating healthy luminous environment could be a form of preventive medicine in the long term since certain amount of daylight per day is healthy for the well being. This research proves the essential need of employees inside office spaces to natural daylight to stay health and be productive.

2.2.2 Employee job satisfaction

There are various theories that investigate job satisfaction, which indirectly relates to the job performance level. Maslow's theory of linking needs to motivation factors is widely known, a theory linking individual employee needs to motivation levels (Porter et al., 2003). According to Maslow's (1954) theory a person's need has influences on the activities until that need is fulfilled.

There are five basic needs that Maslow (1954) identifies:

- Psychological
- Safety and security
- Belongingness
- Esteem
- Self actualization

This theory has led to further investigations and another theory by Herzberg had developed. As Herzberg (1993) introduces the hierarchy theory which asks two critical questions to the participants in the research; the study explained the existence of such things that Herzberg named as 'motivators' that employees experience which affects the performance level. Motivators contained variables such as achievement, recognition, responsibilities, growth and advancement (Porter et al., 2003).

2.2.3 PANAS scale

The PANAS scale is a psychometric scale determining the positive and negative affects both on states and traits of humans. The scale was tested and modified throughout various researches to help quantify and comprehend employee productivity levels within different contexts.

Assessment of well being of employees was analysed through a positive and negative scale affect (PANAS) – (Watson et al, 1988) this kind of assessment contains two self report scales consisting of ten words describing emotions (i.e. upset, enthusiastic, nervous) participants were asked to provide a rating on the extent to which they felt in general in a scale from 1 to 5 ranging from 'very slightly' corresponding to 1 progressing to 'extremely' corresponding to 5, Wright and Bonnet (1992) and Wright and Cropanzano (1997) provided validity evidence. Cropanzano and Wright (1999) used an index originally reported by Berkman (1971). Cartwright (2009) concluded the definition of psychological well being at work as the affective psychological state that people experience during their work. The PANAS scale correlates and consistency reliabilities are performed using the Cronbach's coefficient alpha. Watson el at (1988) states from the findings of the research and analysis that as the time period within the survey increases the probability that a person would experience a considerable affect increases.

Table 2 *Sample* PANAS-X *Protocol Illustrating "Past Few Weeks" Time Instructions*

Use the following scale to record your answers:

- 1=very slightly
- 2=a little
- 3=moderately
- 4=quite a bit
- 5=extremely or not at all

_______ Cheerful _______ sad _______ active _______ angry at self
_______ disgusted _______ calm _______ guilty _______ enthusiastic
_______ Attentive _______ afraid _______ joyful _______ downhearted
_______ Bashful _______ tired _______ nervous _______ sheepish
_______ Sluggish _______ amazed _______ lonely _______ distressed
_______ Daring _______ shaky _______ sleepy _______ blameworthy
_______ surprised _______ happy _______ excited _______ determined
_______ Strong _______ timid _______ hostile _______ frightened
_______ Scornful _______ alone _______ proud _______ astonished
_______ relaxed _______ alert _______ jittery _______ interested
_______ Irritable _______ upset _______ lively _______ loathing
_______ delighted _______ angry _______ ashamed _______ confident
_______ inspired _______ bold _______ at ease _______ energetic
_______ Fearless _______ blue _______ scared _______ concentrating
_______ disgusted _______ shy _______ drowsy _______ dissatisfied with self

Watson (2000) collected data between 1985 and 1993 to analyse their moods. The number of entries reached up to N= 478; where the average moods was reported to be around 43.6 on certain occasions. This was collected using 11 subscales from the PANAS-X scale (Watson and Clark, 1988). The findings were compared when there was 0 percent and 100 percent sunshine, and concluded that the amount of sunlight intensifies the participant's mood and thus extreme positive and negative results were obtained.

Using factor analysis the results from the PANAS scale were reduced from a mass of information into a coefficient that is understandable. Cronbach's α (alpha) is a statistic. It is commonly used as a measure of the internal consistency reliability of a psychometric instrument. The theory was coined the name alpha by Lee Cronbach in 1951, as he had intentions of continuing with further instruments. It can be viewed as an extension of the Kuder-Richardson Formula 20 (KR-20), which is the equivalent for dichotomous items. Cronbach's α measures how well a set of variables measure a single, one-dimensional latent.

Cronbach's α is defined as

$$\alpha = \frac{N}{N-1}\left(1 - \frac{\sum_{i=1}^{N}\sigma^2_{Y_i}}{\sigma^2_X}\right) \qquad (1)$$

Where *N* is the number of components (items), σ^2_X is the variance of the observed total test scores, and $\sigma^2_{Y_i}$ is the variance of component *i*.

Alternatively, the standardized Cronbach's α can also be defined as

$$\alpha = \frac{N \cdot \bar{c}}{(\bar{v} + (N-1)\cdot \bar{c})} \qquad (2)$$

Where N is the number of components (items) $\bar{v}$ equals the average variance and $\bar{c}$ is the average of all covariance between the components.

The Cronbach formulae was abandoned throughout time and the introduction of various computer software that help solve complex equations and perform factor analysis SPSS was designed to undertake such tasks and more. There are several different applications that perform various statistical correlations, and SPSS was chosen for its wide availability, and with other professional high end users.

2.2.4 Employee performance and daylighting

A few studies have examined the influence of different lighting systems on self-reported productivity or on cognitive task performance (Hedge, et al., 1995). Katzev (1992) has analysed the mood and cognitive performance of participants in laboratories with four different lighting systems. The type of lighting system influenced occupant satisfaction and was linked with better reading comprehension (Rashid and Zimring, 2008).

Markus (1967) stated that almost 96% of respondents favoured to work under natural light as opposed to electric lighting. Also, approximately 86% of the respondents preferred having sunshine in their office year round as opposed to only one season of the year or not any daylight at all. Markus (1967) reported that the employees that where sitting near windows were more content, while the ones that where sitting further away from the window openings complained often. Oldham and Fried (1987) reported that when offices were less light the employees were more likely to leave offices when they had a choice, like at lunchtime and during breaks.

Franta and Anstead (1994) showed that a lack of daylighting or insufficient lighting caused headaches, seasonal affective disorder, and eyestrain in a certain number of office employees. Rosenfeld et al. (1998) reported that daylighting created a more positive mood among workers leading to better workplace outcomes. Galasiu and Veitch‘s (2006) research summarised more than 60 daylight studies conducted between the years 1965 to 2004. The various studies concluded the importance of daylight inside office spaces on employee health and well being. Employees complained less about eye strains and headaches when exposed to natural daylight under same working conditions. The fluorescent artificial lighting inside office spaces has caused increased levels of stress.

2.3 Light pipes

2.3.1 History of light pipes

The history of light pipes dates back to the Egyptian Pharaohs, approximately 4000 years ago. The Egyptians used mirrored light pipes to transform the centre of the pyramids, Figure 2.4, into a day lit space (Monodrought, 2004). Light pipes can avoid the loss of daylight by using the concept of fibre optics, which is an optical observable fact called “total internal reflection.”

Figure 2.4 Pyramids of Gaza, Egypt, (http://en.wikipedia.org/wiki/File:Kheops-Pyramid.jpg)

This involves the light pipe to be made of a solid transparent material, such as glass or plastic. The light pipe can be long, and it can have any number of bends (Wulfinghoff, 2000). The original patent of light pipes was a British inventor, Stephen M. Sutton in the year 1988. The system was considered an outstanding success in Australia and the North America, as a method of bringing natural daylight from the level of the roof into the levels below (Monodraught, 2004).

Figure 2.4 describes the various components that make up a light pipe. The dome shaped cover behaves as a collector that brings in the daylight and helps transfer the light into the highly reflective transporting part of the pipe.

The reflective nature of the pipe acts as a means of carrier that through the basic nature of light rays takes the daylight into deeper spaces. Light pipes travel to certain distance through a vertical opening in the slab of a building to deliver daylight into the space. The amount of light reflected and refracted inside the mirrored surface decreases as the distance the light pipe extends (Monodraught, 2000).

2.3.2 Types of Light pipes

Light pipes consist of three main parts, the dome which is the collector, and the pipe where all the light reflection, and refraction takes place until light reach the distributor area which is usually the last part. Light pipes are in 3 basic designs which are: ‘Straight-Pipe’, ‘Elbowed-Pipe’ and ‘Flexible-Pipe’ as demonstrated in Figure 2.5 by Monodraught (2004).

The basic straight pipe goes from the roof through the building or space vertically. The important thing is that the top part of pipe runs all the way through the roof vertically straight. This kind of vertical penetration through the roof will make sure to achieve maximum output and even provide bright output on cloudy days.

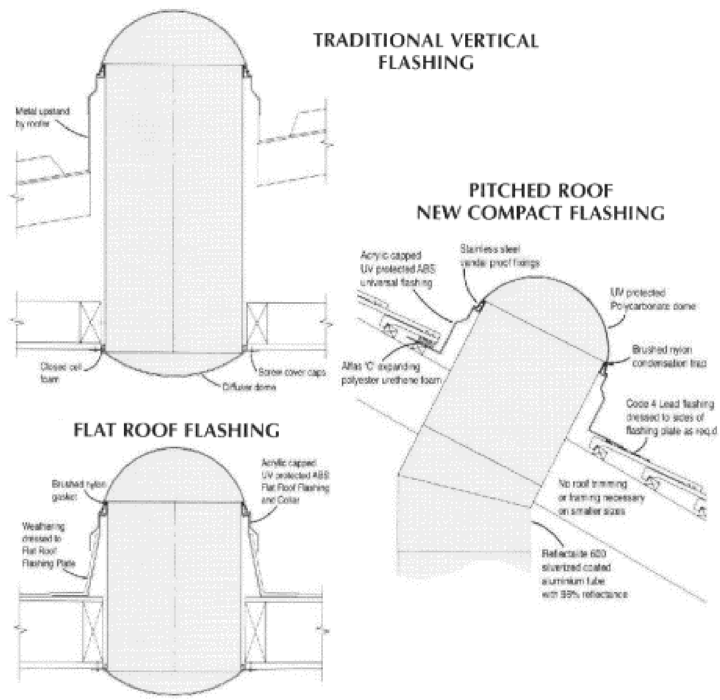


Figure 2.5 Standard design of light-pipe as produced by Jenkins and Muneer (2003)

The dome, as shown in Figure 2.7, is made from a UV stabilized unbreakable polycarbonate, or an impact resistant modified acrylic. Then there is a brushed condensation trap made from a nylon gasket that is applied on top of the light pipe. The internal pipe is made from purity silver impregnated aluminium with a mirror finish and PVD coating with 90 percent reflectance (Monodraught, 2004).

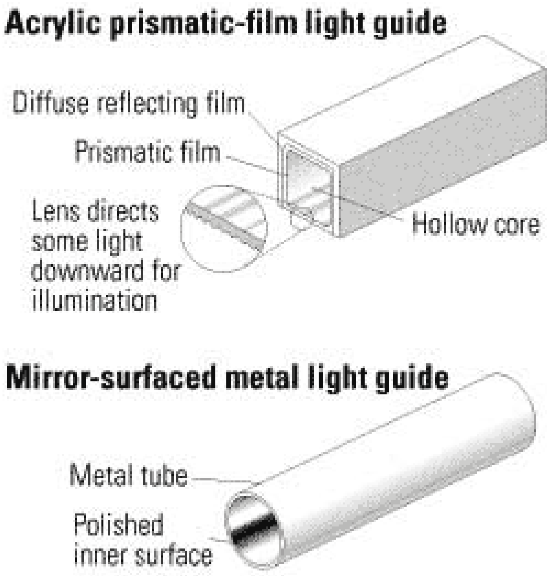


Figure 2.6 Anatomy of a Light pipe, (http://www.uppco.com/business/art/EA33_2.gif)

While with elbowed pipe designs an elbow is used at the top part of the pipe and at the bottom part. The addition of an elbow at the top is to match with the top rim of the roof flashing. Usually the flashing of these products are made for roof slopes with an average of 3-1/2:12. This becomes a challenge for north facing light pipes since it would create the worst daylighting performance level, while the east orientation would be optimal during the morning, and the west orientation optimal during the afternoon, and the south orientation optimal for mid day performance.

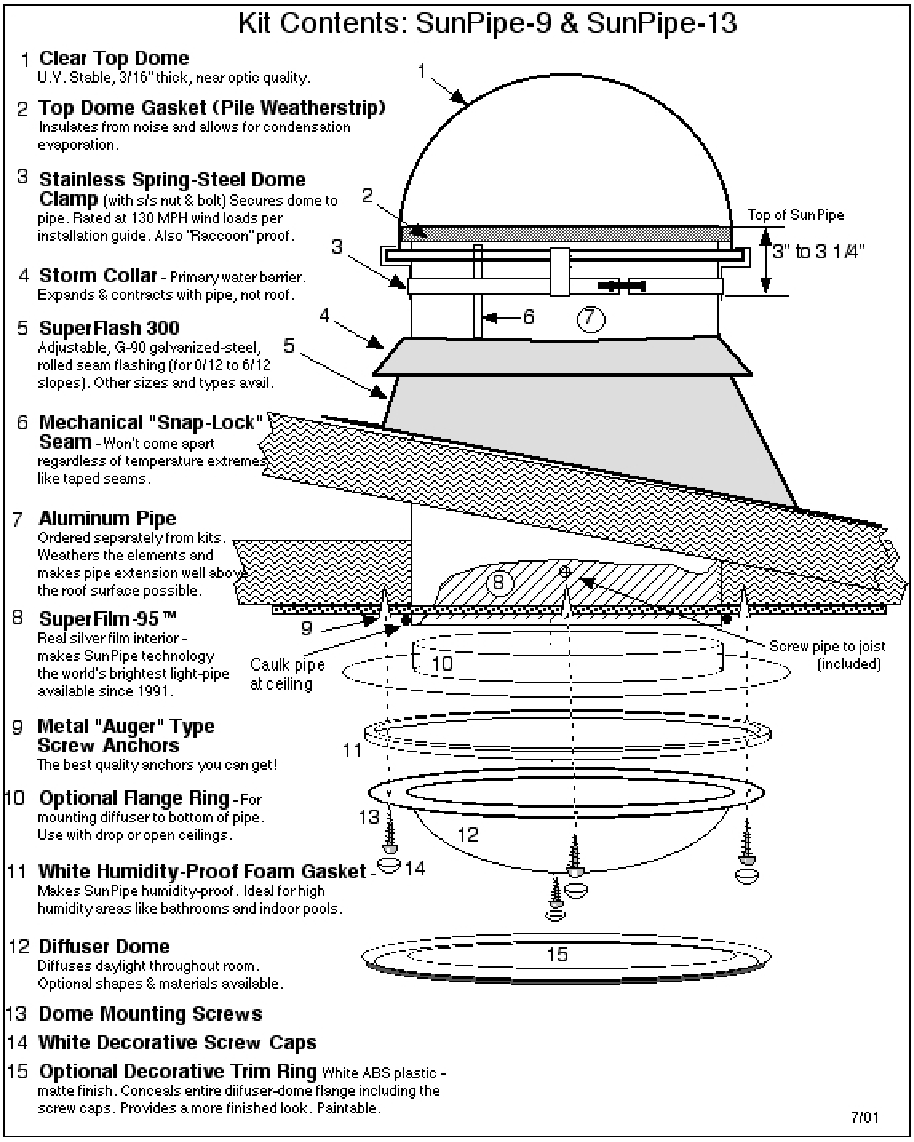


Figure 2.7 Sun pipe components, (www.wednewssite.com)

Flexible pipe design is considered to be one of the worst pipe designs because of two main reasons: i) the top part of the pipe is flush with the slope of the roof, ii) the surface of the pipe reflects daylight everywhere which includes the inside the pipe and all the way back, and iii) low reflective material is employed to make it. There is a 12% reduction of light for each 45° bend used and there is a 6% reduction in light transmission for every metre of light pipe 30° & 45° adjustable elbows can be used with all light pipe applications to direct daylight to where it is required (Monodraught, 2004).

A light pipe can contain a number of elbows. However, the more elbows in the system, the more the overall light will diminish. If many elbows are required, it may be necessary to use a larger diameter light pipe to bring in more light initially (Monodraught, 2004). Sunlight is collected by the top dome and travels down the reflective, mirrored pipe through multiple reflections. The transmission of the pipe is reliant on the material of the pipe having a typical reflectivity of 95%. This daylight arrives at the diffuser area is dispersed into the selected area. The type of diffuser can be different depending on the requirements of the room. The pattern of the diffuser means that the best way of predicting the resulting illuminance is to use an empirical procedure rather than through theory alone (Jenkins and Muneer, 2003).

According to the research conducted by Rossi et al (2004), the main distinction of a light pipe is its capacity to diffuse light allowing its use in every south facing façade. This specific research was conducted with two light pipes being examined and a room 7m width x 11.5m depth x 3.5m ceiling height. Rossi (2004) emphasizes the need to have a highly efficient reflector that is receiving the sunlight and directing the sunlight through the pipe. Equation 3 is used to calculate the average flux from luminaries. As the paper explores the integration of a highly reflective film with a value of total reflectance equals 0.95. To determine the average flux that has to be supplied by the artificial lighting in each one of the five areas of the room in the instant τ, following relation was used (Rossi et al, 2004):

$$\varphi_{m,\_,i} = (E_{m,o} - E_{m,n,\_} P(sun) / K_u K_m) / * A_i \qquad (3)$$

Where

$\varphi_{m,\tau,i}$: average flux provided by the luminaries on the area
A_i in the instant τ [lm];
$E_{m,o}$: average set point illuminance on the work plane [lx];
$E_{m,n,\tau}$: daylighting illuminance on the work plane (clear sky with sun) in the instant τ [lx];
P (sun): sunshine probability coefficient;
A_i: area of the considered room's zone (m2); K_u: utilization coefficient of the luminaries;
K_m: maintenance coefficient of the luminaries.

2.3.3 Performance of light pipes

The research conducted by Shao et al., (2000) demonstrates the performance of light pipes and investigates the energy savings from electricity. The research proves that the reliance and natural daylight will in fact reduce 20 to 30 percent of the total building energy consumption. The research monitors the efficiency and performance of light pipes designed at three different building typologies and then the illuminance data is collected and results were analysed to prove that short distance, straight light pipes are more efficient than long extended, big light pipes. The research by Shao et al is very similar to the main objective of the current study since various sizes of light pipes are tested for this specific office tower.

