The Impact of Daylighting on Occupants of Large Span Roof and Façade in the Tropics: A Case Study of Main Terminal Building, Kuala Lumpur International Airport (KLIA)

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Abstract

The application of natural light, daylighting into large span roof design airport terminal in enclosed public design spaces such as terminal building, has becoming a desirable element and a significant trend in new generation airports. With great aspects of architectural design elements (such as the 'hyper-parabolic'-HP roof form, deep volumetric expression, sophisticated construction, high performance glazing and etc.) represent a high point in architecture and engineering as one of the significant structure in airport design. This paper reviews the impact of daylight in selected enclosed daylit public space in Main Terminal Building, Kuala Lumpur International Airport to measure the assessment of daylighting performance through lighting simulation and field measurement followed by a survey on lighting aspects of these selected areas. The study also include the analysis of skylights above within the HP roof structure and glazed parameter walls facade of Main Terminal Building, KLIA and the controls of the artificial lights and integrated system for efficient use of daylighting. These exercises is also aim to look into the correlation between daylight distribution with design aspects of the long span roof design from both the technical and the users' point of view especially on satisfaction, lighting qualities, and discomfort glare.

Keywords: *large span roof design, daylighting distribution, illuminance level, visual comfort, discomfort glare, glazed perimeter walls façade*

1 Introduction

1.1 Long span roof design and daylighting

There is a rising trend in long span roof design and integration of daylight in airport terminal buildings. However, there are lack of studies in identifying whether or not such strategies have a positive impact in terms of energy use and occupant comfort. In the tropics, the introduction of daylight may lead to increased energy cooling load due to heat gain and the incidence of discomfort glare.

A long span roof can help to facilitate the flow of circulation, provide flexibility and generate the scale and excitement towards the volume of space. However, long span roofs also cause other; nonstructural issues the creation of such an expansion interior volume, deciding where and when to install mechanical, lighting and communication systems and how to economically condition the space (Solomon, NB, Jan 2001).

As a result of the various constraints imposed on airport design, the most interesting architectural feature often turns out to be the roof. There are two main reasons for this: the roof gives definition and character to the building for passengers arriving both on the surface and by air, and it will normally remain unchanged when internal spaces are redesigned (Collins, H., 2003).

In developed countries, all recent long span roof design airport terminal incorporated skylight openings for daylight such as Denver International Airport, Madrid International Airport, and Stansted International Airport. This trend has moved to South East Asian countries such as Bangkok International Airport, Kuala Lumpur International Airport and Terminal 3, Singapore International Airport. Therefore, it is beneficial to see the impact of daylighting on occupants in these new airports in the tropical climate.

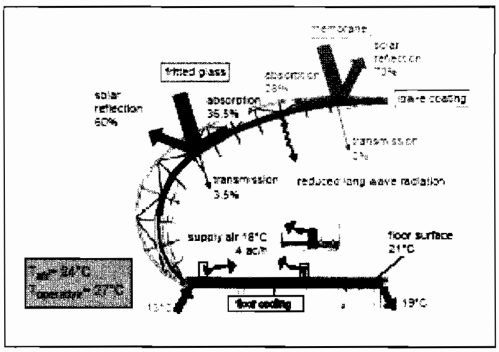

Figure 1: Showing the section of the climate concept of the roof of the New Bangkok International Airport, (Source from Kessling, W., Holst, S., and Schuler, M., 2004)

In New Bangkok International Airport (figure 1), Thailand, the membrane parts of the long span roof design are constructed using a transluscent multi-layer membrane assembly that allows a part of the sunlight to pass as diffuse light into the interior. This ensures sufficient daylighting levels for the building interior Wolfgang, K., Stefan, H., Matthias, S., 2004). Hence, the sophisticated façade and roof design of the airport continue creating a comfortable environment to the occupants as it allows optimum level of brightness and reduce heat gain into the interior spaces.

A parametric study was carried out on the complex roof shading devices which comprise of 3,600 fins under a double glazed roof of Terminal 3, Changi International Airport, Singapore. This is to identify the shading performance and solar penetration based on the overall angle of the orientation of the fins (Mardaljevic, J., 2003). The impact of daylighting was carefully designed through these fins to ensure the effectiveness of diffuse light and disseminate heat gain into the terminal areas.

