INTEGRATING SIMULATION AND VISUALISATION FOR ENERGY EFFICIENCY IN A LARGE PUBLIC MALL IN THE TROPICS

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ABSTRACT**:** *This paper reports on a case study that involved an integrated design process of a large commercial development. In particular, it utilized simulation and visualization to inform strategic design decisions that could reduce heat gain while admitting usable daylight. Additionally, the design intended to avoid extensive air conditioning energy of a large shopping mall in the tropical context of Malaysia. Simulation inputs were presented to a design team throughout the design process and on completion of the building, post occupancy studies were carried out to verify the results. At present, air conditioning is not used in large common public areas and hence, this case study represents a successful application of simulation and visualization tools of such context. The airflow and monitored temperature results verified the simulation output; however, the daylight measurement recorded higher distribution compared to the predicted performance. This may be due to the standard use of 10 k Cie overcast sky in simulation to represent the worst cloudy scenario in Malaysia. Regardless, the results will benefit future planners and developers of large shopping malls by recommending the integrated design process. This process introduces the usage of strategic passive design approach that can save a large amount of energy used in common areas.*

KEYWORDS: *multivolume, atria, canopy, thermal comfort, bioclimatic and ventilation*

1. INTRODUCTION

Large shopping centers are prominent features in developing cities. In tropical countries like Malaysia, these buildings are totally air conditioned and thus, require passive design strategies in order to lessen their lifelong operational costs incurring from active cooling. This research aims to adopt state of the art building simulation and visualization in the designing, building and monitoring of thermal comfort performance of a largely covered 70,000 square meter plaza or atria. In particular, it intends to promote passive design strategies by optimizing roof design that can limit solar gain and allow in daylight. This in turn, will offset trapped heat in a covered space.

Conducted as a case study, this research represents an ecological approach where a developer employs simulation expertise to assist in strategic design decision making for the purpose of reducing energy usage in the tropics. In particular, it aims to:

1. Identify the causes of heat gain, and
2. Determine predict and monitor both daylight and thermal comfort performance within the proposed space.

In tropical urban design, there is a growing trend of building residential suburbs on plaza outdoors (Hung & Chow, 2001 and Sharples & Lash, 2007). This feature acts like an external atrium or a courtyard, which often serves as a commercial and social hub in new urban developments. Constructed as an opened, semi-opened or covered space, the spacious courtyard often houses commercial activities like outdoor bazaars and food-courts.

Large urban spaces become prominent in tropical countries for several reasons. First, they serve to reduce isolation of city dwellers. Often included with this feature are glazed canopies that admit more variable and dynamic daylight and hence, produce a bright and cheerful atmosphere that can enhance marketing of goods and services. Following increased significance, developers begin to include such spaces as part of their marketing efforts.

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In view of the increasing importance of common spaces in large commercial buildings, it is imperative to ensure that these spaces do not consume a lifetime of high energy. For instance, a covered space may be typically designed with daylight admission and natural ventilation, which create a sort of enhanced semi-outdoor large atrium-like space. Equally important is to note that the roof of a large building (like shopping centers) in equatorial climate can represent the largest source of heat gain, particularly through radiation and conduction.

Some innovations in countries of temperate climate do not apply in their equatorial counterparts. For example, glass-covered atriums in those countries may introduce roof heat radiation and conduction when set up in tropical countries. Henceforth, more in-depth understanding is required to serve as parameters for tropical urban design, where thermal comfort in outdoor urban areas is more extended and varied than that of indoor climate.

2. METHODOLOGY

Through schematic and design development processes, a series of options were tested in order to optimize an innovative roof design to offset trapped heat in a covered space. The use of simulation tools was introduced at the very schematic design stage. Based on an existing design, the team worked closely with an architect to propose and test several options in line with aesthetic preferences. When options were shortlisted, the team further studied the performance of optional roof profiles in terms of daylight, glare and wind. These options were then, induced with cross ventilation results.

Results from the above processes were used to identify, determine and predict visual and thermal comfort performances of the selected options within the proposed space. Specifically, the study intended to predict possibilities of introducing roof elements to promote balance between daylight and heat gain. Harmony was also required between natural and mechanical ventilation, as this could improve the thermal comfort performance of a large area. Eventually, the process aimed to upgrade visual and thermal comfort performances in the covered atria.

The project is essentially a large covered atrium in a proposed large shopping complex in *Bukit Jelutong*, *Shah Alam*. It is currently completed in terms of construction. The original design of the covered atria or plaza is shown in Figure 1. As shown from the figure, the design represents part of large scale development of commercial and social urban space, with pedestrian circulation, and commercial stalls being proposed in the developing city of Shah Alam. The proposed development consists of blocks of 4-storey shop offices and commercial complexes at No. 6, Persiaran Pasak Bumi, Taan Bukit Jelutong, Seksyen U8, 40150 Shah Alam, Selangor, DarulEhsan. Built by Mainstay Development Sdn. Bhd, the covered atrium is located in-between the commercial blocks as shown in Figure 2.