There is a need to be able to have an accurate predictive tool to be able to prove the performance of light pipes. Jenkins and Muneer (2003) investigated a tool to be able to measure the various versatile arrangements of light pipes. The research conducted was very extensive and helped to understand the performance of light pipes. A model was produced to calculate levels of light at two main stages. The luminous flux of light pipes was calculated using the external illuminance transmitting through the pipe and the cross sectional area of the pipe. The transmission hυ, external illuminance E and the pipe radius R:

$$\text{Luminous flux} = h\upsilon Er2 \qquad (4)$$

To be able to use equation 4, the dimensions of the light pipe, including the diameter and the length the light pipe is extending is required. This is the first stage of the research conducted by Jenkins and Muneer (2003).

The second stage is to translate the luminous flux data obtained from the first stage into and illuminance level at a specific given position inside a space. The amount of light arriving at the dome of the light pipe varies between direct from the Sun and sunlight reflected from the clouds and sky. The research tests a model measuring luminous flux of a pipe that is 1.2 meters in length and 300 millimetres in diameter. The results prove that the direct light from the

Sun will provide some areas with more light since the position of the Sun plays a vital role. While when there is a clouded day and the light is reflected from the sky and off the clouds there is a more even distribution of light. There were limitations and challenges on the research conducted by Jenkins and Muneer (2003). As a result of this problem, the authors suggest to use the mathematically calculated illuminance model for calculating internal fluxes in conditions when the external illuminance is not measured to be larger than 40,000lux.

Based on this challenging outcome the research investigates a tool called luxplot, which is using MS Excel software, where the illuminance values are calculated for a grid of points on a two dimensional plane. The luxplot is a useful design tool to help decide on the size and configuration of light pipes (Jenkins and Muneer, 2003). The luxplot model requires input information such as the size of the room, the light pipes employed and the external illuminance. The light coming from window units are calculated separately and added to the illuminance values to help produce a combined luxplot.

2.3.4 Optimal orientation of a light pipes

The orientation and location of the position of the light pipes play a critical role in their function. The orientation of the light pipe is considered a crucial part of the design since it is the first stage to attract daylight into the building. The location and orientation of the dome of the light pipe on the roof of a building is important as there is a maximum distance for the light pipe to become efficient. The most common light pipes have been the vertical ones that start from the roof and go below the ground to the basements of certain houses. Recently horizontal light pipes are being explored to expand the efficiency and application in certain buildings where vertical light pipes can not be used.

In terms of visual comfort, the advantages offered by the light pipe are evident: the values of the illuminance gradient on the work plane and the values of the illuminance in the deeper zone of a standard room have shown the right distribution and uniformity of the luminous field that is an essential condition to obtain an adequate level of luminous comfort and to prevent and reduce the visual fatigue (Rossi et al., 2004).

Horizontal light pipes from the south façade are being explored since there will be challenge to provide light pipes from the roof to the lower floors. There are currently no horizontal light pipes available for high rise towers and research is still under progress to achieve that. The advantage of horizontal light pipes is yet under analysis but the fact is that once horizontal light pipes are functioning, many buildings will be able to capture daylight and transport it to deep interiors. The direct relationship between light pipes and employee productivity is not widely available and this type of research is important for this technology to develop and become a part of the essential design strategies.

2.4 Aims and Objectives

As concluded from all the numerous researches conducted, during the past years, on the integration of light pipes and the use of light pipes in deep spaces, light pipes aid in transporting daylight and help transform the interiors of a space into a naturally daylight space. Human psychology is affected by the natural settings of a space and is affected by messages received from the different sensory organs sending various messages simultaneously.

The level of daylight inside a given space provides many benefits to the health and contributes to the well bring of the employees. Introducing effective natural daylight strategy will help reduce the impact of artificial lighting load on the building systems and in turn reduce the amount of energy consumed during the life time of a building. Light pipes are considered a means of integrating natural daylight into spaces. The main issue is that vertical pipes have limitations and can transport daylight up to a certain distance. Therefore horizontal light pipes are investigated at the lower floors of the building while the conventional standard light pipes are designed for the top floors. Light pipes have various sizes and the research addresses the issue of having multiple light pipes and multiple light pipes of various sizes.

Within defined parameters this research seeks to integrate the optimal number and size of light pipe inside an office space and thus improve employee productivity levels. During the comprehensive literature review it was evident that light pipes are an efficient daylighting strategy but there was little in-depth analysis produced linking the employee performance level inside a work space and the amount of daylighting.

Chapter 3 – Methodology

3.1 Methodology Outline:

The primary method of collecting evidence is through daylight measurement, and measurement is a more reliable tool than simulation. To be able to develop a grounded theory the collection process needs to be meticulous and accurate to the situation (Gillham 2005). Regular measurements and interviews with the employees in the office building, helped compile the accurate comprehension about the performance levels of employees subjected to natural daylighting at their workspaces.

The data is collected through various parts and the results are then compiled to achieve an understanding of the ultimate goal. The first data collection method was surveying the lux levels currently available inside the given office space. The levels where recorded through a duration of time and an excel sheet was prepared to record the findings. Simultaneously with this light measurement, the office employees were asked to take part in a survey which was related to their seating position and their usage to light. The importance of this stage is that this first analysis and data collection establishes the relationship between employees who are seated close to a window with access to natural daylight and those employees that where seated far away from an external opening.

The following step was conducting a survey using the PANAS scale; this was sent out to the participants from the first survey asking them to answer 60 words within a scale of 1 to 5, to measure their performance levels. A simulation model was prepared for modelling the light pipes inside the office space, using Sketch Up version 7 to model and Ecotect version 5.5 for analysis and Radiance was used for lighting analysis. As the survey results were collected from the various participants inside the office space, factor analysis software, SPSS version 16.0 was used to analyze the data collected from the PANAS scale.

The main challenge of integrating light pipes into high rise buildings so far was the limitation that light travels up to a certain distance. Light inside pipes reflects and refracts up to a maximum distance of 32 meter (Monodraught, 2004) and since high rise buildings need more than that length it would be difficult. Several detailed simulation tools are available to evaluate the benefits of daylighting such as ADELINE and RADIANCE. However, these simulation tools require extensive input process and are time-consuming to be trained and utilized for most architects and designers. (Krarti, et al., 2005)

3.2 Different methods used by previous papers

This study examines the effects of daylight at office spaces on the employee productivity levels. The main research papers that dealt with this similar research question using the various research methods are further selected after analysing the various techniques used. The investigations in the past were mainly regarding the efficiency of light pipes and the measure of the amount of energy reduction using light pipes. There is very little research done linking employee productivity and daylighting through light pipes. Literature review is proven to collect substantial background knowledge of the topic and recommend changes and improvements.

3.3 Research Methods

There are mainly two types of observational methods; first one is a qualitative type or participant observation and the second is a quantitative type or structured/systematic observation. Systematic observation has its origins in social psychology; the study of interaction. Concentration on those two approaches has tended to eclipse a third one, which may be styled *unobtrusive observation*. Its defining characteristic is that it is non-participatory in the interests of being *non-reactive*. It can be structured but is more usually unstructured and informal" (Robinson 2005, p 310). Assignment of participant employees to various lighting conditions than what they are usually used to. Observing reactions and recording the findings to reach a scientific theory. One or more variables are manipulated and the effects on variables are measured while all of the other variables are held constant in the testing field.

The main advantage of developing this method is that it acquires data from direct observation from the real situation in the real world; which in term gives more credibility to the experiment. Qualitative data would supplement and illustrate the quantitative data obtained from the experiments. "…the strategy of qualitative research is one of first-hand encounters with a specific context. It involves gaining an understanding of how people in real world situations "make sense" of their environment and themselves (Groat and Wang 2002).

During the research about the nature and performance qualities of light pipes it was found that the main research methodology was based on observation and simulation, while there was literature review type of research conducted to deepen the understanding about the qualities of daylighting produced through various light pipe sizes and types. Surveys may be of two basic types, the descriptive and the analytic. Descriptive surveys are used to gather information largely on what people do and think. Analytic surveys are usually used to answer research questions or to test hypotheses. The research collects, from the general workers population detailed information on their health habits, e.g. diet, exercise, smoking and so on. This information might then be used to make predictions concerning the state of health of the working population. It might be possible to predict how well these worker work under certain levels of natural daylighting and how well they think under those conditions.

3.4 Appropriate methodology:

The ideal methodology which helps to collect first hand data from participants in the actual office space is the survey. The survey and qualitative interview collect accurate data from the existing situation and help raises awareness to the growing need of employees of daylight to help introduce a healthy workspace. The second optimal methodology that does help analyse the problem from a different angle is simulation. Simulation introduces a platform of finite testing area where many possibilities could be tested. The main concern of this method for this specific type of research question is that the exact environment has to be duplicated in order to accurately assess the effectiveness of the light pipe.

The general trend in the construction industry is to achieve maximum amount of lease able office space and usually value engineering takes place to cut costs. The main objective of the research is to introduce light pipes into the fast growing construction of office buildings. The main research method adopted by these selected research papers was the observational, interviews and simulation method; where the participants were placed under observation to record their reactions and simulate the workspace. Since the outcome was collected and presented by using graphs and charts; both a qualitative and a quantitative method were employed.

Galasiu and Veitch's (2006) conducted research based on literature review regarding the daylight levels inside office spaces. Based on the researcher there is an extensive literature regarding the link between daylighting and distribution of illuminance levels inside office spaces and there are some gaps regarding the daylighting and shading controls and its interaction with employees and its effect on energy consumption. Canziani et al., (2004), have a simulation based research that uses a basic model to introduce light pipes as simple, cost effective and efficient daylight performance model.

Oakley et al., (2000), used the quasi-experimental method to support the testing performed. The quasi-experiments are a research design involving an experimental approach but where random assignment to treatment and comparison groups has not been used. The main concern in this type of study is the threat to validity. The authors propose to employee light pipes to help save up to 20 to 30 percent of the overall building energy consumption. The paper performs a study using an actual area that has light pipes installed and a monitoring approach is chosen to record the performances of the light pipes. This type of research was very important to establish a vivid comprehension about the quality of daylighting brought into the space through light pipes.

While Jenkins et al., (2004) used mainly systematic calculation method, where the two experiments conducted lead up to quantitative data that is analyzed. The paper describes the way to use the cosine law of illuminance to help describe the way light is distributed inside the light pipe diffuser, taking in to account the bending of the light pipes. The basic concept of the light pipe from the roof is used, and took into account the various reflectance qualities of the light pipe which affects the transmission values. The aim of the paper was to calculate accurately design a light pipe to achieve a specific light level in a room. This specific research paper helped to calculate the efficiency of light pipes.

Chirarattananon et al., (2000), used a simulation method mainly to confirm the results from light pipes using physical measurement and calculation methods. The paper chooses a city on the tropics, Bangkok, and studies multi storey commercial buildings that are fully air-conditioned, and proposes to integrate light pipes placed at the plenum above the ceiling of the floor. Lux meters where used to measure the illuminance levels on different parts of the surface of the plenum and the ceiling. A simulation model of the room is designed with light pipes to help simply model the performance of the light pipe. While the lumen method employed to calculating the daylight illuminance for building interiors. This research paper was found to be very useful and helpful to achieve a base for understanding the performance of light pipes.

3.5 Survey and Qualitative Interview approach

A form of data collection process through the observation of an actual case was chosen. For the specific nature of this research a building that had integrated daylighting techniques was selected. This specific site visit was arranged by Monodraught salesman since various sizes of light pipes where in use. Large glazed openings on the southern orientation and skylights and light pipes of various sizes were also used.

A site measurement was conducted on a under construction building with light pipes. The building is a sales centre, figure 3.1, which is occupied during the day as a show case for the models of the project. The sales centre is located on Ras Al Khor road in Dubai, as shown in figure 3.2; this area is a low rise area currently with mainly industrial zone on the opposite side of the road.

Figure 3.1 Lagoon Sales Centres, Personal Archive (2009)

Figure 3.2 Location Map of Sales centre, Image Source- (www.bhomes.com/uae/lagoons.xhtml, 2009)

This specific location was accessible and had the three main sizes of light pipes already integrated and in use at the time of the research. All the artificial lighting was switched off and the whole building was lit using the various light pipes size, as demonstrated in figure 3.3.

There are small meeting rooms that allow for people to sit and look at drawings of the housing units they are inquiring about. The main purpose of this site visit was to explore the main daylighting qualities inside the space. The efficiency of light pipes where measured through conducting a visit to a building that has adopted light pipes into the interiors. A showroom at Ras Khor area, in Dubai, was visited and measurements were conducted with the various sizes of light pipes to measure the quantity of daylight filtered into the space.

Figure 3.3 Size of Light pipes at Dubai Sales Centre, Dubai, UAE, Personal Archive (2009)

One of the main limitations was arranging for the site visit and taking measurements, since the buildings had been already constructed and a special request had to be obtained from the Owner. Time was a constrained since there was a specific time allocated for the visit. Transportation was a secondary issue since the location of the site was not in the city but in the industrial area and outskirts of the city where taxis where not readily available.

3.5.1 Daylight survey

A series of interviews and questionnaires and on site data collection where conducted in order to examine the existing day light at workspaces across high rise buildings in Dubai. This survey focuses on employee productivity and comfort levels of employee at these workspaces. The main participants where architects with 70 percent, 20 percent engineers, and 10 percent other various clerical occupations. The problem was documented through measurement inside the office space throughout the working hours of 35 days during the month of January and early February. The winter season was chosen mainly because during these months there is less daylight and therefore more challenging to introduce and test light pipes inside deep spaces. Daylight at workspaces at various intervals from the window exposure was measured through the use of a lux meter. The minilux meter is a portable instrument that uses a crystal to sense the quantity of illuminance is available and the meter reflects that through a reading from 100 to 1000 lux, the details of the measurements can be found at Appendix D. The budget for this type of experiment is basically very low, since all the items required range from cost of pencils, paper and transportation charge. The survey was distributed and people where each allocated 30 minutes to fill in the questions. The main obstacle with this approach is the interference of the research with the natural setting. The workers could exhibit different kind of behaviour when they are aware that they are under special supervision. That would hinder the research and provide false information regarding the construction site.

3.5.2 Qualitative interview

Sampling method has demonstrated to be practical and proven method for estimating descriptions of a large working population. Rea and Jaekel (1983, 1987) found especially high correlations ($r>0.98$) between comprehensive (e.g., continuous video monitoring) and sampling techniques. Constant visits to the office space provided an accurate method for obtaining occupancy and light function data (Maniccia et al., 1999). Due to lower costs and higher practicality, a systematic sampling technique for both daylight levels and occupancy performance levels was used in this study.

The first questionnaire involves questions that are a direct result from survey of reports from post occupancy evaluations from similar studies. The questions help to analyse the main effects the quality of light in the space has on the employees that daily inhabit the space. Bringing daylight into deep high rise office spaces was a big challenge since as a rule of thumb daylight travels 7 meters maximum inside. The current office space is 19.4 meters wide and the further workspace from the façade is measured to be 8 meters while the rest of the depth is for corridor space and left for services. The name of the participants was irrelevant for this specific post occupancy survey conducted. The full results from the survey and questionnaire are located at Appendix D.

3.5.3 PANAS –X scale

The volunteer participants from the pervious survey did not all participate during this part of the research for various different reasons. The PANAS-X scale was administered to a total of 50 employees that chose to take part. The 60 item scale was emailed to the participants and each where given 10 minutes to fill in the scale rating the way they had felt during the past six months. The duration is very important since there have been various factors that could affect this rating during the past couple of months. One of the main issues was the global financial crisis that affected the construction business in Dubai; therefore many people were made redundant, and also caused salary cuts for many other businesses. Critical issues as those that affect the global situation would in turn affect them and play a role in the way the participants respond to this type of survey.

The 60 item scale provides a measuring tool to understand how the mood of a participant can and will affect the performance levels. The participants emailed back their responses and the results where compiled into one excel sheet. One of the important and critical factors that were observed during this process was the exact seating location of the participants. The results from the scale were carefully sub-divided into East, North and West orientation. The majority of the participants are seated on the North side since the shape of the office floor plate is rectangular and it's wider in that orientation. The complete results are placed in Appendix E for further information.

3.5.4 SPSS software

The SPSS software is a median for analysis and displaying information using various techniques. The SPSS technology uses the advanced mathematical and statistical proficiency to bring predictive information that and makes them adaptive to develop outcomes. The software is mainly used for four various functions that include data collection, modelling, statistics and deployment of analytical facts that impact day to day decision making (figure 3.4). The software is used to combine analytical business solutions with architecture in and intends to achieve a sustainable advance. Factor analysis aims to classify the underlying variables that help explain the pattern of correlations within a set of observed variables. Factor analysis is frequently used for data reduction to identify a small number of factors that clarify the most of the variance observed in a much larger number of manifested variables.

SPSS Predictive Analytics Software will assist in those main issues:

- Capture all the information you need about people's attitudes and opinions
- Predict the outcomes of interactions before they occur
- Act on your insights by embedding analytic results into business processes

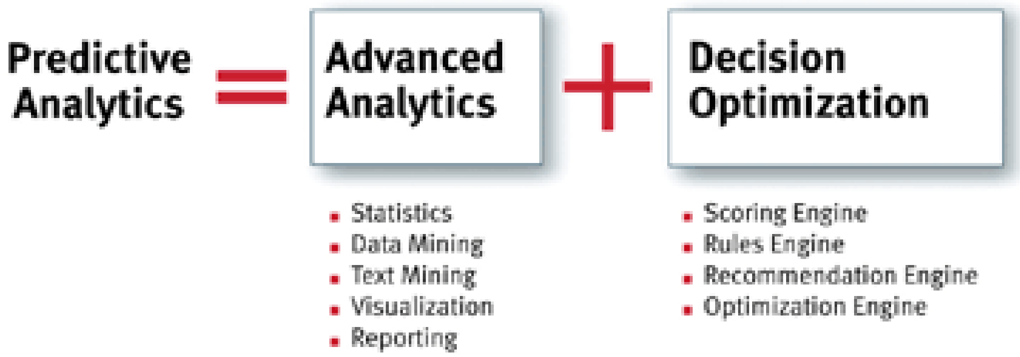


Figure 3.4 SPSS Analysis, (http://www.spss.com/predictive_analytics/work.htm)

The main aim of bringing this software into the research is to use the factor analysis function to help analyse the data that is collected from the PANAS –X scale. The software is a professional one that is used worldwide for various reasons stated above. The results from the PANAS-X scale require factor analysis software to analyse and to understand the impact of daylighting on the employee performance. The scale provides the raw data collected and the software help analyse and also introduce predictive outcomes.