In local Malaysian context, new airports such Langkawi International Airport, Kota Kinabalu Airport and the new proposed LCCT incorporated the skylight into its roof design as an important element for daylighting to the building interior.

The need to also integrate comprehensive system which supports the design goals of providing an efficient, cost effective and fantastic flow on line with new technologies and innovative materials in building envelope and type of glazing.

There is lack of studies of the impact of daylighting in the tropical climate. Therefore, this paper aims to bridge the gap on this subject matter.

1.2 Benefits of Daylighting

Efficient daylighting design in airport terminal building is not only to provide illuminance levels sufficient for good visual performance but also to maintain a comfortable and pleasing atmosphere that is appropriate to its occupants.

Different lighting conditions can change the mood of occupants in building. Peripheral luminance location such as windows are strongly favoured in most public and working places for the delivery of daylight as they provide view as well as granting a pleasant atmosphere to the spaces; as long as they do not cause any visual discomfort (glare) or visual disability (impairment) (Boyce, P., Hunter, C. and Howlett, O., 2003) .

Excessive brightness contrast within the field of view, is an aspect of lighting that can cause discomforts to occupants. The human eyes can function quite well over a wide range of luminous environments, but do not function well if extreme level of brightness are present at the same field of view (Gregg D. Ander, 2007).

Increasing the area of the skylight increases the amount of direct beam sunlight that would need to be controlled for glare and would necessary increase loads on the heating and cooling systems (Weiner,J. and Milne,M., 2003). One of the major issues in visual comfort is glare and how can it be controlled to avoid discomfort glare to the occupants or users especially in the field of view.

In this study, an area of floor space is considered to be daylit when it receives 300 lux or more for over 85% of the working year. This is based on the recommended illuminance levels for airport and transportation hubs recommended by the IESNA Handbook of Lighting Standards 2000 (table 1).

Table 1: The IESNA lighting Handbook: Source, Mark S.Rea, 9th Edition, New York, NY: Illuminating Engineering Society of North America, 2000. Chapter 10, pg 13 and Chapter 17, pg 16

Transportation Terminals	Illuminance Horizontal (lux)	Illuminance Vertical (lux)
Waiting Room and lounge	50lx	30lx
Ticket counters	500lx	300lx
Baggage Checking	300lx	50lx
Rest Rooms	50lx	500lx
Concourse	30lx	30lx
Boarding Area	50lx	50lx

1.3 Case Study 1: Main Terminal Building, KLIA

The aim of studying KLIA is 1) to assess the skylight design, daylight and heat gain; 2) to make a preliminary study of occupants; 3) to evaluate whether daylight can contribute to energy savings.

The KLIA was built based on a concept of 'symbiosis' that integrates an atmosphere linked to an expression of Malaysian natural heritage and identity with a man-made tropical rainforest surrounding the airport, and in the central garden space of the building. The KLIA incorporates various passive energy saving features such as double-glazing for windows and glass walls enabling maximize use of daylight as well as reducing penetration of heat load during the day (KLIA_MTB Audit Report, 2007).

Description

The main terminal building is located in between the two runways. The Main terminal Building, KLIA consist of six levels with a total floor area of 170,640 sqm. The main terminal spans 38.4m along a grid pattern allowing for easy expansion in the future. The design consists of a well oriented east west building with the long axis running east and west and major glass areas facing north and south (contact pier and entrance of Main terminal Building, KLIA).

Architecturally, the Main Terminal Building consists of a series of 'hyperbolic-shaped' roof forms (figure 2) and the Contact Pier (CP) comprised of two linear buildings attached to the east and west wings of the complex and have a monopitch sloping roof. Both buildings are fully glazed perimeter walls, however the adoption of double glazing and roof insulation reduces heat gain into the building (KLIA_MTB Audit Report, 2007).