Fig. 1: Space U8 _ original design without roof canopy

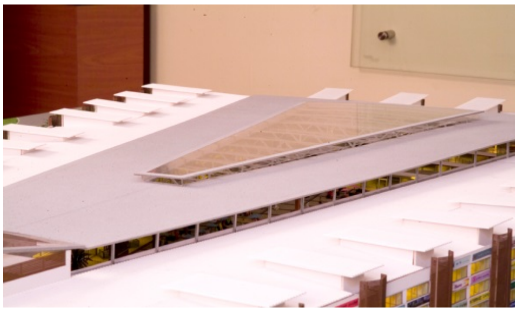

Fig. 2: Space u8-Original design with initial roof canopy design

Among the discussions made during the design process was to incorporate more openings at the top. This will allow hot air to escape through natural stack effect and also through wind driven ventilation to a certain extent. Such bioclimatic interventions may assist the building to 'breathe' besides balancing conflicting trade-offs in tropical climate. The improved options or interventions were analyzed and summarized as shown in the following figures:

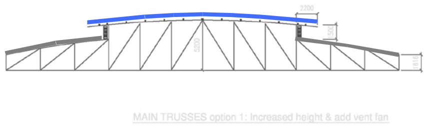

Fig. 3: The fully covered plaza option

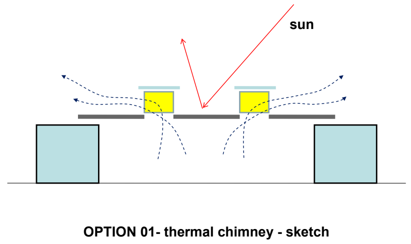

Fig. 4: The 1st Alternative option proposed

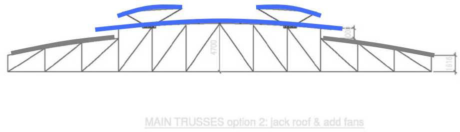

Fig. 5: The 2nd alternative option proposed

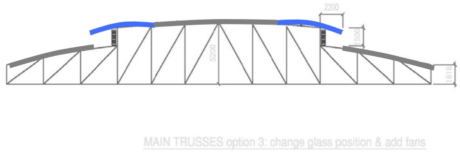

Fig. 6: The 3rd alternative option proposed

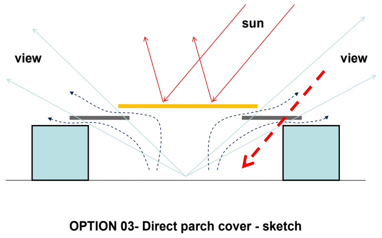

Fig. 7: The 4th alternative option proposed

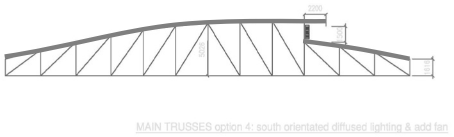

Fig. 8: The 5th alternative option proposed

2.1 Thermal prediction through simulation and analysis

To model ambient air flow, a simulation tool called Computational Fluid Dynamics (CFD) was utilized. This tool has demonstrated an efficient performance over conventional empirical and scale modeling techniques in terms of results accuracy and cost effectiveness (Neilsen et al., 2007 and Posner et al., 2003). Through detailed CFD simulations, all options were tested including the incremental effect of ‘original roof’ and ‘improved roof’, with more focus being directed to peak temperatures.

The simulations showed that (1) a combination of roof design that creates a jack roof between strips of roofs and (2) selection of low-e roof materials may result in internal thermal conditions of 30.2 °C. In contrast, covering the atria with a laminated glass roof or skylight would have created an internal thermal condition of 34°C, a temperature of 4 °C higher that the enhanced roof design.

The simulated results of the temperature and air flow distributions can be visualized as follows:

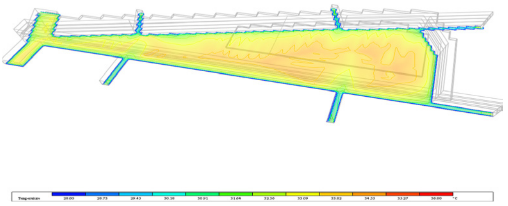

Fig. 9: Temperature distribution snapshot at ground floor (+350mm) with Low-E glass

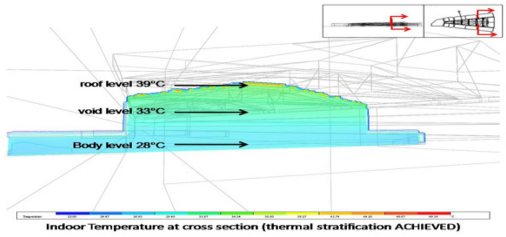

Fig. 10: Indoor temperature at cross section

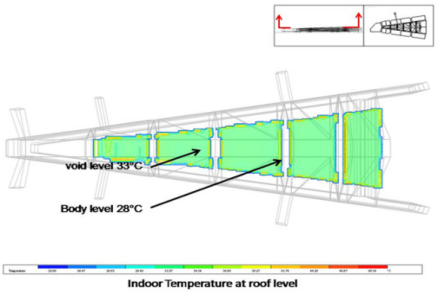

Fig. 11: Indoor temperature at the roof level

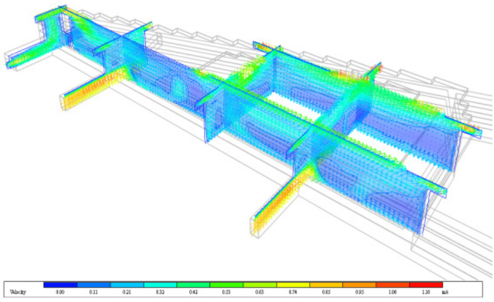

Fig. 12: Air flow distribution slicing through several sections within the plaza with low-e glass