3.6 Simulation

This type of research involves modelling the real context for the purpose of analysing dynamic interactions inside a specific setting. For this research the office space at Sheikh Zayed Road was chosen since it is the current location of the researcher and there is a daily interaction with that office. Sketch-Up version 7 was used as the 3D modelling software as a base. The office space was simulated in 3D from the ground floor up to the last level.

Radiance, a computer simulation package is used to simulate and visualise the amount of daylighting in a given space. Radiance is an advanced lighting simulation program that uses ray tracing to accurately predict the behaviour of light in spaces. The simulation package will analyse the indoor daylighting performance and daylight factors at different levels of the office building. Using the weather tool extracts information regarding the climate of the UAE and also establishes the daylight zones and hours of the month, also it is important to know the amount of diffused and direct solar radiation.

Radiance software can be downloaded from the Ecotect website for free of charge. It is software that is compatible with Windows XP and Mac. Radiance requires the model to be exported from ecotect therefore the user needs to have prior knowledge and capability of using ecotect as modelling software. Radiance in its current form is not a user friendly program since it only works with text files.

3.7 Refining project boundary: Efficiency of light pipes at bringing daylight into high rise office offices and improving employee performance at the United Arab Emirates.

The United Arab Emirates is compromised of seven emirates and Dubai is one of the main Emirates chosen for this specific research. The city of Dubai enjoys sunny clear skies most of the 365 days of the year as per the weather data tool used to study the general solar climate of the city. Dubai is located on the geographic coordinates 25° 15' 8" North, 55° 16' 48" East. Dubai presents a growing hub of office buildings in the Middle East as there is an always demand for office space since many businesses are opening new offices in the city. There is a need to address the challenges with high rise office spaces and aim to available abundant resources such as daylight into our design of office buildings.

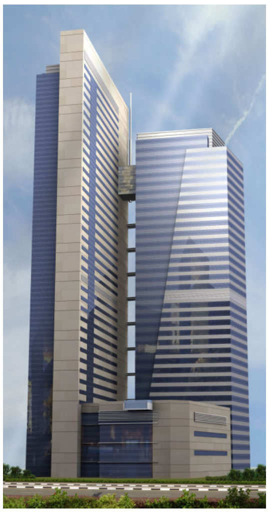


Figure 3.5 Monarch Office Tower, RMJM (2008)

The 34 storey office tower, named Monarch Office Tower is located on Sheikh Zayed road in Dubai, United Arab Emirates. The building is composed of a hotel tower to the left while the other building is a dedicated office tower, figure 3.5. There is a multi-storey parking to the south orientation; as presented in detail sectional elevation in appendix C. This is a view of the tower from the south side. The space is occupied from 8 am to 6pm during the weekdays. The area of the single module of office space taking part for this research purpose is 1400sqm (72meters by 19.4meters).

3.8 Forming a Hypothesis

One of the passive strategies in space design is daylighting. For the protection of the environment and the health of the occupants of the space; light pipes technology was selected. Light pipes are one technology that will introduce even distribution of daylight into deep office spaces with minimum implications on the floor area of the office interior. These various sizes light pipes will help create a uniform distributed daylight in the office which will help improve employee performance levels (figure 3.6).

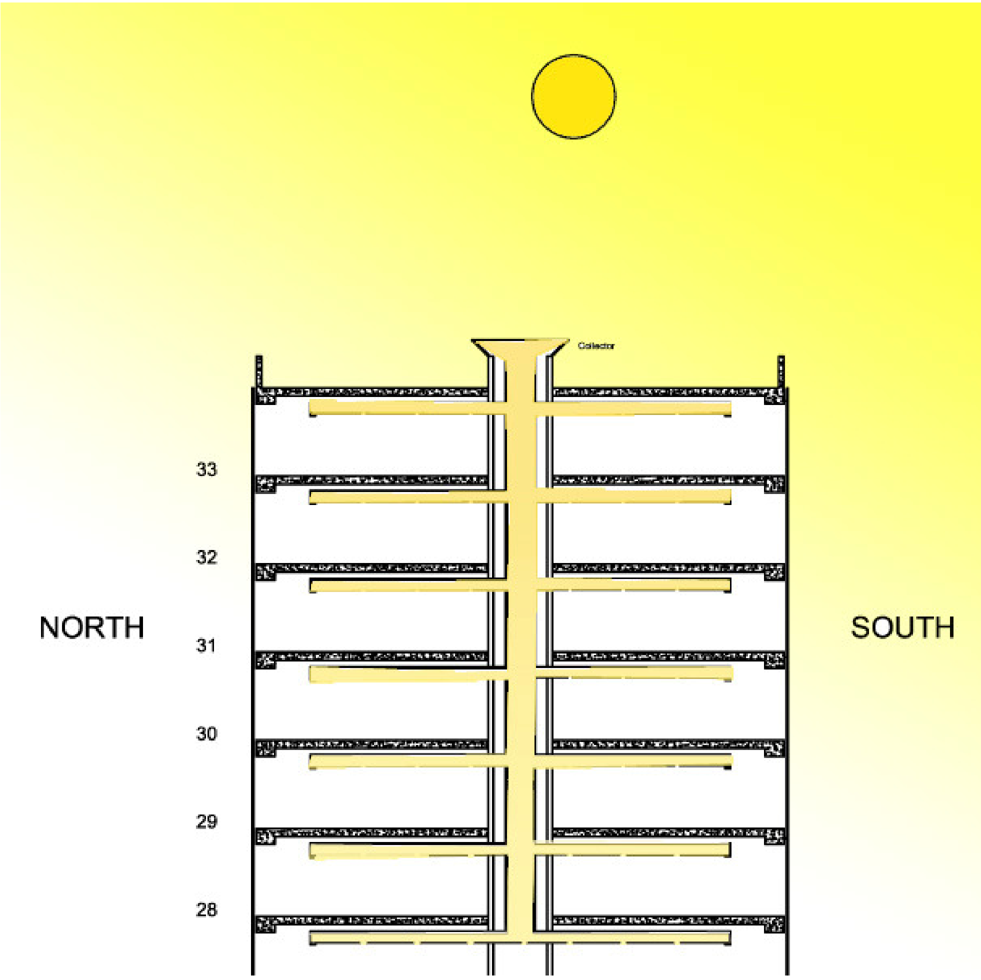


Figure 3.6 Diagrammatic Section through office building presenting vertical light pipe

The research takes place in three different parts carried out simultaneously at certain time to help achieve accurate results. The first part was a survey of the current lighting levels at the proposed office building. This was conducted with the help of a lux meter, and the lighting survey was carried out for a period of four months while the data was used to correlate with the next survey. The office occupants where each presented with a survey of answer regarding their current seating location and the amount of daylight they have at their workspaces. Theses information was translated in to a chart to help clarify the exact problem. Next the PANAS-X scale was administered to the participants that chosen to take part in this survey, since not all the participants from the first survey where available to take part. This part of the research was critical to establish the level of employee performance currently at the office space. The data collected with the help of the surveys was channeled into the 3D simulation software, Ecotect, to quantify the amount of daylighting achieved from the various sizes of light pipes proposed, hence linking the amount of daylight with the employee moods, PANAS-X scale, and establishing the link between daylighting and employee performance levels.

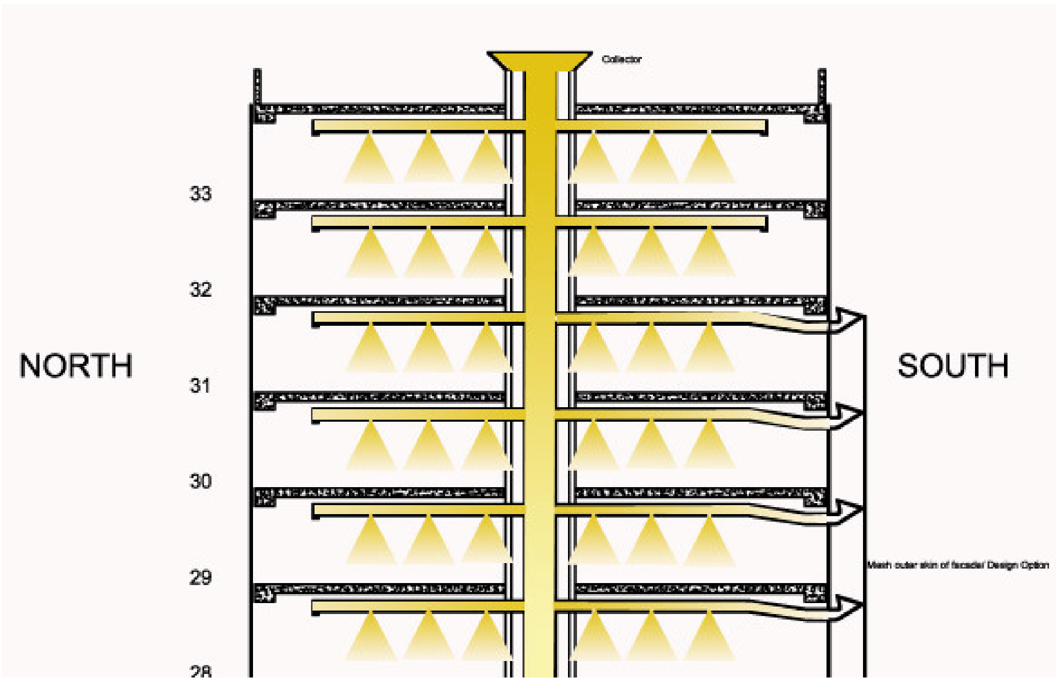


Figure 3.7 Vertical and Horizontal light pipes

This concept is explored with using mainly two methods; one involves monitoring, surveying and documenting the actual problem; while the second method uses 3D modelling and simulation method to help model the proposed light pipes and analysis the quantity of light transported into spaces. The survey brings to the research accurate measured information from the actual office interiors. There are various factors that affect the amount of daylight inside an office space. The materials and colours of the interiors of the office play an important role just as the size and location of the opening. The various types of finishing materials have a range of absorption and reflectance values.

Figure 3.7 explains how the horizontal light pipes distribute daylight through openings in the transportation pies. Those openings look from the inside of the office just as regular lighting fixtures. The vertical light pipe acts like a light well or an atrium space that collects light and then distribute to the spaces on the sides. One of the main challenges was to bring sufficient amount of daylight into the lower floors since light can travel a specific distance inside the reflective surface of the light pipe.

Chapter 4 – Results

4.1 Survey and Interview Results:

The results of this research are a compilation from data collected through 3 main procedures, which are a survey, questionnaire and a simulation model. The participants carefully had been very specific about the light levels in their office spaces and that was a useful tool as part of this research. The numbers submitted by each participant was an average number and since a field survey of one office space was conducted to compare the numbers with the actual office space, the daylight levels submitted where close to the accurate figures shown on a lux meter.

4.1.1 Daylight Survey results

Designing various layouts of light pipes with various sizes to obtain consistent level of daylight across the space is the main goal of this research. Larger light pipes bring in more daylight and hence they should be designed in such a manner as to have the distance between each light pipe sufficient to have even distribution of daylight and to avoid dark areas in between.

Table 4 Daylighting Survey measured with a Lux meter

Daylight levels at 3 meter from Façade(LUX)				
Time of day	east	north	west	south
8am	600	100	100	200
9am	900	100	100	200
10am	800	100	100	200
11am	650	120	100	400
12pm	500	150	100	400
1pm	350	150	100	400
2pm	200	150	100	400
3pm	150	120	150	400
4pm	150	120	250	400
5pm	120	120	250	400
6pm	100	120	100	400

An interview was conducted with 40 participants of the same office to achieve a daylighting distribution matrix and get a better understanding for the current challenge. The daylighting matrix was conducted as per the current seating layout of each employee taking into consideration the seating location, distance from the window as measured in meters, and the orientation of the workspace with relation to the North-South axis, figure 4.1.

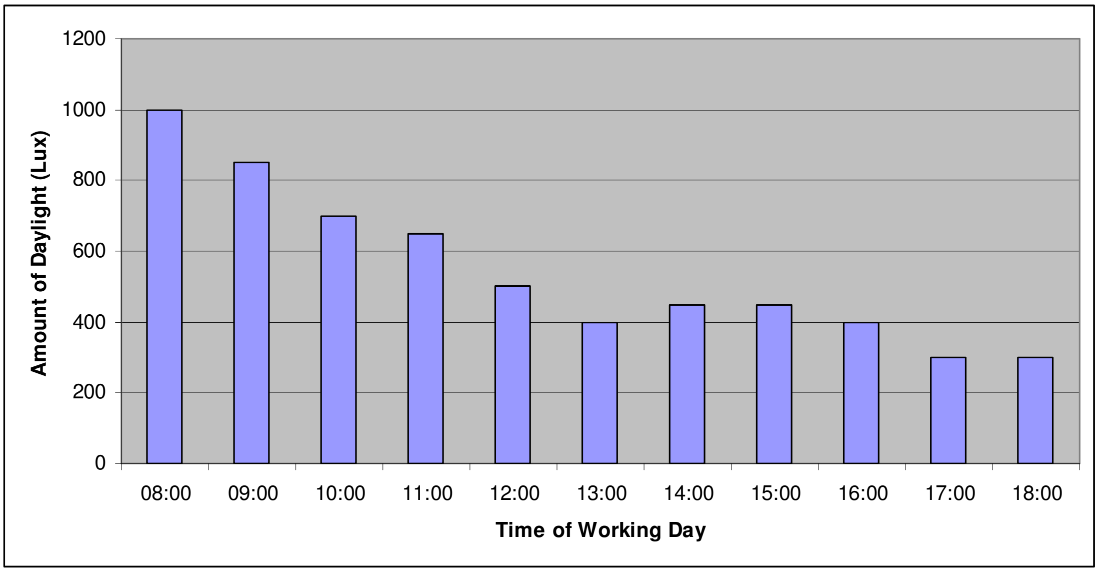


Figure 4.1 Daylight levels per hour from East Oriented workstation

4.1.2 Qualitative Survey results

A total number of 120 people from the working population from different offices around Dubai where chosen for the interview. A questionnaire with 9 questions was prepared covering aspects including the hours spent on average at the office, view, orientation etc. the main focus of the questions where about the amount of daylighting at the workspace, Appendix E.

Employees that participated in the interviews and survey opted to be seated at the vicinity of windows. The main concern was raised by the employees that were seated on the east and west orientation of the office building, since there was glare produced on the computer screens which made working conditions uncomfortable. Over 20 percent of employees responded to the fact that sunlight accompanied with view to the outside promoted the production processes and had positive effects on the thinking processes. Five percent of the respondents included the fact that the location of the computer screen with relation to the window was critical factor which helped avoid glare issues.

There where questions that inquired about the seating location of the employee with regards to the coordinates, and how much having a view has an impact on their work.

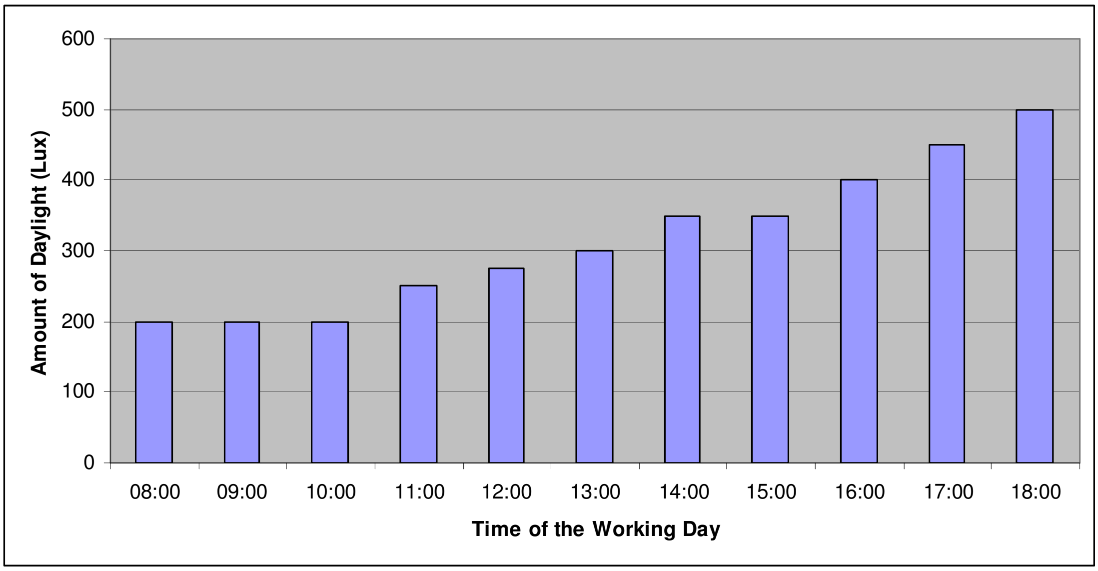


Figure 4.2 Daylight levels per hour from west oriented work station

4.1.3 PANAS-X scale results

The PANAS- X scale was administered to all the participants who chose to volunteer and take part in this experiment. Each of the participants who had earlier answered the first part of the survey received a copy of the 60 item schedule and they where each given 10 minutes to complete. The critical part of this interview was to record the seating arrangement of each participant in relation with their respective answers. The PANAS –X scale helps measure specific affects that mankind goes through during a lifetime. The response from each participant was separated into four different stacks. Each stack represents one of the four coordinal orientations, north to west. Next these measures where plotted on to a chart to understand and establish the relationship between employee performance and daylight. Employee performance levels are concluded based on the PANAS – X scale where positive affects lead to higher performance since the employee is at a better state and more enthusiastic to respond to work, while negative affects would lead to lower performance levels.

The main results obtained from the scale was that the majority of the participants that where seated on the East and North side of the office space where positive while the participants that were seated on the West had high negative scores. Table 5 presents part of the results from the survey as the participants responded to the way they felt at work in the past six months. The full results including the 60 items is in Appendix F.

Table 5 PANAS-X scale results

PANAS SCALE / ORIENTATION	EAST							
	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8
cheerful	4	2	3	4	5	4	4	3
sad	3	1	2	2	1	2	3	2
active	4	5	5	5	5	5	4	3
angry at self	4	1	2	3	3	3	2	2
disgusted	2	1	1	1	1	1	2	1
calm	3	4	3	4	5	5	4	4
guilty	1	1	2	2	4	1	1	1
enthusiastic	4	3	3	2	2	1	2	4
attentive	4	2	2	3	4	4	5	3
afraid	1	4	2	1	2	1	1	2

4.1.4 SPSS results

The excel sheet that contained all the combined result collected from the participants was exported into SPSS version 16.0 for factor analysis. Using the data analysis tools factor analysis was performed. Once the output is calculated the results are exported back into excel sheet and summarized into a chart.