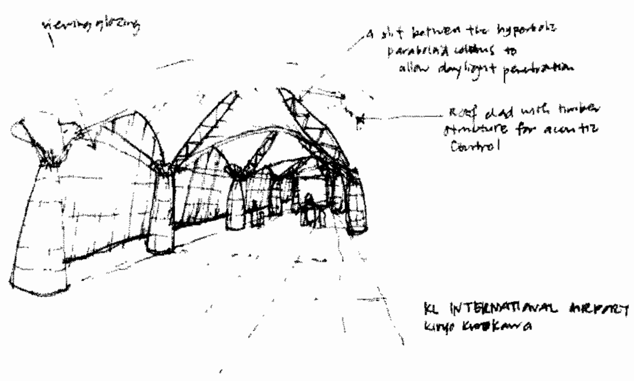

Figure 2: Showing the 'hyperbolic-paraboloid' roof form of the KLIA and its glazed perimeter wall

According to Kisho Kurokawa, the principal of Kisho Kurokawa Architects & associates, whom the architect of KLIA, mentioned that in order to achieve a well-balanced distribution of light across the floor with regards to the hyper-parabolic ceiling which has height varies from about 11 to 23 m, the lighting design (skylights and lighting fixtures) had to cope with this variation in distance. Simulations were performed and an illuminance uniformity of 0.7, which demonstrated good uniformity, can be achieved.

In this study, we will observed the significant of daylighting performance and its magnitude, with regards to the hyper-parabolic roof with skylights and glazed perimeter walls facade of the terminal as well as looking into how well the distribution of daylight in the spaces.

1.4 Aim and Objective

In this case study, we review the issues of daylight in long span roof airport terminal design which include; building envelope, choice of material, long span roof structure design, integrated lighting system and daylighting strategies (more focus on toplighting and sidelighting). It is aim that this analysis will eventually be used to create a better quality glazed pedestrian and public space in long span airport terminal building.

This research will also look into whether daylighting strategies with integration of lighting systems of selected glazing area in KLIA main terminal building could identify the optimum level of lighting and glare indices which will cause discomfort to the occupants of these spaces.

1.5 Some Research Questions

Does incorporation of daylight design strategies in KLIA main terminal building long span roof design contribute to energy efficiency and provide sufficient daylight for visual comfort?

Does the sophisticated structure H-P roof design with skylights which support the KLIA long span roof design influence the distribution of daylighting towards the space to create the expression, ambience and mood of space and occupant?

Does the overall strategy on daylight have any impact in terms of human perception to visual comfort?

2 Methods and Procedure

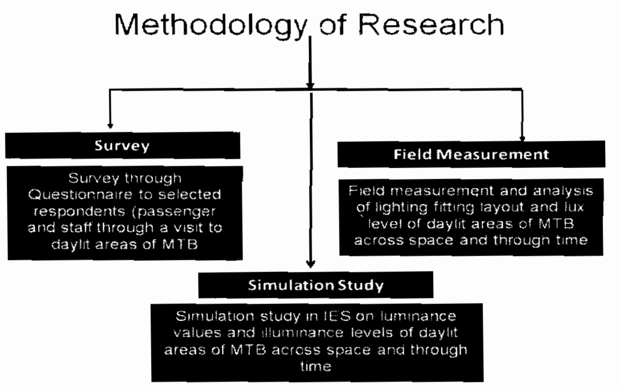

Figure 3: Showing the methods of research project

2.1 Simulation Study

The first method used in this research which is the simulation method with daylight field data was used as a preliminary data and a comparison and validation exercise (figure 3). The emphasis on simulation is to overcome the shortcomings of the monitoring data – due to time constraints and the short time period of study. The parameters and assumptions within the simulation are presented and discussed. The comparison between predicted and measured performance allows the estimations of the extent of errors from the prediction tools. Hence computer simulation is used to predict the daylight distribution of the space based on the materials specifications and the architectural dimensions given by the KLIA management.

The simulation is also aimed to evaluate the daylight admittance under standard 10K CIE overcast sky through calculation of interior lighting distribution (luminance values and illumination levels) based on the geometry and massing of the MTB with regards to sun, building orientation and daylight admittance in order to understand the sun irradiation and heat gain (figure 4). Radiance in IES was used to quantify the daylighting within the space. In relation to the survey, the simulation was to simulate the visual performance of space through the 3D views rendered in Radiance as well as to measure aspects of the occupant's response to these virtual environments.