The results, figure 4.3, show that the positive affect was higher for the participants that were seated on the East side of the office space. While the office employees that were sitting on the West side had more negative affect since they had natural daylighting only during the later hours of the working day.

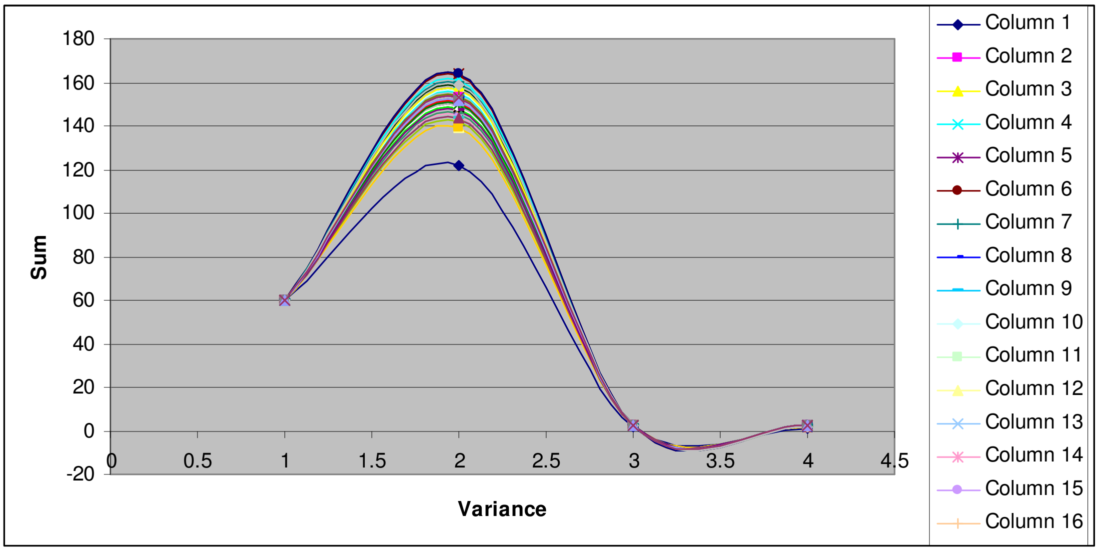


Figure 4.3 PANAS-X scale results by factor analysis using SPSS V16.0

4.2 **Simulation Results:**

The validation, for the simulation model, process started by first taking a measurement for the amount of daylighting measured with a lux meter at 3 meter distance from the true coordinates, north to west direction. The average of one month survey of these workspaces is presented in the chart above.

According to figures 4.1 and 4.2, workers are exposed to high levels of daylight while at the west orientation there is little daylight inside the office space. The current office situation was modelled using sketch up version 7 and exported as a 3D model to ecotect. The 72 meter by 19.4 meter office plan was modelled as a module 9meter by 6 meter, as shown in Figure 4.4 the highlighted red box defines the simulation parameters. Each office module was introduced to the options of introducing 3 different sizes of light pipes to achieve the consistent and adequate amount of daylight underneath. One office floor on the second floor was taken as part of the study as well as the office floor on the twenty-seventh level. Ecotect was used to perform lighting analysis and to acquire information regarding the percentage of daylight factor inside the office space.

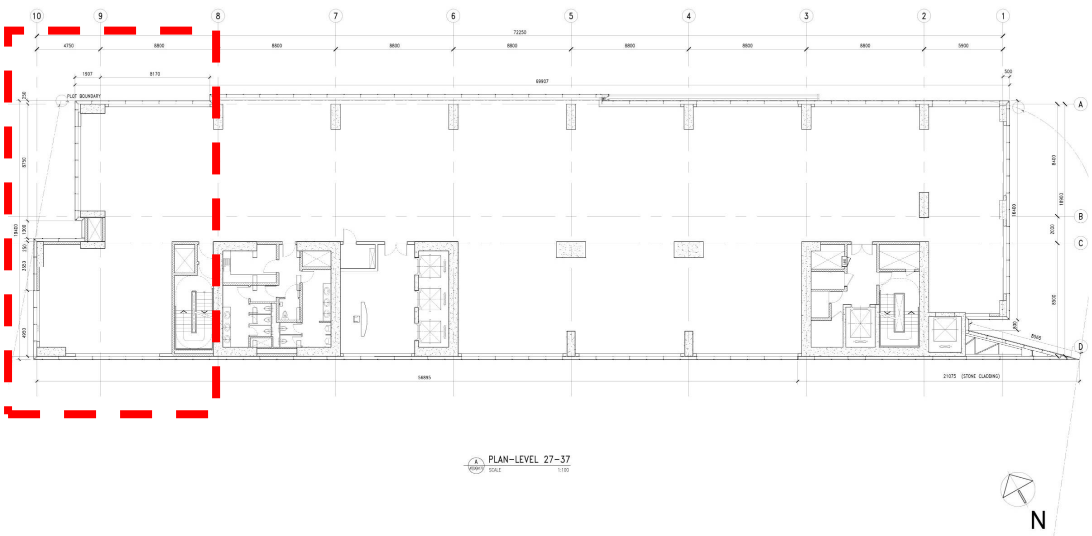


Figure 4.4 Monarch Office plan typical office plan, Personal Archive, 2007

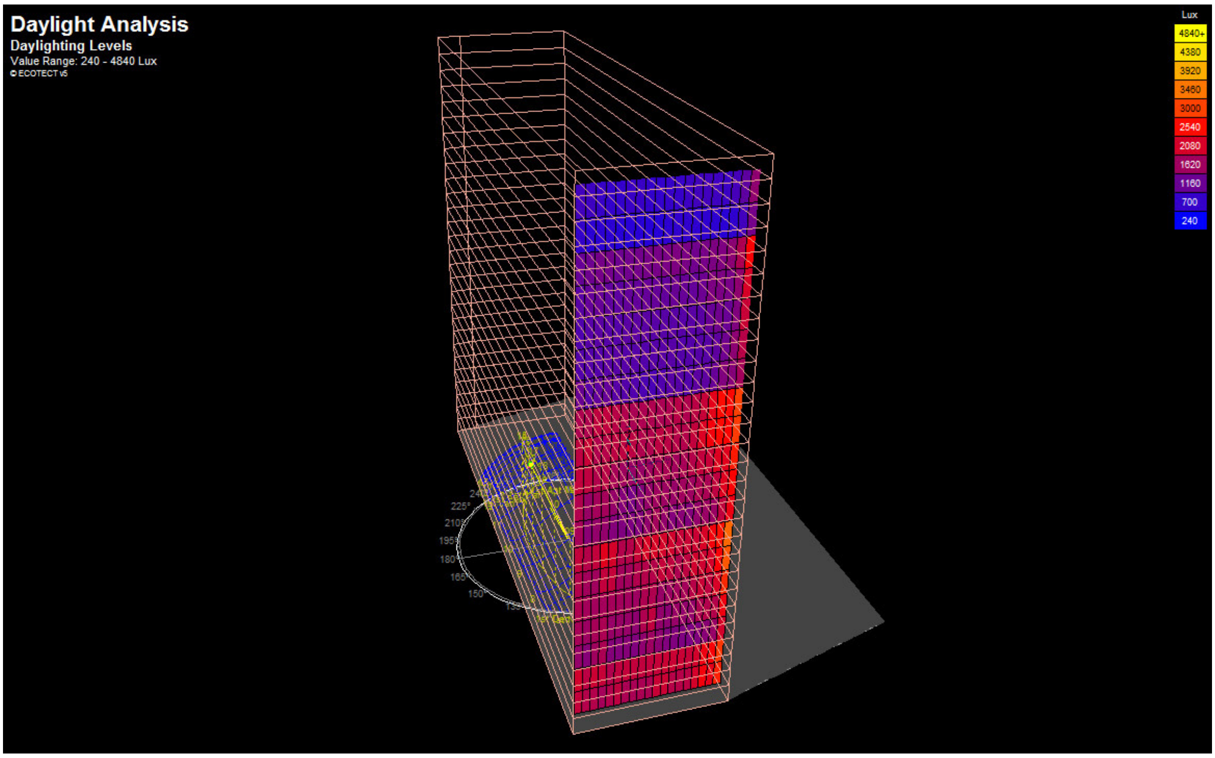


Figure 4.5 Ecotect Model - Daylighting Analysis of East Façade

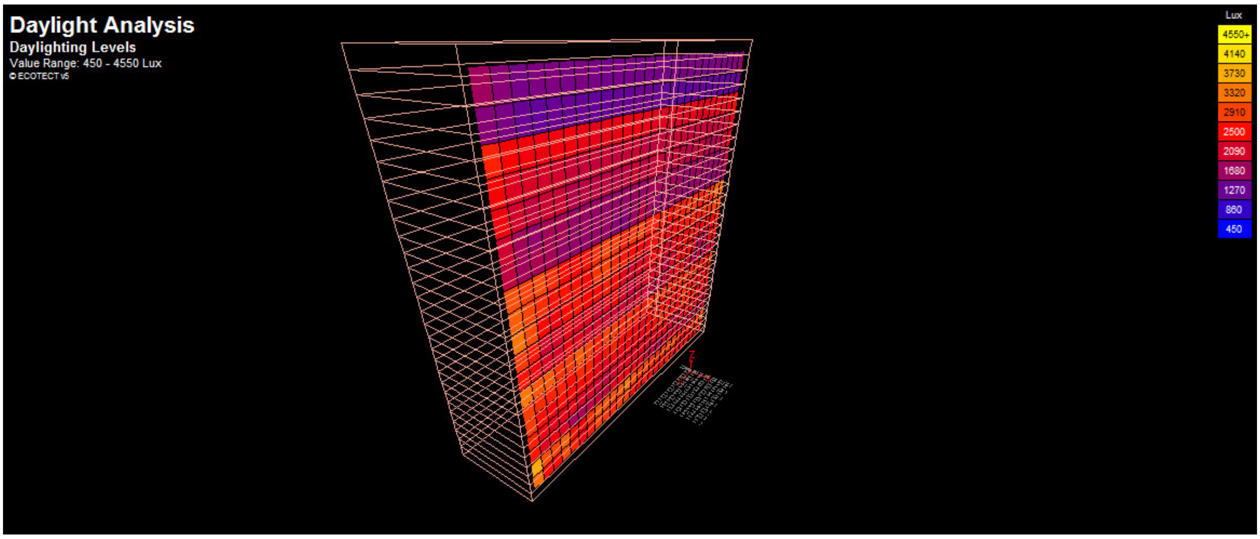


Figure 4.6 Ecotect Model - Daylighting Analysis of North Facade

The daylight measurement was taken at a standard workspace level which in this case was 1.2 meters above ground level. The lux level at the workspaces was measure from the same spot at 3 different distances from each of the four coordinate sides. The first measurement was at 1 meter distance from the East, North, West and South window at the workspace level at the same times.

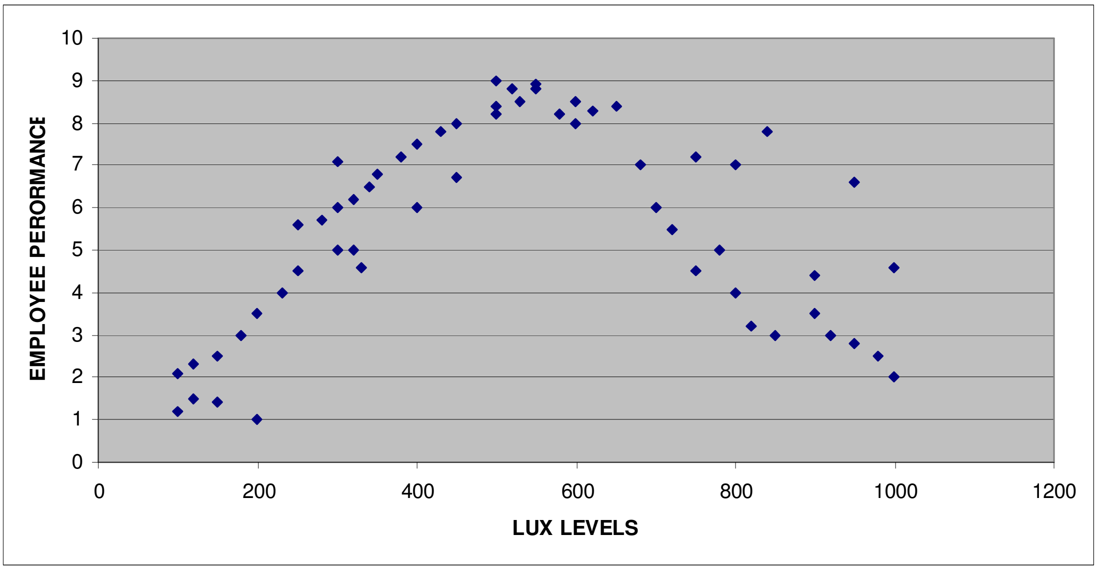
4.3 Measure of productivity – Performance Index

To obtain a comprehensive understanding and to be able to quantify employee performance levels a specific scale was used thus establishing an index. As per the literature available, Watson et al (1981) established the PANAS-X scale for non clinical use to establish an index to help measure positive and negative moods that are directly linked to the performance levels.

The performance level is an average obtained from the results of the surveys and on a PANAS –X scale, according to the results obtained from the survey and observational analysis, presented in figure 21. To give employee performance a numerical measure a rating from 0 to 9 was used. Previous researches linking moods to performance levels stated the average of the results being positive or negative and that was used to establish an understanding. The range from 4 to 6 is considered to be the acceptable while numbers outside this range is considered too high or too low. When the employee performance levels are from 0 to 3; this suggests that the desired levels for this specific research are not obtained. The main of this research is to prove and establish a link between the daylighting levels and employee performance.

The data in this chart was a collaboration of data collected through survey and observation. At certain time during the working day, employees frequently yawned and presented symptoms of fatigue, these employees where sitting on the East and West side of the office space. As recorded through field measurement taken, the lux levels available on the workspace on the East side early in the day was almost 1000 lux. These observations and lux levels established a measuring tool to rate employee performance levels inside an office space.

It was evident during the research that after certain amount of daylighting the employee performance levels was unaffected and almost constant. The higher the amount of daylight levels the employees where exposure to the more irritated the employees felt and the less they spent time focusing on their work. Figure 4.7 explains and proves the proposed observation.



While on the same time on the West side, employees had very little daylight during the early hours of the working day, which measured up to 150 lux levels. The graph represents the fact that employees tend to show lower performance levels under low lighting levels and when exposed to high levels of daylight. The outcome was the definition of a performance index that helps link the amount of daylight through light pipes with the efficiency of office workers. This index is a criteria based to help design various daylighting strategies for an efficient working environment.

4.4 Design Strategy:

The results are complied from the survey and 3D simulation model. The glazing on the windows was low-emissivity insulating blue tinted glass. The blue tinted glass reduced the summer cooling air-conditioning needed for this particular office building. This blue tinted glass also reduces the visible transmittance.

The design of the high-rise office building was oriented to the North- South axis to maximise the use of the available plot. Minimizing the east and west oriented windows exposures will help reduce glare conditions on the computer screens. The maximum glazing was on the North facing orientation which provided diffused lighting that was considered insufficient when measure with a lux meter and when the employees seated on that orientation reported. The figure 4.8 presents data extracted from ecotect v 5.5, provides the total monthly analysis for the amount of solar radiation available in Dubai

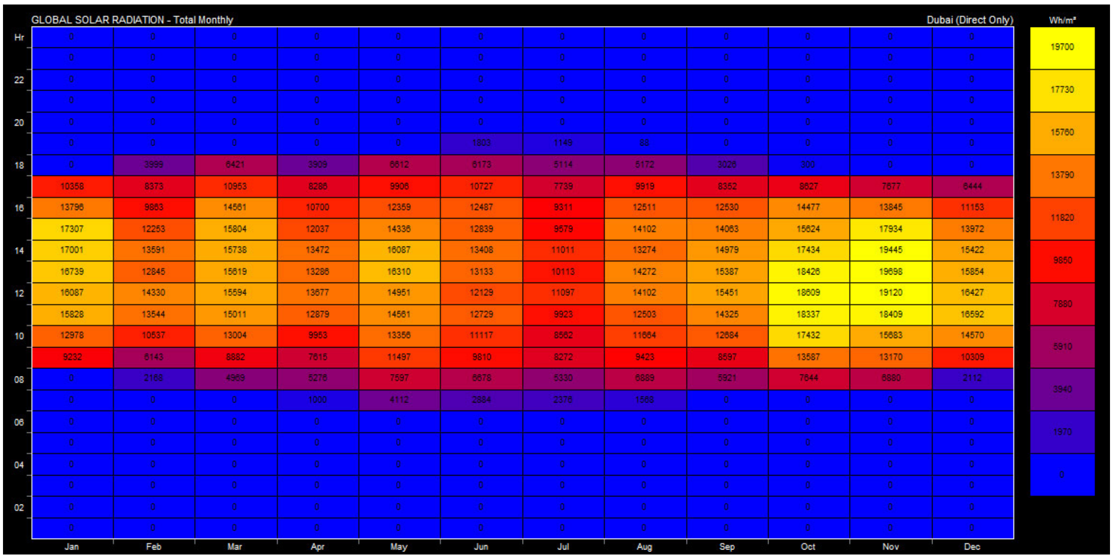


Figure 4.8 Ecotect Solar Radiation Analyses, Ecotect v 5.5

A number of design strategies could be explored during the design process. These strategies include general passive strategies:

1. Increase perimeter that receives the maximum daylight zones— widen the perimeter footprint to maximize the usable daylighting area.
2. Allow daylight penetration high in a space through the integration of light pipes as part of the concept.
3. Reflect daylight within a space to increase room brightness.
4. Slope ceilings to direct more light into a space.

5. Understand that different building orientations will benefit from different daylighting strategies
6. Introduced light pipes at close distances that are centre to centre distance is less than 2 meters, to help achieve consistent efficient daylighting.

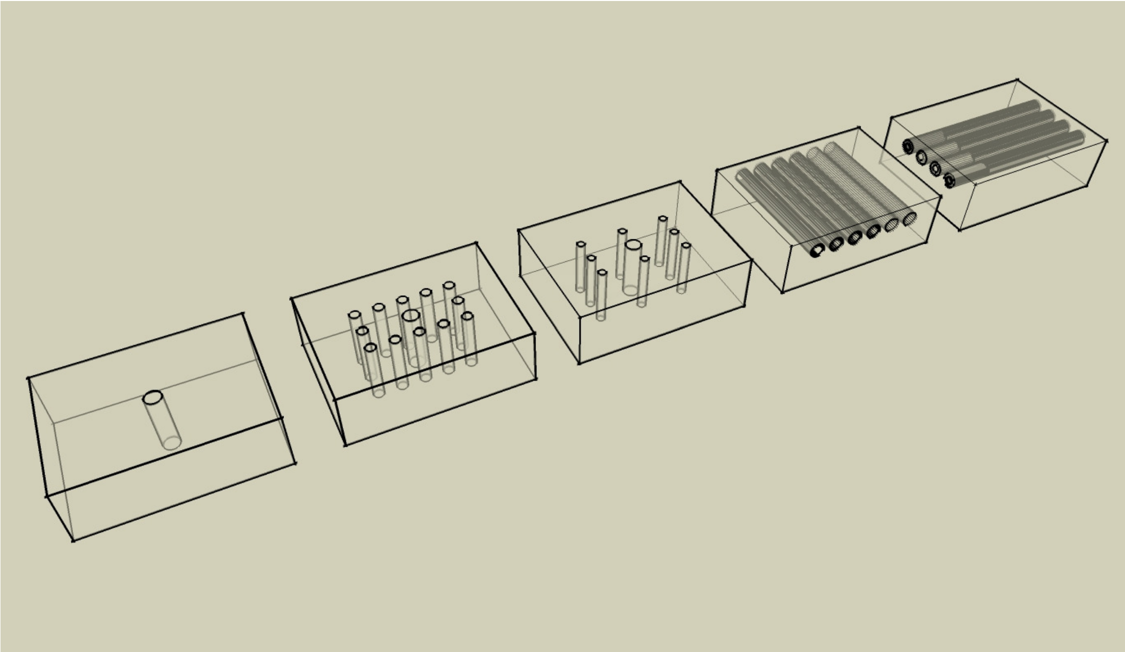


Figure 4.9 3D models for various light pipe location and sizes, Sketch-Up v.7

Offices in the Emirate of Dubai have utilized around 1800 different sizes of light pipes in different building typologies (Monodraught, 2008). Schools, sales centres and warehouses that have vast deep spaces and little façade openings have integrated light pipes into the roofs to bring daylight inside the building. The analysis was done on three various sizes of vertical light pipes and one option of having the whole tower daylight using horizontal light pipes, figure 4.9. The analysis takes part through zoning the office plan into equal modules in to order to facilitate the simulation process and make the study more efficient.

This plays an important role in the design of the spaces inside the office tower. The workspaces will be positioned in such a way as to allow sufficient amount of daylight throughout the office working hours. The employees are seated around openings to achieve efficient amount of work during the day and to help maintain employee well being.

4.5 Lighting Strategy:

The successful integration of light pipes into the deep high rise office spaces will help achieve an even distribution of daylight. The location of the workspace no longer requires being seated beside the window or glazing. Daylight is collected mainly from the roof of the building, and then light is channelled through shiny mirror like shafts that transport the light into the distributor at the lower end. This applies for the upper floors but at the lower floors light pipes are designed horizontally and transfer light in ducts which deliver to the space directly, which is a case of side lighting since the south façade is employed for this purpose.

Employees seated at 7 meters from the façade will have daylighting which will enhance their visibility of colour and improve their overall job performance. The light pipes are designed in such a manner as to avoid having dark unlit areas in between each pipe. The light pipes are designed to be 1 meter in diameter for this specific office building. These light pipes are placed at 5 meter distance from diameter to diameter, while they are 5 meters distance from the East and West glazed facades.

The North orientation is considered to be a critical condition which required smaller light pipes. Light pipes where placed that are half meter in diameter each, with 2 meter distance between each of these smaller pipes, to help bring even distributed daylight, while the distance from the glazed North façade was at 3 meters. Very special attention should be provided to specify a highly reflective light pipe to ensure the amount of daylighting reaching the diffuser is the maximum since as the distance the light travels increase the amount of light reaching the end point decreases.

Horizontal Light pipes are carefully proposed and oriented to introduce light from the façade of the tower and channel light into specified zones in the tower with there are deeper office spaces and direct natural light does not encounter. The office space is occupied throughout the daytime and unused after the sunset. The maximum energy demand and consumption is reached when the artificial lights are turned on at the duration of use. Taking this into careful consideration the location of the horizontal and vertical light pipe is chosen according to the initial survey of the amount of daylighting available and also keeping in mind the employee workspace locations.

4.5.1 Case A: One uniform size of vertical light pipe

A single light pipe is first introduced into the simulation model of the office layout. The light pipe is designed starting from the roof of the office building and going down six office floors, since the maximum a light pipe can travel and still maintain its efficiency is around 30 meters. The single light pipe is 1 meter wide which is currently the largest size of light pipe used for this type of building use, figure 4.10.

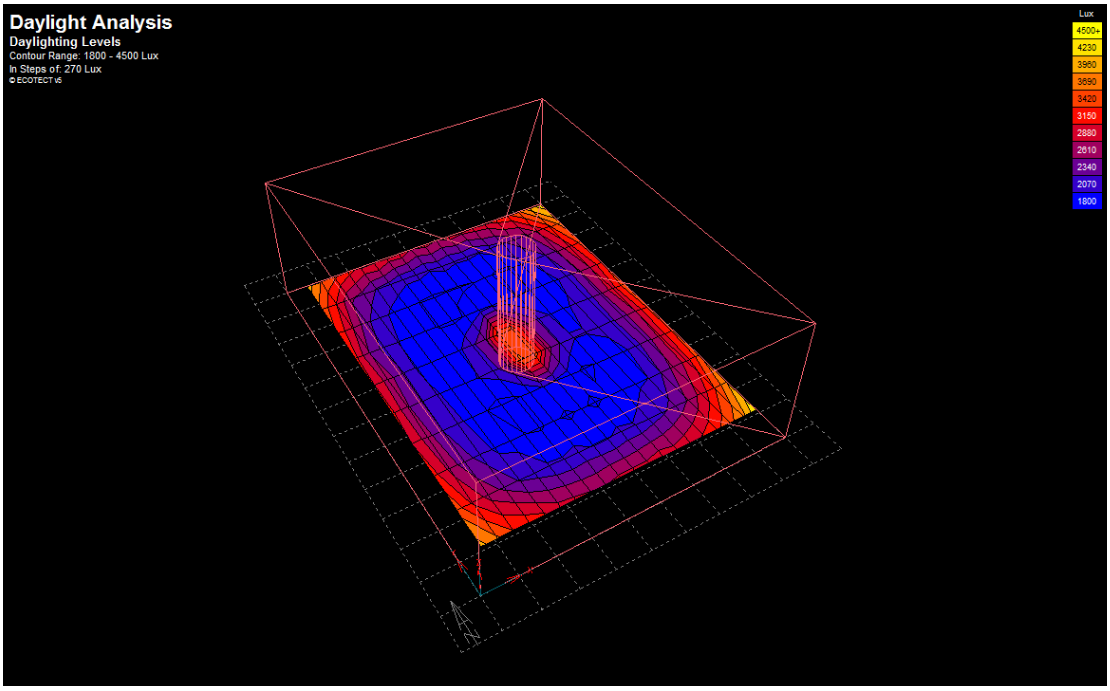


Figure 4.10 Single 1 meter diameter wide light pipe lighting analysis, Ecotect v 5.5

The dimension of the vertical light pipe is essential through the various phases of structural and architectural design since those vertical transporters cut through the structural elements, such as floor slabs and beams. The design of the various sizes of the vertical light pipe and its mirror like qualities is important for its effective function in the space. There is daylight reflected and coming in from the glazing and that contributes to the results obtained from the simulation model and also from the results obtained from the lighting survey measured in the actual office with the lux meter.

The lighting levels obtained from one single vertical light pipe are effective for the employees seated with in a specific distance. The employee levels as obtained from the index in figure 25 show an average of 5, which is good for the immediate occupants within that radius. Therefore this option was eliminated since it does not provide a global criterion to apply light pipe, it does however establish an understanding for the effectiveness of the light pipe within a specific zone of the office space being analyzed.

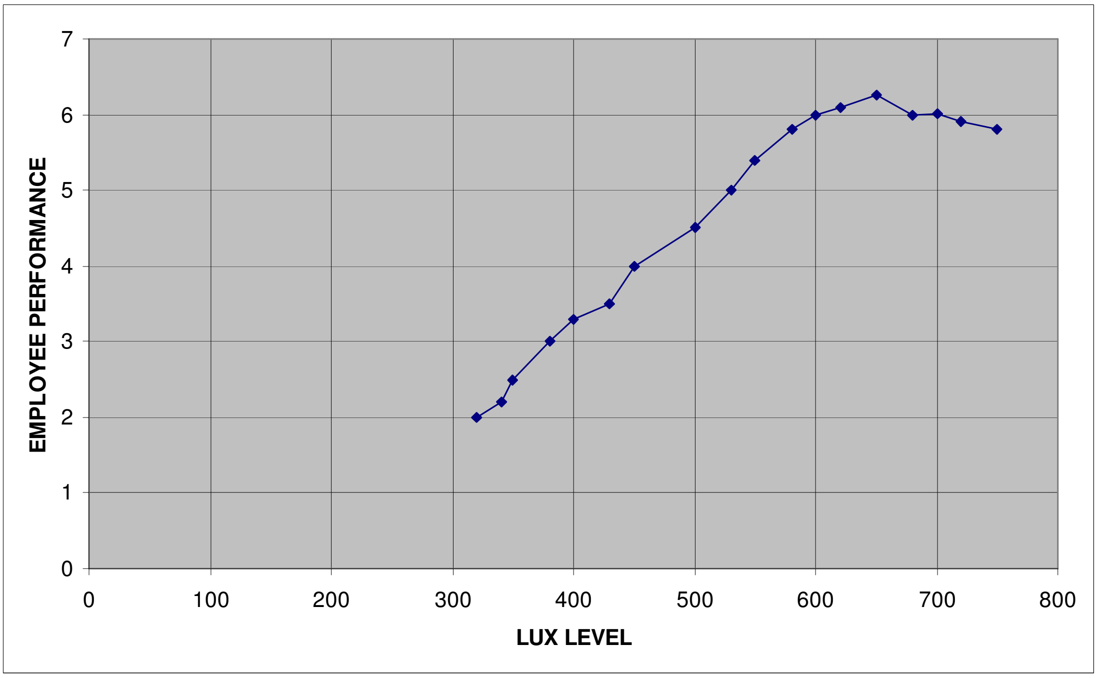


Figure 4.11 Employee Performance and Daylight levels

4.5.2 Case B: one main size of Horizontal light pipes

Horizontal light pipes are introduced to various floors of the office building to transport light from the south façade into deep office space. In this specific option a series of horizontal with a diameter of 50 centimetres are studied. The main advantage of this option is that the whole building will be designed using only one system and one single type of light pipe which is designed from the south façade.

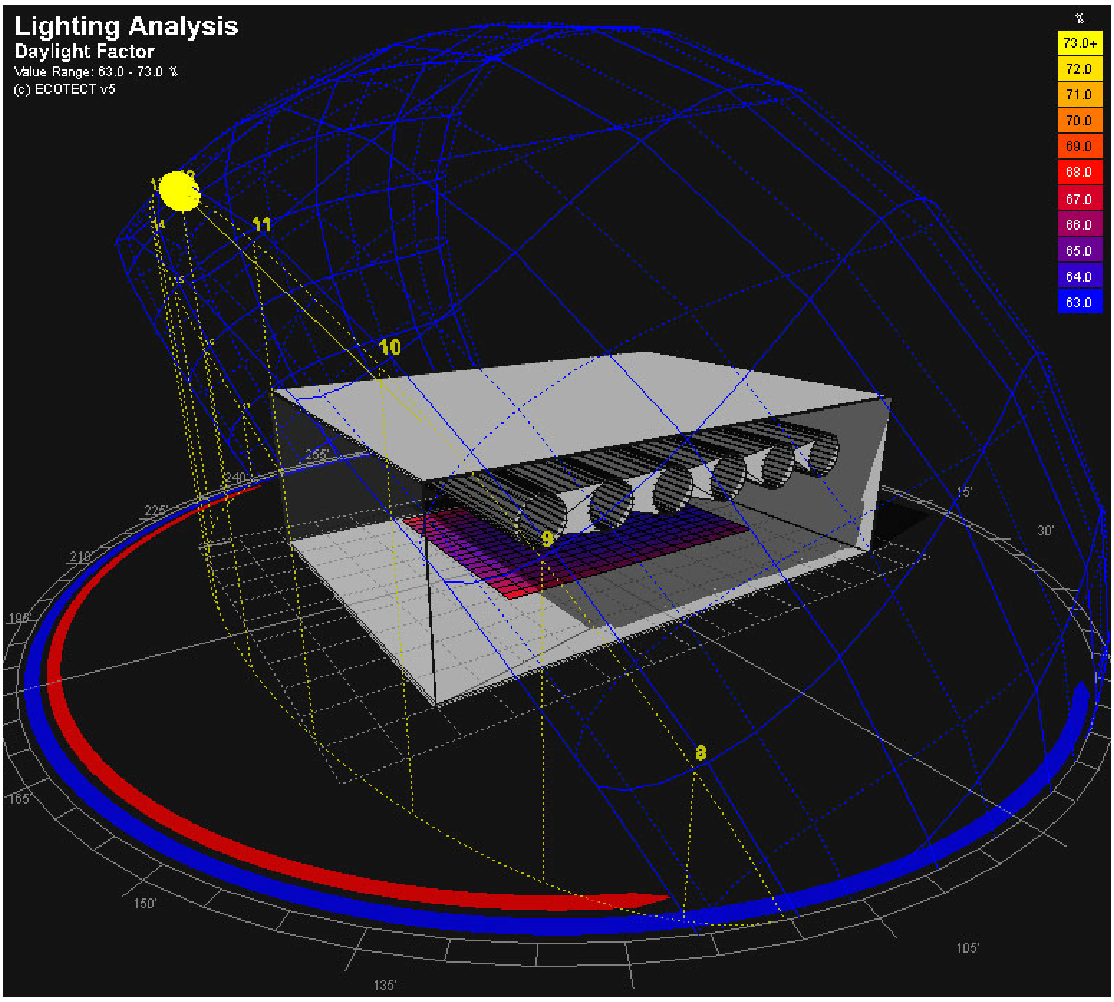


Figure 4.12 Series of Horizontal light pipes analyzed in Ecotect

This option using a simulation model is formed to find out how effective light travels inside horizontal pipes into deep spaces where the vertical pipes can not reach. This method is found especially useful for the lower floors of high rise towers where vertical light pipes can not transport enough light effectively.

Horizontal light pipes are currently under study to provide sufficient data to ensure their efficiency in delivering enough daylight. Horizontal light pipe with a diameter of 1 meter is added to the 3d simulation model to investigate the efficiency, figure 4.12.

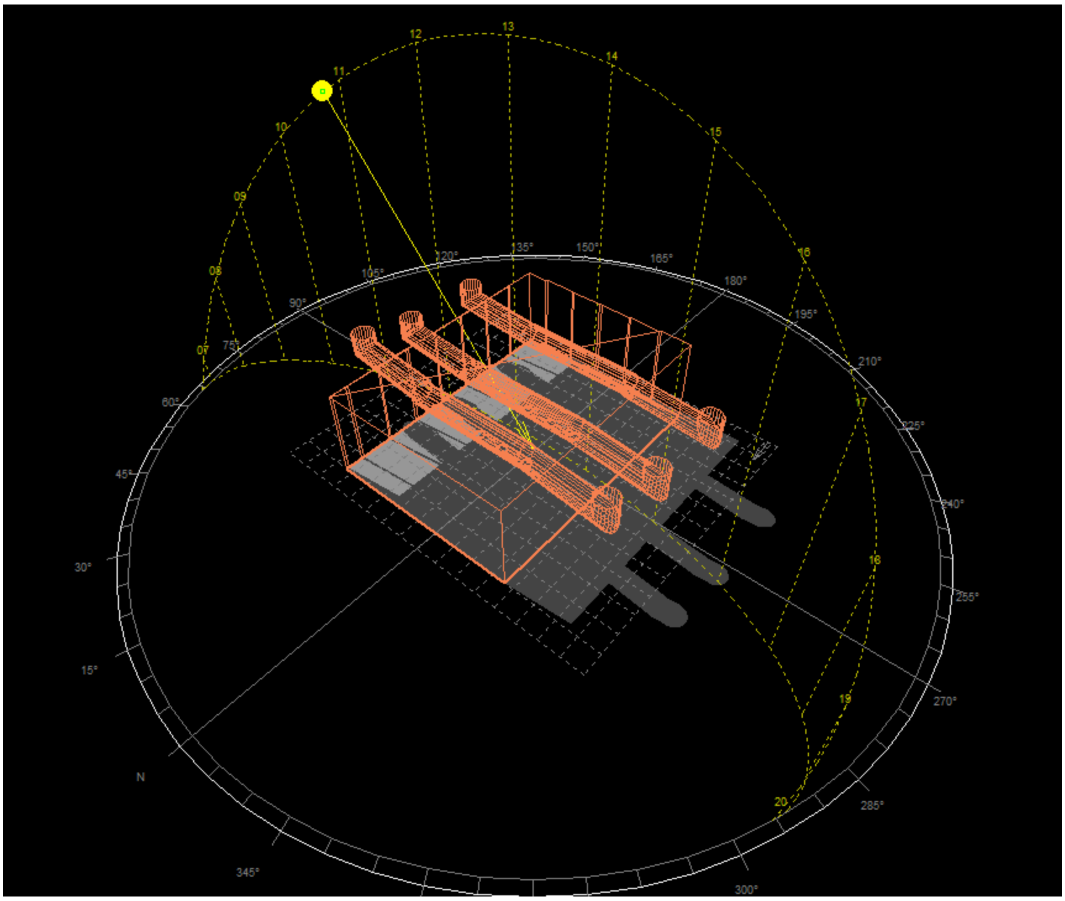


Figure 4.13 One meter diameter wide Horizontal light pipe, Ecotect

The single size of a horizontal light pipe helps maintain a continuous amount of daylighting throughout the space. This typology as helps keep the financial load of purchasing the light pipes at the low range since there is a mass purchase for horizontal light pipes throughout the tower. Another very important advantage of having only horizontal light pipes in high rise towers is the structural stability.

Having vertical light pipes in a building does have an impact on the structure of the building, since theses vertical light pipes go through the slab from one floor to the other hence requiring special study and treatment of the structural elements. Horizontal light pipes do not interfere with the structure since they are penetrating the space from the curtain walls or concrete walls on the sides of each floor hence not playing a major role in the structural design. This would play an important role in the design for the façade of the building. Since one of the reasons why architects avoid introducing light pipes is due to that fact that they affect the whole architectural theme of the project.