Sky conditions in Kuala Lumpur	Description (including) maximum solar radiation
Cloudy : 51% (including partially cloudy)	Cloudy The occurrence of cloud cover during the entire day, from early morning to late afternoon, Max = 121 4 W/sq.m. Partially cloudy day. Max. = 1142.9 w/m.sq (higher than on a clear day)
Clear. 16%	Maximum instantaneous solar intensity for a clear day = 971 W/sq.m.
Rain (overcast) 14% Afternoon rain. 19%	For days with afternoon rain (from about 2.00 -5.00 p.m.) Max = 957 W/sq.m

Figure 4: Frequency of sky conditions in Malaysia (Source from Othman et.al., 1993)

The determination of daylight levels in buildings typically makes the assumption that the sky is completely overcast i.e. based on 10k CIE overcast sky. In this study, the value 10 000 lux is thus used as the representative external illuminance to calculate internal illuminances.

2.2 Field Measurement

The second method for the research is through field measurement and analysis of lighting fitting layout and lux levels of daylit areas of Main Terminal Building of KLIA across selected space and through time.

2.3 Comfort Survey

In this study, a Comfort Level Survey was carried out to a sample of passengers and employees to provide an assessment of passengers' and employees' response to thermal and visual comfort aspects of the internal environment. A total of 286 passengers and 63 employees were interviewed in this survey. The Kuala Lumpur International Airport Terminal Building Comfort Level Survey was carried on Friday 30th November 2007 until 2nd December 2007 from 10.00 am till 12:00 am.

The objective of the passenger survey is to provide a simple assessment of passenger's responses to thermal and visual comfort aspects of the internal environment. The survey questions were prepared and focused on thermal and visual comfort aspects of the internal environment. Through the survey, occupant can view the possible visual outcome of daylighting condition prior to rating lighting quality to indicate their preferences.

3 Results

3.1 KLIA Departure Hall Simulation Results

In this study, the simulation method is used with daylight field data use as a comparison and validation exercise. The emphasis on simulation is to overcome the shortcomings of the monitoring data – due to time constraints and the short time period of study. The parameters and assumptions within the simulation are presented and discussed. The comparison between predicted and measured performance allows the estimations of the extent of errors from the prediction tools. Hence computer simulation is used to predict the daylight distribution of the space based on the materials specifications and the architectural dimensions given by the KLIA management.

The model used is modeled with the application of massing, roof forms and dimensions of Main Terminal Building, KLIA. The reflectance values based on the materials specification as used in the simulation models are as below (table 2).

Table 2: Reflectance values for Interior materials used in simulation

Surface Properties	Reflectance value
External Wall (ext)	0.371
External Wall (int)	0.718
Internal Partition	0.718
Roof (ext)	0.250
Roof (int)	0.900
Ground (ext)	0.418
Ground (int)	0.582
Floor/Ceiling (floor)	0.250
Floor/Ceiling (ceiling)	0.900
Door	0.336

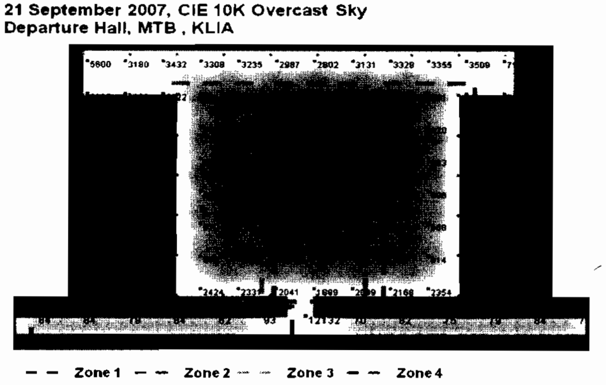

Figure 5: Distribution of zones for daylight magnitude of departure hall and contact pier, MTB, KLIA