This type of horizontal light pipe is effective especially for the lower floors in a high rise office tower since daylighting can not be transported through vertical light pipes from the roof. The employee performance levels as obtained from the index shows that the average of 3 is obtained from the chart when corresponds the lux levels with the employee performance index. This expresses that the performance levels of the workers has not changed significantly even with the availability of natural daylight on their workspaces. The main reason for this option was to be able to integrate light pipes after design and maybe after the building was built, since those horizontal light pipes do not affect the layout of the space and its function. Employees can be seated any place and with any orientation they desire and those pipes would be integrated with the HVAC system of the building and covered with the false ceiling.

Figure 28 presents the results obtained when measuring the employee performance levels with this specific case. The low lighting levels measured in the centre of the office space still present an issue since the employee performance levels drops to almost 1. The horizontal light pipes bring sufficient amount of daylight from the south façade but due to the length of the pipe there is daylight lost in the transporting pipe and the opening closer to the façade are the ones that distribute more daylight into the office space. This is one drawback from designing only horizontal light pipes since the depth of the space proposed could be a challenge.

At the average level of daylight required in an office space, 500 lux levels, the amount of employee performance measured started to remain constant. This could mean several things, but one important observation is that employees require only a certain amount of light after which it causes symptoms such as exhaustion from over exposure and nausea at some.

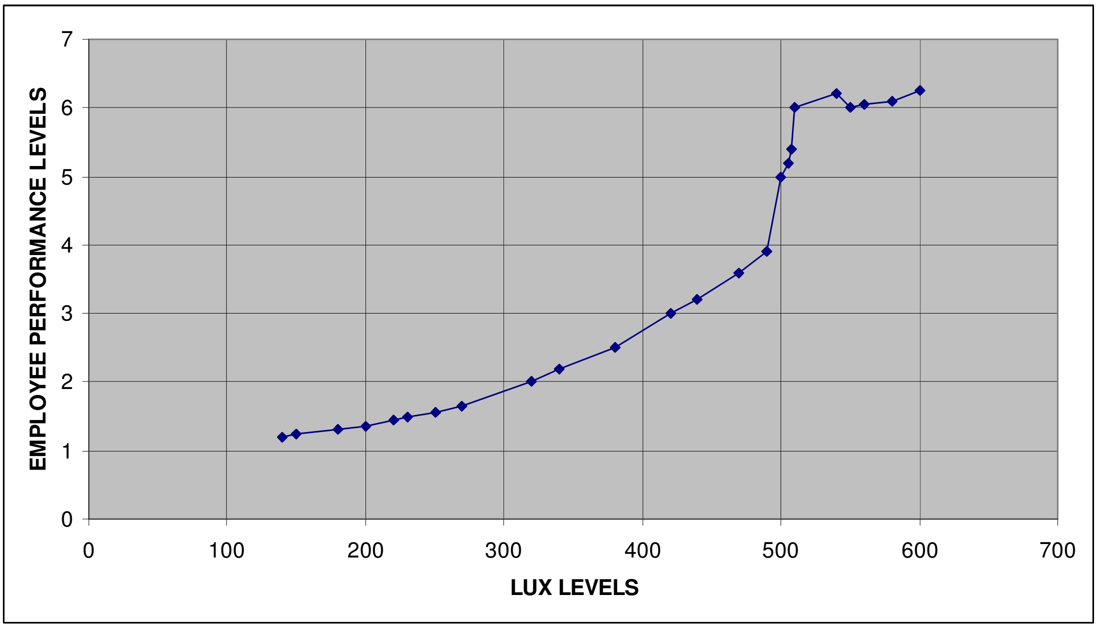


Figure 4.14 Employee performance levels result

As per figure 4.14, the average employee performance for this specific case is almost 3.6. The conclusion from the case was the fact that employee performance levels where affected positively with the availability of daylight and the areas around the light pipe that provided ranges between 450 and 600 lux levels had an average rating of 5.5 as per the employee performance index.

4.5.3 Case C: Three various sizes of Vertical

A combination of three sizes of vertical light pipes was chosen to study the amount and quality of daylight distribution inside the office space. The three sizes are the three standard sizes used by Monodraught which are 50 centimetre, 75 centimetre and 1 meter in diameter light pipes. These are the exact same sizes that where explored by Muneer (2002) during the research undertaken to provide a method for selecting sizes of light pipes to be integrated into office building.

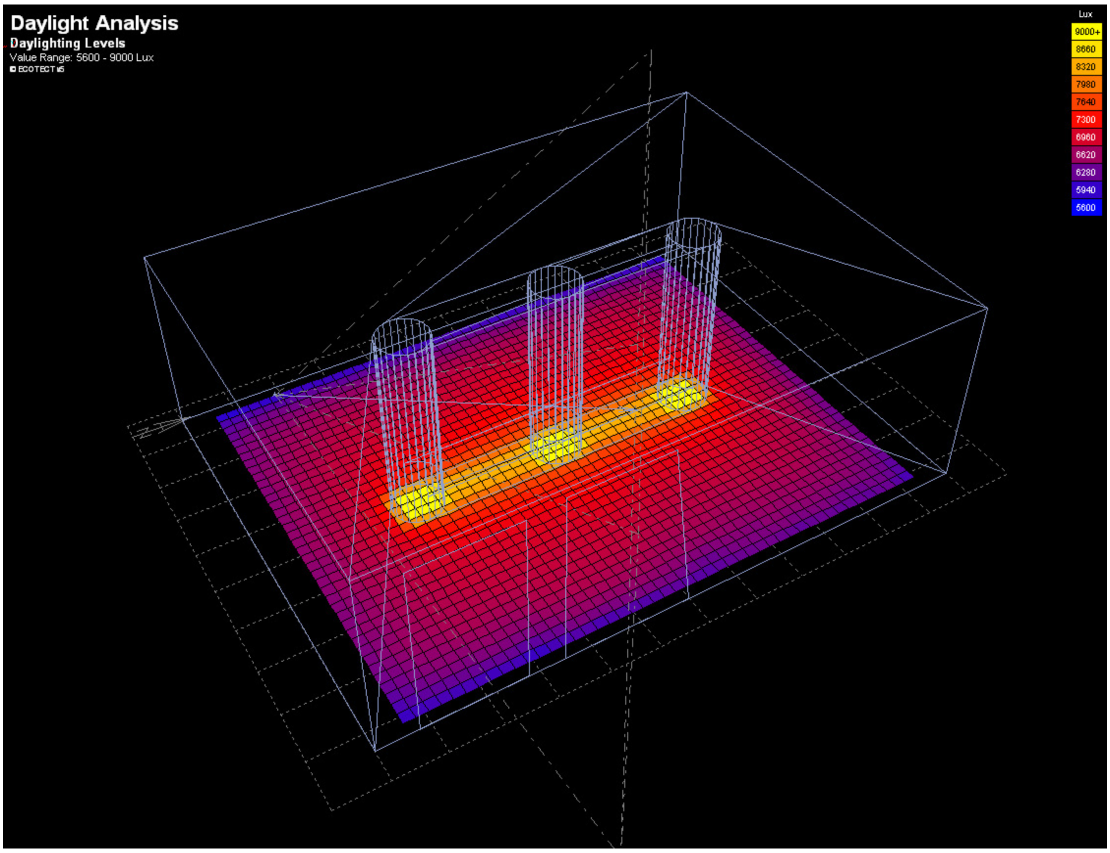


Figure 4.15 Three Sizes of light pipes in Ecotect

This case shows that the amount of lux levels obtained from three vertical light pipes is an average of 600 lux at the radius of almost 1 and half meter distance from the light pipes, while lux levels reach up to 350 lux a radius of 3 meters from the light pipes. This is a good lux level inside the office space since some of this light delivered will be reflected and refracted inside the office space and between the office furniture and finishes.

The lux levels from the lighting analysis obtained using Ecotect is translated to employee performance levels using the index. As per figure 4.16, the average employee performance is almost 5.2, which is considered average amount of performance. One of the important factors that this research is seeking and investigating is making sure that there is a constant level of employee performance, and as per this research so far it has been evident that around daylight levels of 550 to 680 employee performance levels are above average and are constant at that level.

Figure 4.16 Employee performance levels using 3 vertical light pipes

As demonstrated in figure 29, the vertical light pipes are located at the centre of the space being investigated. The next case was to introduce one single size of horizontal light pipe, figure 4.17. Figure 4.18 demonstrates the office seating arrangement to accommodate many offices where the natural daylight is delivered.

4.5.4 Case D: Three various sizes of Vertical and One Horizontal

The sketch up model is exported into Ecotect to perform lighting analysis. As per the results from the lighting analysis grid the light is at average of 300 lux approximately 5 meters from the light pipe, which was one of the main reasons for introducing the horizontal light pipe from the South façade, figure 4.18.

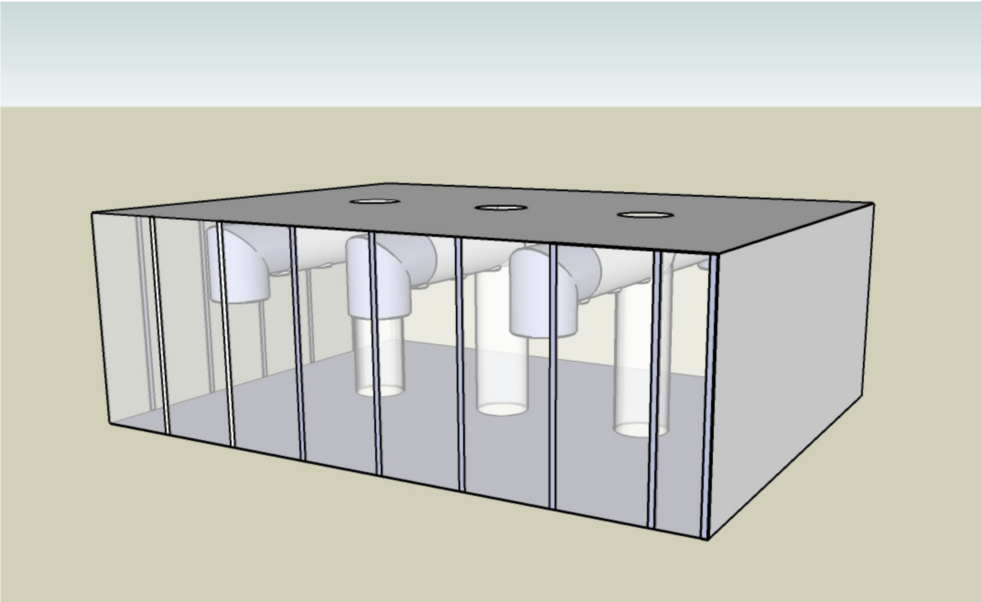


Figure 4.17 Combination of Vertical and Horizontal light pipes

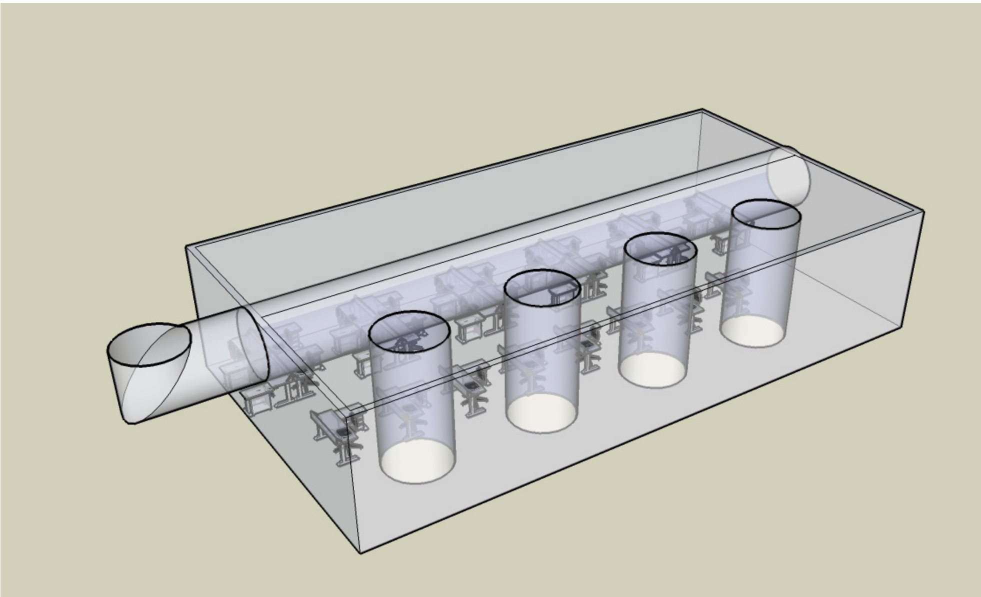


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Figure 4.18 Combination of Four vertical and on horizontal light pipe

According to the daylighting analysis grid obtained from Ecotect, the average amount of daylight reaches up to 700 lux close to the light pipes and extends to a perimeter of almost 3 meters around the vertical light pipe. This is the ultimate results obtained since the average daylight is the required for office activity levels. To measure the employee performance levels; those lux levels where checked on the employee performance index.

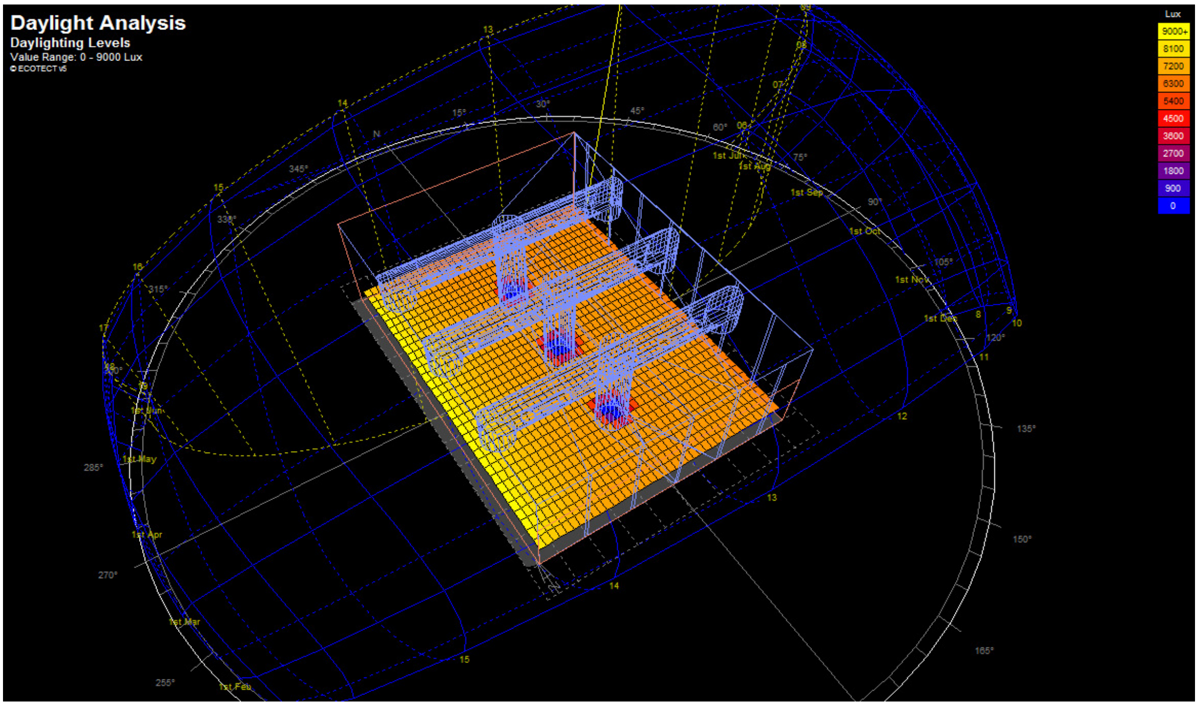

Figure 4.19 Horizontal and 3 various sized Vertical light pipe

Figure 34 expresses the rise in employee performance levels as daylight levels, obtained from the ecotect simulation model, are higher. The employee performance levels rise up to an average of almost 6.5 and then drop as the levels of light increase above 620 lux levels. This proves to be the ultimate solution for this office space as it provides sufficient amount of daylighting into the space and also helps maintain a constant performance level.

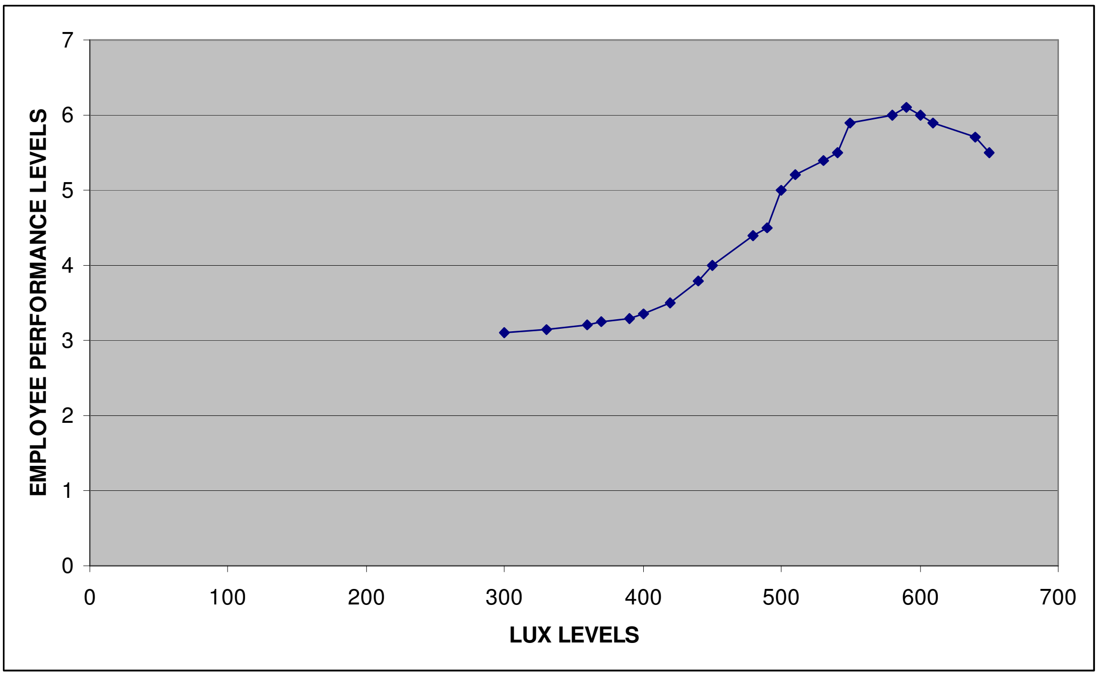

Figure 4.20 Daylighting levels and Employee performance levels

Chapter 5 – Conclusion and Recommendations

5.1 Conclusions

Although this research work was based on a sample of the working population in Dubai, and further work is needed, the research conducted and information obtained expresses promise for alterations and further in-depth analysis. Light pipes have been explored in high rise buildings, and horizontal pipes are introduced since light in the pipes can only travel a certain distance before the light diminishes. The amount of light transported through the light pipes into deep high rise office spaces will help introduce a better work environment where employees have daylight workspaces.