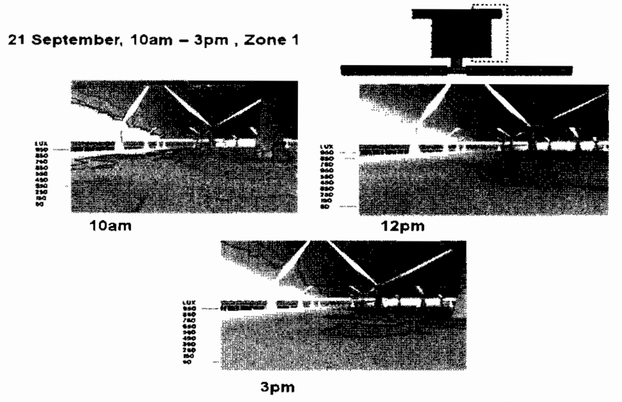

Figure 6: Daylight magnitude distribution –perspective view west portion of the departure hall

There is a substantial contribution of day lighting from the glazed walls and skylights within the Departure Hall and concourse areas. Areas near the glazed perimeter walls have consistently higher daylight levels exceeding 1000 lux (exceeding the target of 300 lux illuminance level) (figure 5). Skylights in departure hall were evaluated. The quantity and quality of the daylighting from the skylight is beneficial to give a uniformity of diffuse lighting condition at the departure hall, MTB, KLIA (figure 6). It is observed that because of occupants' movement and short duration of occupancy at these areas, passengers are relatively tolerant to the direct sunlight from the glazed perimeter walls, irregularities of daylighting and sky conditions (illuminance levels) and visual comfort irregularities.

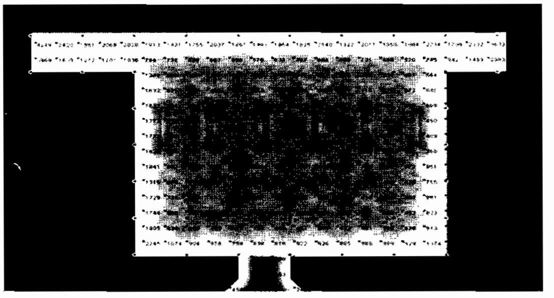

Figure 7: Daylight level and distribution - Departure Hall and entrance (with skylight)

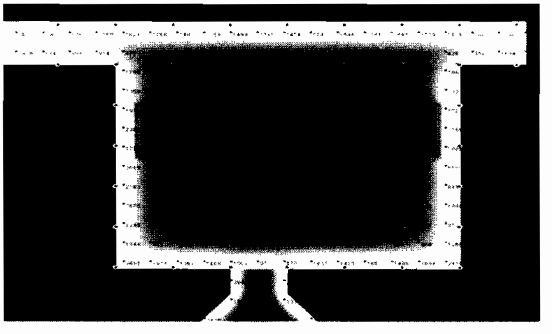

Figure 8: Daylight level and distribution - Departure Hall and entrance (without skylight)

It is also observed that the daylight from skylight have been shown to have positive impact both on human comfort and visual comfort due to contribution of diffuse lighting condition from the skylights. Results show (Figure 7-8) that the impact of skylights is to increase total areas daylit on the core and perimeter of the building. In other words, in terms of daylight, eliminating the skylights causes a decrease in the amount of usable daylight at the core areas in all three cases, it can also be seen that the illuminance levels near the facade are quite high and fall rapidly towards the building's interior.

3.2 Field Measurement Results

Following the simulation study, a field measurement was carried out to document data of the illuminance level of selected zones of departure hall of KLIA main terminal building on selected days of the months (September, October and November). The figure below is showing the comparison between measured data and field data. It is observed that these standard patterns are influenced by the sky condition, time and day of the illuminance level which are measured at these areas.

Comparison of lux levels, departure hall, MTB

- **With skylight (simulation)**
- **Without skylight (simulation)**
- **Data from Pusat Tenaga Malaysia (Malaysia Energy Centre) Audit Energy Study**
- **Data taken on 14 Sept** *Equipment used – Testo Portable Lux meter
- **Data taken on 9 Oct** *Equipment used – Lutron Digital Lux meter & Extech Heavy Duty Lux meter
- **Data taken on 26 Nov***Equipment used – Lutron Digital Lux meter & Extech Heavy Duty Lux meter
- **Data taken on 27 Nov***Equipment used – Lutron Digital Lux meter & Extech Heavy Duty Lux meter

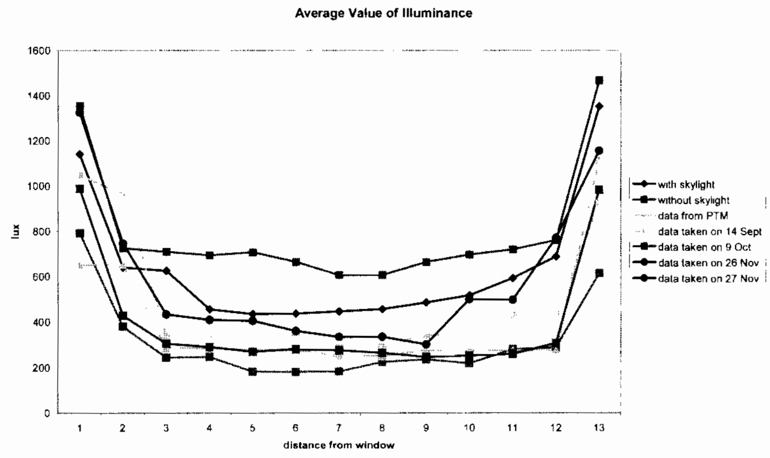

Figure 9: KLIA MTB – comparison between simulation data and average field data

Similarly to the KLIA simulation results, it can be found that the results from the field measurement has similar distribution of daylight level which has higher daylight levels exceeding 1000 lux near the glazed perimeter walls façade and average of 300 lux under the hyper-parabolic skylight roof (figure 9).

With the integration of expansive structure and skylight which allows diffuse illuminance to the space, this will help to boost the occupants' mood and giving them assurance despite of their anxiety and stress.

3.3 Sun Path Simulation Results

The sun path was used to effectively portray the dynamic path of the sun in the glazed perimeter wall (east-west façade and north-south façade) as shown below.

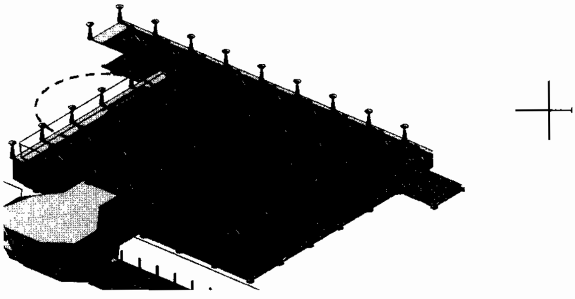

Figure 10: Showing the solar path and sun patch of designated time and day of the year

The results of the simulation show that, there are some incidences of direct solar penetration on the eastern façade at 10am and western façade at 4pm. Hence the need to improve the overhang design is greater as the sun patches that the building did not provide adequate protection for certain areas during the critical times of the day. In addition the probability of incidence of glare (figure 10) is predicted at the highlighted glazed perimeter walls façade.

The glazed perimeter wall orientation which elongated on an east-west axis generally achieves lower heat gain and consequently lower energy use due to angle of daylighting penetrating through the glazed facades. The overall massing of MTB, KLIA in lieu with optimal orientation, as the longer facades face due north and south towards the diffuse Malaysian skies while the short facades are facing due east and west. This orientation reduce incidence of direct solar penetration.

3.4 Comfort Survey Results

Answers were analysed using SPSS (statistical calculation software). Most of the data were nominal data, therefore, the results were analysed through descriptive analysis such as frequency, percentage and cross tabulation method of assessment. A few data were analysed through correlation test in order to further investigate the relationship between various answers of the tested variables.