Horizontal light pipes have been studied and integrated into the lower floors of the high rise office tower. The research conducted achieves the required lux levels inside the office space to help improve the employee performance levels. The amount of 500 lux is required for reading purposes inside office spaces; therefore the main challenge was maintaining a level between 300 to 600 lux inside the office space during occupancy hours. Case A concludes with almost an average employee performance level of 5, case B has an average of 3.6; case C has an average of 5.5, while case D has an average of almost 6.

Employees, represented through an interview and survey conducted, expressed their need for daylight. The employee productivity increased as did the decrease in office sickness syndrome and other psychological behaviours such as depression. The measure for productivity is known up to date and many researches conducted tried to measure productivity through years of observation. Light pipes have proven to bring daylight into deep office spaces and this research investigated into introducing light pipes into high rise office towers in Dubai. The main challenges where the distance the light had to travel and the location of the light pipes in relation to the seating spaces of the employees.

5.2 Recommendations

Daylight inside office spaces provided a healthier working environment and gave the employees an opportunity to improve the quality of work. The health of the employees is the main concern at the interior of office spaces. The amount of daylighting inside office spaces should be at the range of 400 to 500 lux according to all the research up to date. It is recommended after this research to integrate 1 meter diameter wide light pipes especially at the North side of the office space to ensure that there is even distribution of daylighting.

As past of this research further passive daylighting strategies need to be explored to be able to improve the working environment and to be capable of creating opportunities to use available resources. A study on the effect of the shadows of surrounding buildings could be very informative as the city is in a constant growth and the site around this specific office tower is under construction. The impact of the upcoming Dubai metro would be an interesting study as to the effects of the views from the office building.

Further research correlating those findings in the long term could provide a strong basis for effectively employing daylighting strategies into high rise buildings. Investigation of the various components that make up a single light pipe can be further explored to enhance the amount of light being transported into the deep spaces. Reflective film inside light pipes helps effectively transport daylight through vertical and horizontal light pipes respectively into the office spaces.

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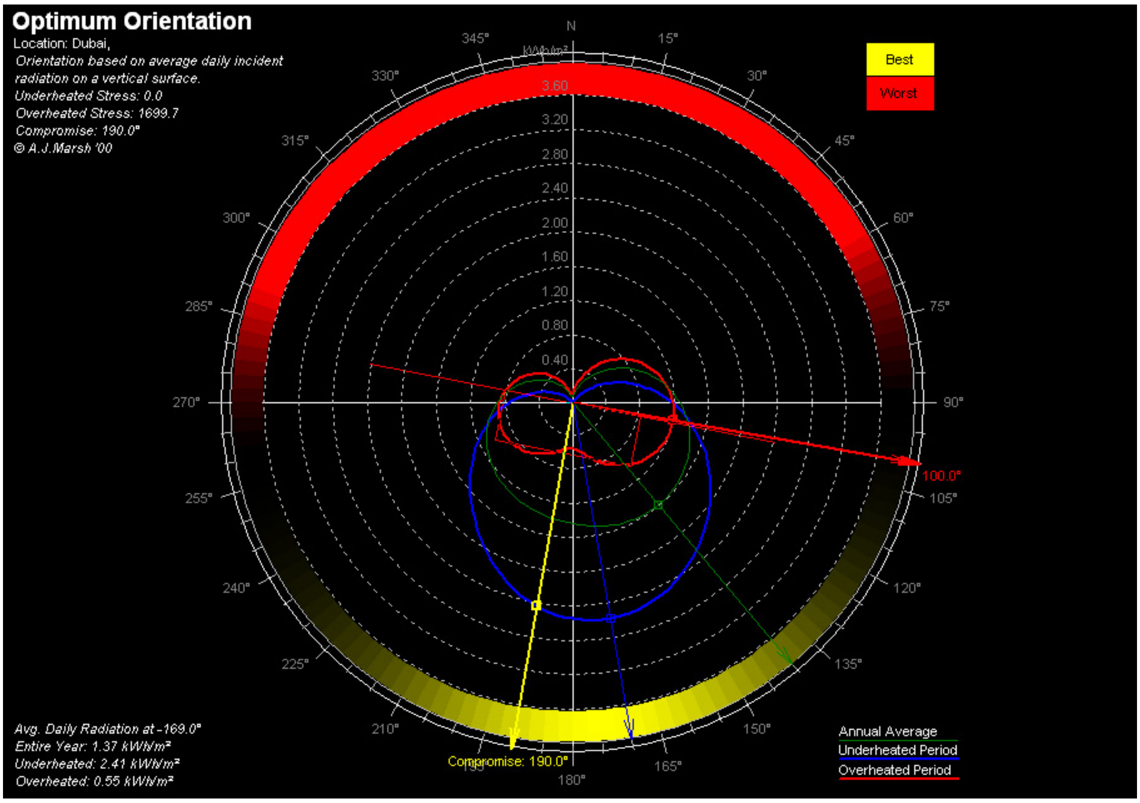
Appendices

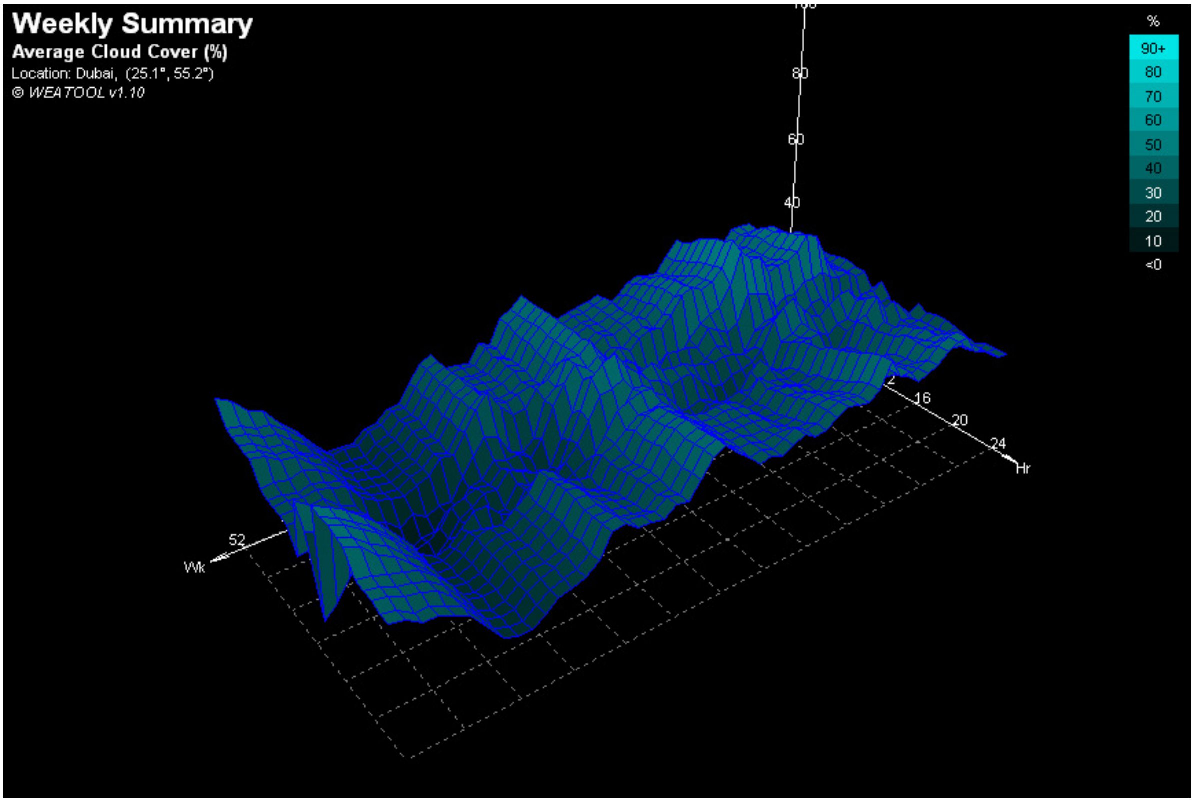
Appendix A

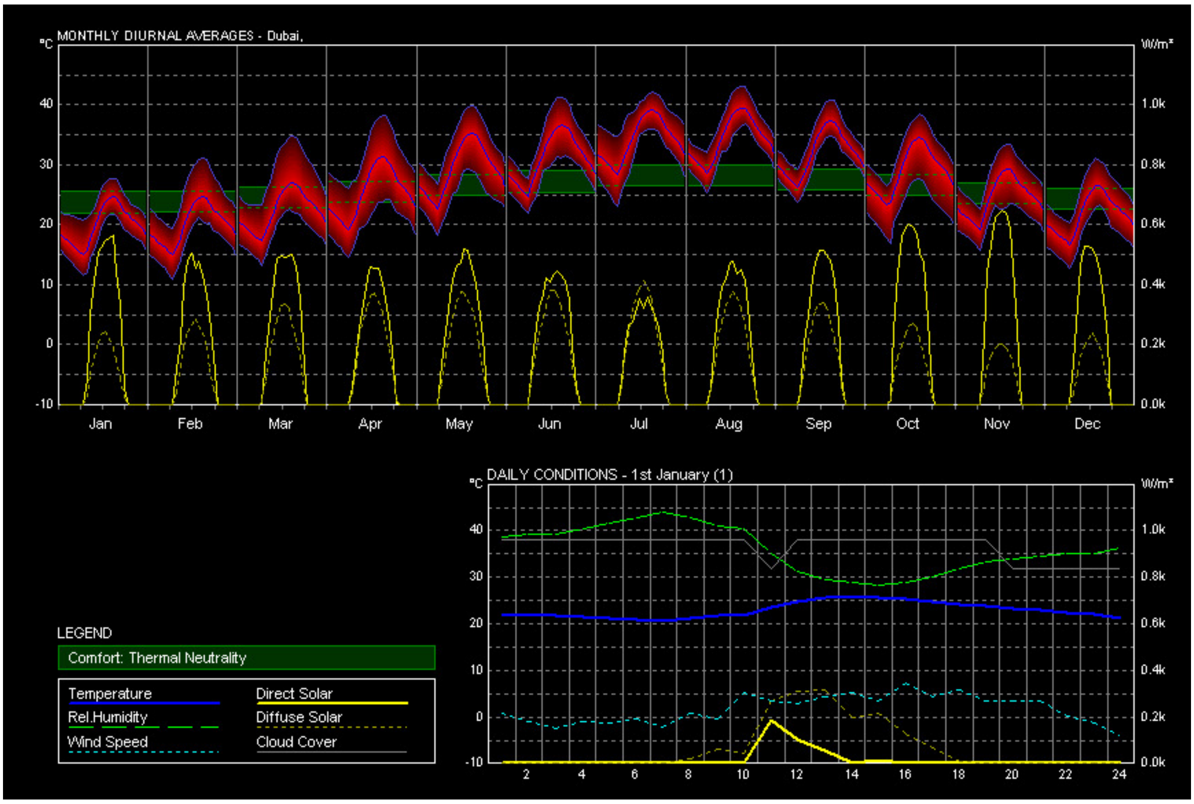
List of definitions as part of BS8206; Recommendations for design of daylighting for buildings.

1. **Daylight**: visible part of global solar radiation [BS EN 12665:2002]
   NOTE Daylight consists of a combination of sunlight and skylight.
2. **Daylight factor** ratio of illuminance at a point on a given plane due to light received from a sky of known or assumed luminance distribution, to illuminance on a horizontal plane due to an unobstructed hemisphere of this sky [BS 6100-7:2008, 59011]
   NOTE 1 for the purposes of the calculation of daylight factor in this standard, it is assumed that the sky has the luminance distribution of the standard overcast sky.
3. **Average daylight factor** ratio of total daylight flux incident on a reference area to total area of reference area, expressed as a percentage of outdoor illuminance on a horizontal plane due to an unobstructed hemisphere of sky of assumed or known luminance distribution [BS 6100-7:2008, 59012]
4. **Sunlight** that part of the light from the sun that reaches the earth's surface as parallel rays after selective attenuation by the atmosphere
5. **Probable sunlight hour's** long-term average of the total number of hours during the year in which direct sunlight reaches the unobstructed ground
   NOTE a period of "probable sunlight hours" is the mean total time of sunlight when cloud is taken into account.
6. **Skylight** that part of the light from the sun that reaches the earth's surface as a result of scattering in the atmosphere
7. **working plane** horizontal, vertical or inclined plane in which a visual task lies [BS 6100-7:2008, 52002]
   NOTE if no information is available, considered to be horizontal and 0.7 m above the floor for offices; horizontal and 0.85 m above the floor for industry and in dwellings.

Appendix B: Dubai Weather Summary, Ecotect

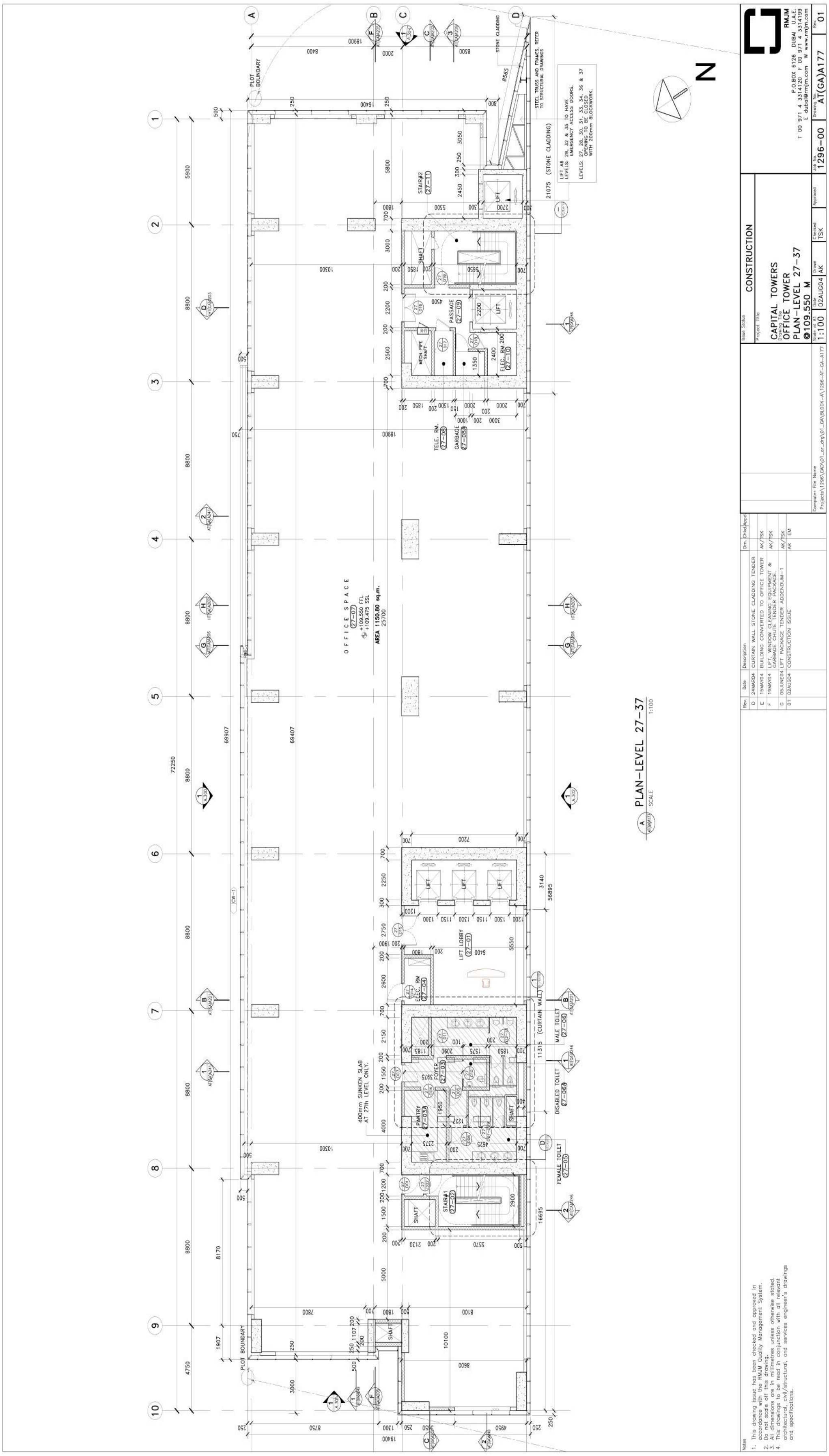




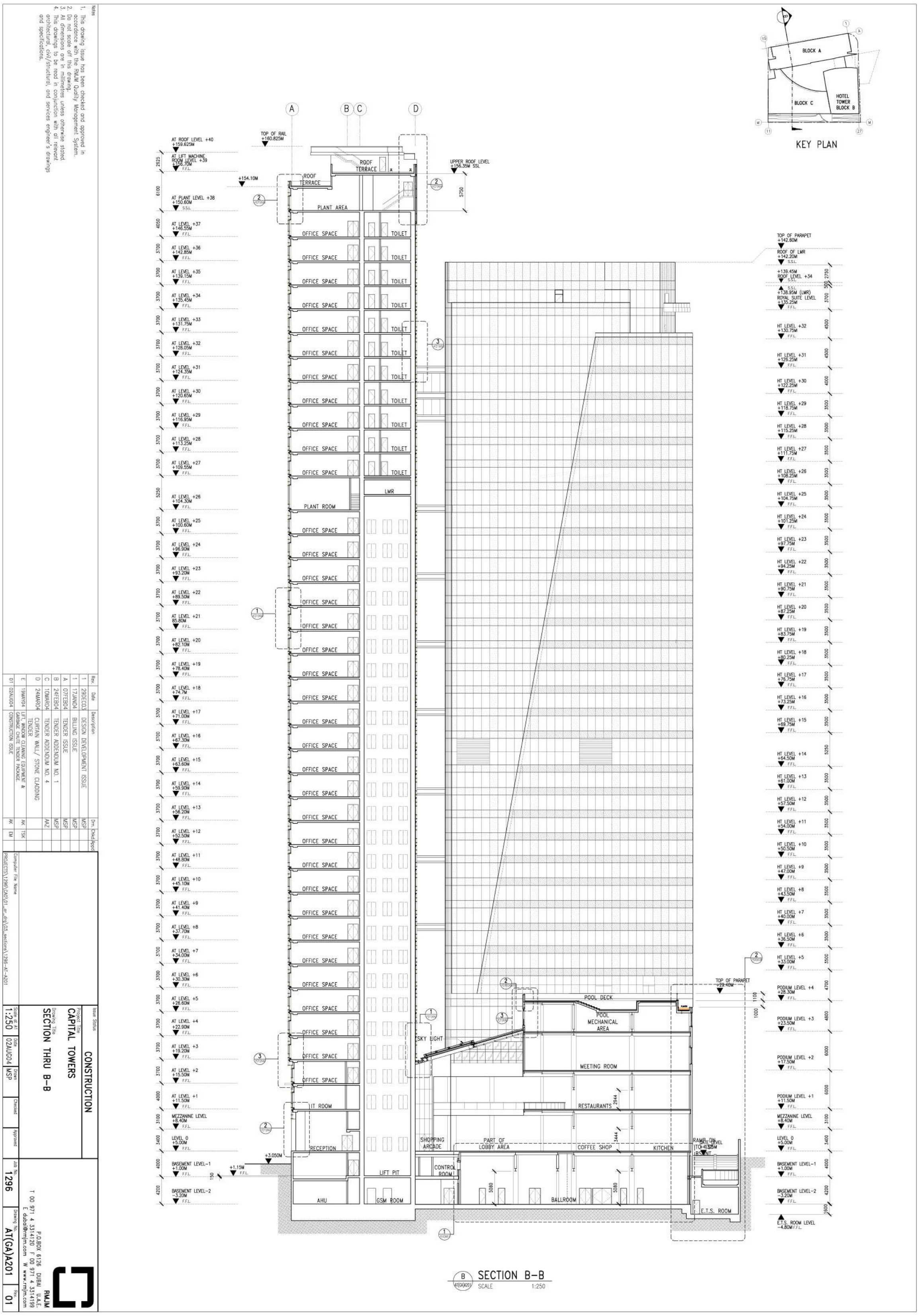


MONTHLY DIURNAL AVERAGES - Dubai,
°C
W/m²
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DAILY CONDITIONS - 1st January (1)
LEGEND
Comfort: Thermal Neutrality
Temperature
Direct Solar
Rel.Humidity
Diffuse Solar
Wind Speed
Cloud Cover