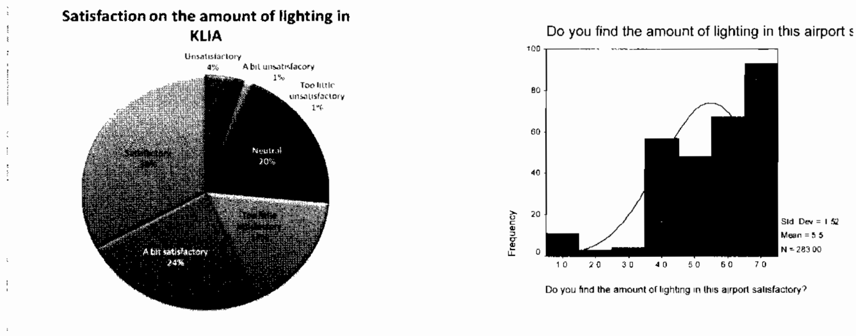

Figure 11: Showing the percentage of occupants' satisfaction on the amount of lighting in MTB,KLIA

From the figure 11, a higher number of the respondents in the survey find the amount of lighting in KLIA satisfactory (33%) and 41% of respondents find the amount of lighting in KLIA a bit satisfactory and too little satisfactory compared to 20% of respondents find the amount of lighting in KLIA just right-neutral. Whereas the rest of the respondents (6%) find the amount of lighting in KLIA too little unsatisfactory or less satisfactory, with the mean= 5.5 and SD=1.52.

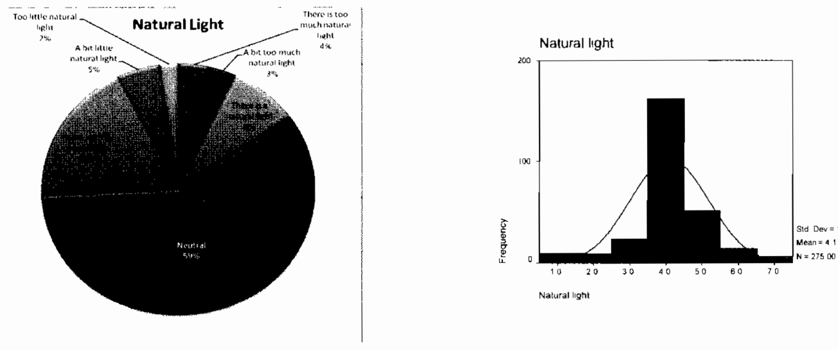

Figure 12: Showing the percentage of occupants' perception on the presence of natural lighting in MTB,KLIA

From the figure 12, a higher number of the respondents find that the amount of natural light at the location of the survey to be just right-neutral (59%) and 19% of respondents find that there is little amount of natural light at the location of the survey, (5%) a bit little natural light and (2%) too little natural light compared to 8% of respondents find that there is natural light at the location of the survey, (3%) a bit too much natural light and (4%) of respondents find that there is too much natural light, with the mean= 4.1 and SD=1.06.

From the survey, most respondents are satisfied with the lighting conditions of the building. Many of them did not find the amount of lighting from daylight and artificial light glaring.

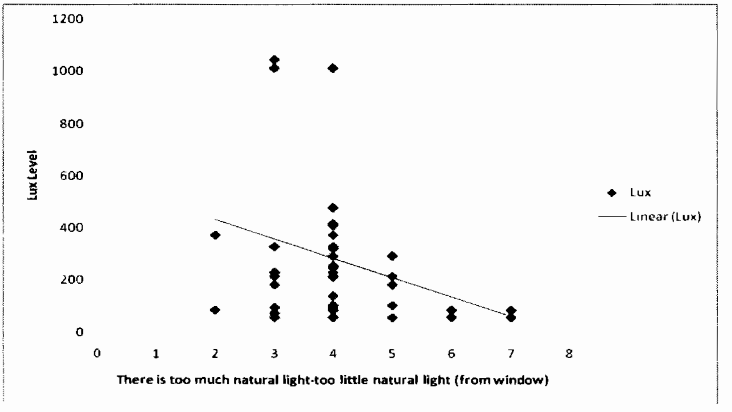

Figure 13: Showing the correlation between the illuminance levels and occupants' perception on the presence of natural light at MTB, KLIA

From the figure 13, it is observed that the more quality of natural light is presence in lower lux levels (illuminance levels) compared to higher lux level. Therefore there was an inverse correlation perceived natural lighting quality and measured illumination levels.

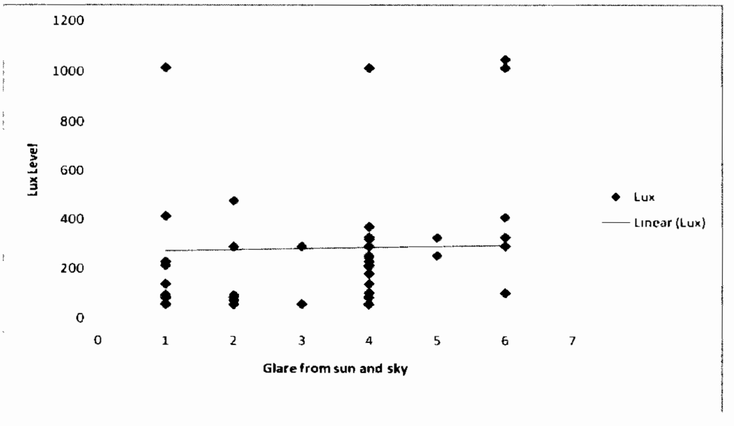

Figure 14: Showing the correlation between the illuminance levels and occupants' perception on the presence of glare from sun and sky at MTB, KLIA

From the figure 14, it is observed that the glare from natural light and sky is presence in lower lux level (illuminance level) compared to higher lux level. Therefore, there was a direct correlation perceived glare from sun and sky and measured illumination levels.

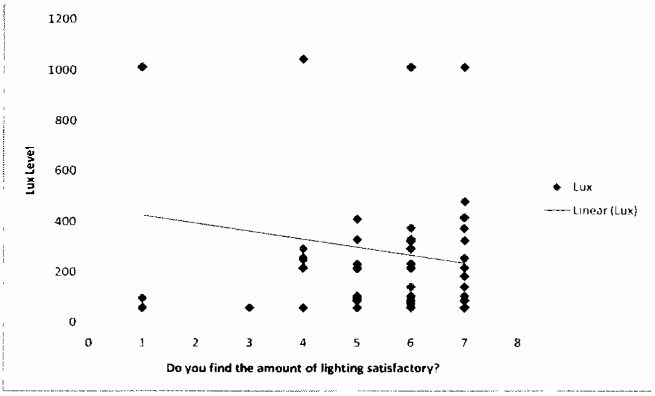

Figure 15: Showing the correlation between the illuminance levels and occupants' satisfaction of the amount of light at MTB, KLIA

From the figure 15, it is observed that the occupants are more satisfied with the lighting condition of departure hall of KLIA main terminal building in the lower lux level (illuminance level) area compared to the higher lux level area. Therefore there was an inverse correlation satisfied with the amount of light and measured illumination levels.

Based on these results, it is observed that the illuminance level of departure hall of KLIA main terminal building was found to have affected the occupants' degree of satisfaction, assurance and relaxation. Hence, the presence of glare being tolerated due to the expansive volume and structure as well as the placement of skylight and perimeter glazing wall as human eyes can adjust to high levels of luminance as long as it is evenly distributed.

In addition, considerable level of brightness along the glazed perimeter wall orientation still shown positive effects on both the human comfort and visual comfort through the freedom to change orientation or move out from the sun patch areas as well as views towards the surrounding of the airport terminal building.

4 Conclusion Remarks

On the basis of the mentioned data and study it can be concluded that daylighting through the application of skylight in long span roof design of Main Terminal Building, KLIA do contribute to energy saving as well as creating a pleasant ambience and environment to its occupant or users. This study also proves that the intention of Architect Kisho Kurokawa incorporating effective daylighting in the Main Terminal Building, KLIA, with regards to the positioning of skylight and its glazed parameter wall facade, has given an impact to the human and visual comfort.

In relation to the extensive volume through skylight and perimeter glazing of the building envelope, diversity of illuminance level of the terminal building has given a significant overview of achieving a baseline of lighting level in lieu with occupant comfort and satisfaction in long span roof building design.

The work presented in this research aimed at contributing to improve the links between qualitative and quantitative approaches on daylighting distribution and qualities in Main Terminal Building, KLIA and its facade in the tropical climate.

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