Appendix C: Office Building Floor Plan



Appendix D: Office Building Sectional Elevation



Appendix E: Daylighting Survey

occupation	age	sex	Nationality	Avg.number of hours working in the office a day	Avg.number of hours reading at the office	What is the color of the light you have in your workspace?	How much daylight do you have in your workspace? (lux)	Do you prefer bright workspaces?	Are you sitting beside a window?	How far away from a window is your workspace?(meters)	Do you prefer the view or natural daylight?	Do you use a side table light?(toplight, sidelight..)	Which Orientation is your workspce? (NSWE)	How many hours do you spend looking outside the window?
Architect	30	M	Australian/ Taiwan	12	4	white	200	Yes	No	3	Natural Light	No	North West	1 Hour
Architect	38	M	Australia	9	1	Filtered through tinted high performance glass	250	Yes	Yes	2.5	Yes	Yes	NW	Whenever I can
ARCHITECT	33	F	INDIAN	8	8	WHITE	100	NO	NO	4	BOTH	TOP LIGHT	W	1 HOUR
Architect	28	F	Indian	9	7	white	100	yes	no	2.5	both	top light	WE	1 hr.
Architect	26	F	Iranian	8	2	White	600	No	No	3.5	Yes	No	NE	1
Architect	35	male	british	9	4	white	700	yes	yes	0.5	both	toplight	East facing	1
ersonal Assista	29	F	German	10	8	white	80000%	Yes	Yes	1	Natural daylight	Yes	E	None
Project Manager	43	M	Egypt	9	5	White Florescent	150	it dose not matter, only sufficient light to be provided.	NO	2	yes	Room ceiling Light only	N	Nil
Architect	27	F	Jordanian	9	5	white	400	yes	yes	2	view	no	W	iam facing the window
Architect	28	M	Syrian	9	8	white	300	yes	against window	2.5	yes	no	NE	I should mention 2 but the fact is 9)
esign Manage	33	M	indian	9 hrs	1	Day Light	70000%	yes	yes	0.75	yes	Top light	East	30 Min
Marketing	35	F	Indian	8hrs	7	White	200	Most certainly	sadly no	3	View		W	not sitting near the window does not apply.
Arch Draughtsman	37	M	Indian	8	2	Florescent White	0	Yes	No	7	Yes	No	South West	Nothing
Architect	25	F	Jordaninan	11-Sep	0	Florecent (White)	13000%	yes	yes	0.3	view	no	NW	30 min
Architect	34	F	Filipino	8.5	5	white	150	not really	no	4	natural daylight	no	NE	2
architect	29	m	indian	9	3	white	150	yes	no	3	both	no	N	all the :) (1hr)
Landscape Architect	38	M	British	9	9	White	230	Y	N	4	Natural	N	S	1
Engineer	30	M	UK	9	4	White	450	yes	yes	3	natural daylight	No	West	1
Arch Tech	Old	M	British	9	5	White	800	Yes	Yes	0.5	Natural Daylight	No	East	0
Government	42	Male	New Zealand	6	3	white	120	Yes	No	No windows	Natural Daylight	No	West	None
Chairman	41	male	German	9	0.5	white	200	yes	yes	1	daylight	toplight	S	0 (window is behind the chair)
assocaite architect	33	m	uk	9.5	2	white	500	yes	yes	0	both	occasionally	north west	1/2 hour
Operation Officer	30	M	Iranian	5	2	white	Many	Yes	Yes	1	natural daylight	No	N	1.5 hours
Architect	36	m	British	9	3	3500K	none	average	no	no outside windows	Natural Daylight	No	unknown	none
orthodontist	29	female	turkish	8	1	white	250 lux	yes	no	2.5	natural daylight	no	north	15 minutes
structural Eng	26	M	Jordanian	8	1	white	I'm next to a window	yes	yes	0	both	no	n	0
MEP Engineer	24	Male	Jordanian	8	5	Florecent	have a window behind my desk	yes	yes	0.5	view	no	I don't know proably North	0 its behind me
Global PR	25	F	Iraqi	9.5	4	white	9.5	yes	yes	0.5	view	no	North-West	10 min.
Logistics	28	m	Canadian	9.5	2	white	9.5	yes	yes	2	View	no	NE	10 Mins
Material Engineer	25	M	Jordanian	9.5	8	white	9.5	yes	yes	0.5	view	No	North East	10 min

Appendix F: PANAS-X scale results

	1 = Very slightly	2= A little		3= Moderately		4= Quite a bit		5= Extermely or Not at all																				
PANAS SCALE / ORIENTATION	EAST								NORTH																			
	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11	P 12	P13	P 14	P 15	P 16	P17	P 18	P 19	P 20	P 21	P 22	P 23	P 24	P25	P26	P27	P28
cheerful	4	2	3	4	5	4	4	3	2	2	3	2	3	5	2	3	3	2	2	2	3	3	2	3	2	4	2	3
sad	3	1	2	2	1	2	3	2	1	2	1	1	1	2	2	1	1	1	1	2	3	2	1	1	1	2	2	2
active	4	5	5	5	5	5	4	3	2	5	4	4	4	5	5	5	4	3	4	4	5	5	5	5	5	3	4	4
angry at self	4	1	2	3	3	3	2	2	1	1	1	1	1	2	1	1	1	2	2	2	1	3	2	2	2	1	1	1
disgusted	2	1	1	1	1	1	2	1	1	1	2	1	1	1	1	2	1	1	1	1	2	1	1	3	1	1	2	1
calm	3	4	3	4	5	5	4	4	5	4	3	4	5	4	4	4	3	4	2	5	4	4	4	4	3	1	4	4
guilty	1	1	2	2	4	1	1	1	2	1	1	1	2	1	1	1	1	1	1	2	2	3	1	2	1	1	2	1
enthusiastic	4	3	3	2	2	1	2	4	5	5	4	3	5	5	4	5	4	4	3	2	2	3	4	4	3	5	3	3
attentive	4	2	2	3	4	4	5	3	4	4	5	2	3	3	4	4	4	4	4	3	4	4	5	4	4	4	4	4
afraid	1	4	2	1	2	1	1	2	3	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1
joyful	4	4	5	5	4	4	4	4	5	5	5	5	5	5	3	4	3	3	3	4	4	4	4	4	3	3	4	3
downhearted	1	1	1	1	2	1	2	3	2	2	2	1	1	1	2	3	2	2	2	2	2	1	1	1	2	2	2	1
bashful	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
tired	2	4	3	3	1	1	2	2	3	2	4	3	2	2	2	2	3	2	2	2	2	2	2	3	3	4	3	3
nervous	2	3	2	1	3	2	1	1	1	2	3	1	2	4	1	2	1	2	1	1	1	2	2	2	2	2	1	1
sheepish	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
sluggish	1	2	2	4	3	1	1	2	5	4	3	3	3	3	2	3	3	3	4	3	3	3	3	2	2	1	3	3
amazed	2	4	3	4	5	4	4	3	3	2	2	2	3	2	3	3	3	4	3	2	3	5	3	2	2	2	4	4
lonely	1	1	1	1	2	1	1	1	1	2	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1
distressed	2	1	2	1	1	2	1	1	1	1	1	2	4	1	3	1	1	1	1	1	3	1	1	1	2	1	1	1
daring	2	3	3	2	3	5	4	5	4	4	3	4	4	4	5	3	2	5	5	5	5	4	3	4	4	4	3	5
shaky	1	1	1	3	1	3	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
sleepy	1	3	3	4	3	4	1	1	3	4	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
blameworthy	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
surprised	1	2	1	3	1	3	3	1	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
happy	3	4	3	4	5	4	3	4	5	4	4	3	4	4	4	5	5	3	4	4	4	5	3	4	4	4	5	5
excited	3	4	4	5	5	4	3	5	4	4	3	4	4	5	5	3	4	4	4	5	5	4	4	5	5	3	4	4
determined	3	5	4	4	4	3	5	5	5	5	5	4	4	3	5	5	5	5	4	4	5	4	4	4	4	4	5	4
strong	3	4	3	5	5	5	5	4	4	3	4	5	4	4	3	4	5	5	5	5	4	4	5	5	5	4	4	5
timid	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
hostile	1	1	1	1	2	1	1	2	1	1	1	2	1	1	2	1	1	1	2	1	1	2	1	1	1	2	1	1
frightened	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
scornful	1	1	3	1	1	2	1	1	1	3	1	1	2	1	1	1	3	1	1	2	1	1	1	3	1	1	2	1
alone	1	2	3	2	2	1	1	3	3	1	5	4	1	2	2	3	1	1	4	1	1	2	2	2	1	3	2	1
proud	3	4	5	5	5	5	5	5	5	4	4	3	4	4	4	3	5	5	4	4	3	4	4	4	3	5	5	4
astonished	1	1	1	1	2	2	2	1	2	2	1	2	2	1	2	2	1	3	2	2	2	2	2	3	2	1	2	1
relaxed	3	5	4	4	3	4	4	5	4	3	5	5	5	4	3	4	4	4	5	4	3	4	5	4	3	3	5	5
alert	3	1	3	1	1	5	5	5	4	4	3	5	5	5	4	4	3	3	4	5	4	4	3	3	4	5	4	4
jittery	1	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2	1
interested	3	4	5	5	3	4	4	4	4	4	4	4	4	3	4	5	5	5	5	5	5	4	5	5	5	5	5	4
irritable	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1
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at ease	1	2	3	4	2	5	5	5	5	5	2	3	4	2	4	4	4	4	1	3	2	2	4	4	4	4	5	5
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												WEST								
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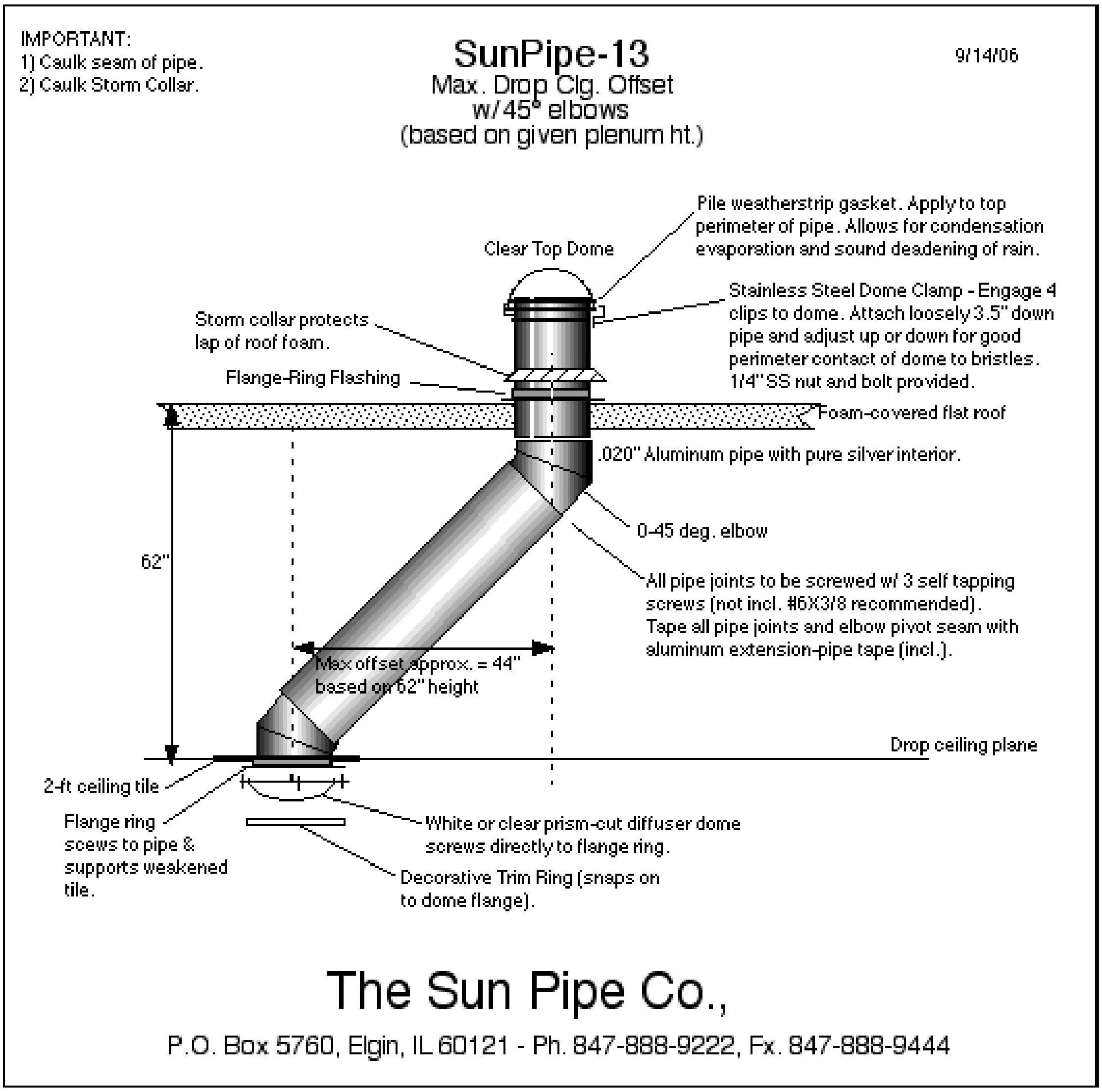
Appendix G: Monodraught technical data



Appendix H: Light pipe Specs

Diameter	Full Summer Sun (105klux)		Overcast Summer (45klux)		Overcast Winter (20klux)		Area Lit (to a normal daylight level)
	Lux Value	Lumen output of systems	Lux Value	Lumen output of systems	Lux Value	Lumen output of systems	
230mm (9")	360	2160	170	1045	65	370	7.5 sq.m (approx 80sq.ft)
300mm (12")	760	4460	330	1940	130	760	14 sq.m (approx 150sq.ft)
450mm (18")	1820	10770	750	4410	300	1768	22 sq.m (approx 230sq.ft)
530mm (21")	2530	14995	1050	6265	430	2550	40 sq.m (approx 430sq.ft)
750mm (30")	4350	25568	1975	11620	900	5300	50 sq.m (approx 530sq.

							ft)
Other Sun Pipe sizes available with hemispherical top domes							
900mm (35")	7700	45300	3850	24650	1425	8390	60 sq.m (approx 650sq. ft)
1000mm (40")	13630	80180	7505	43380	2250	13050	70 sq.m (approx 750sq. ft)

Note: A 100w light bulb generates approximately 1000 lumens or 170lux.

Appendix I: Light pipe sizes and efficiency

105000 Lux horizontal external illuminance - Mid Summer - Solar angle 60.4 deg							
Length, m	**Diameter**	**230mm**	**300mm**	**450mm**	**530mm**	**750mm**	**1000mm**
0.6	Sun Pipe	472	808	1833	2548	5122	9126
1	Sun Pipe	462	796	1814	2526	5090	9084
2	Sun Pipe	440	766	1768	2472	5013	8981
3	Sun Pipe	419	737	1724	2419	4937	8878
4	Sun Pipe	398	710	1680	2367	4862	8777
5	Sun Pipe	379	683	1638	2316	4788	8677
6	Sun Pipe	360	657	1597	2267	4715	8578
7	Sun Pipe	343	633	1557	2218	4644	8480
8	Sun Pipe	326	609	1517	2171	4573	8383

20000 Lux horizontal external illuminance - Mid Winter - Solar angle 13.8 deg							
Length, m	**Diameter**	**230mm**	**300mm**	**450mm**	**530mm**	**750mm**	**1000mm**
0.6	Sun Pipe	75	134	318	448	922	1666
1	Sun Pipe	65	120	295	421	882	1612
2	Sun Pipe	45	91	246	360	791	1485
3	Sun Pipe	32	69	205	309	709	1368
4	Sun Pipe	22	53	171	264	635	1260
5	Sun Pipe	15	40	142	226	569	1160
6	Sun Pipe	11	30	118	194	510	1069
7	Sun Pipe	8	23	99	166	457	984
8	Sun Pipe	5	18	82	142	409	906

(http://www.monodraught.com/technical/silver.php)