2.2 Daylight simulation and prediction

To cut heat radiation, the researchers also had to balance between limiting heat gain through the roof and letting in sufficient daylight. Hence, daylight simulations were undertaken by using an advanced lighting tool called RADIANCE. The performance monitoring of daylight shows good agreement between simulation, predicted performance and actual performance. Figure 13 and 14 show the simulated results of daylight level in the courtyard.

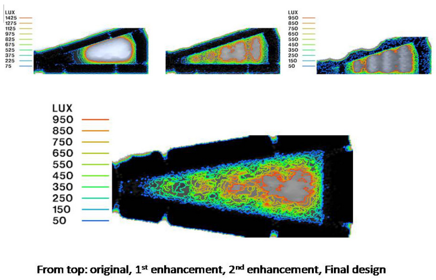

Fig. 13: 1st Enhancement, 2nd Enhancement, Final Design

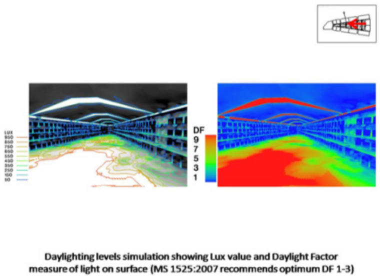

Fig. 14: Daylight level simulation showing the measure of light at the courtyard

2.3 Optimization of final roof canopy

A final improved design was configured based on thermal, economics and structural requirements and constraints as shown in Figure 15. This model consists of strips of skylights that are arranged in such a way to allow openings (like louvers) to be interspersed along the skylight. The improved design and roof performance is due to several thermal and heat transfer mechanisms and principles.

Firstly, lighter hot air at the top of the roof cover is given an outlet by the ‘jack roof’ elements. Thus, an escape mechanism is created between the strips of roof covers, where trapped hot air can be exhausted from the lower internal space. The outlet also creates pressure differences, or thermal buoyancy, that causes cooler air to replace the outgoing air. This thermal buoyancy then would create air movement that offsets the trapped heat from the covered atria.

Secondly, the low-E glass has a high efficacy value (high ratio of daylight admission and heat minimization). Low E is specified based on the requirement of admitting daylight. It also prevents heat gain from entering the space. In comparison, laminated glass has much lower efficacy as it does not effectively prevent heat transfer despite being used to reduce glare. The enhanced roof model, which uses the low-E glass roofs, has in fact recorded an internal air temperature of 1.6 °C. This is lower than the one recorded for the laminated glass option.

Fig. 15: The final design of the covered plaza and courtyard of Shopping mall

To cool the space further, air circulation systems and water features were strategically placed. As shown from Figure 16 and Figure 17, the installed fountains and suspended water walls represent passive humidification measures, which help to elevate the cooling effect by mean of convention. In fact, these features also enhance the interior's aesthetics and ambience.

Fig. 16: The Water fountain inside shopping mall courtyard

Fig. 17: The water feature inside shopping mall courtyard

3. MEASUREMENT AND MONITORING STUDIES

The post occupancy audit was carried out in two periods: 2011 and 2012. Apart from monitoring the performance of the final built plaza and shopping center, the audit also served to validate results obtained from thermal and daylight simulation tools. The audit was conducted for five days, on different periods of time throughout working hours as shown in Table 1. The 12 of HOBO™ Data Logger temp/RH was logged continuously for 3 days while the portable ALNOR Velometer AVM 440 was used to measure air velocity at 11.00 am and 2.00 pm daily. To measure indoor horizontal illuminance, a simple illuminance meter was utilized.

Table 1: Timeframe of post occupancy audit

Date	Starting Time	Finishing date
May 30, 2011	11:00 AM	June 1st, 2011
September 6, 2011	12:00 AM	September 9, 2011
March 18, 2012	10:50 AM	11:50 AM
March 20, 2012	3:45 PM	4:45 PM
April 8, 2012	5:35 PM	6:35 PM

3.1 Setup and location of on-site measurement points

As shown in Figure 18, the points for measuring temperature and relative humidity were located. The temperature was measured by utilizing the HOBO™ Data Logger temp/RH. For indoor measurement, horizontal illuminance was taken at specific testing points over three horizontal longitudinal axes from the atrium's south façade. The measurement was taken using a simple luminance meter located 0.8 m above the floor level.

Meanwhile, a short luminance measurement of glare or brightness was measured at specific testing points over five vertical longitudinal axes from the south facade of the atrium space beneath the atrium skylight.

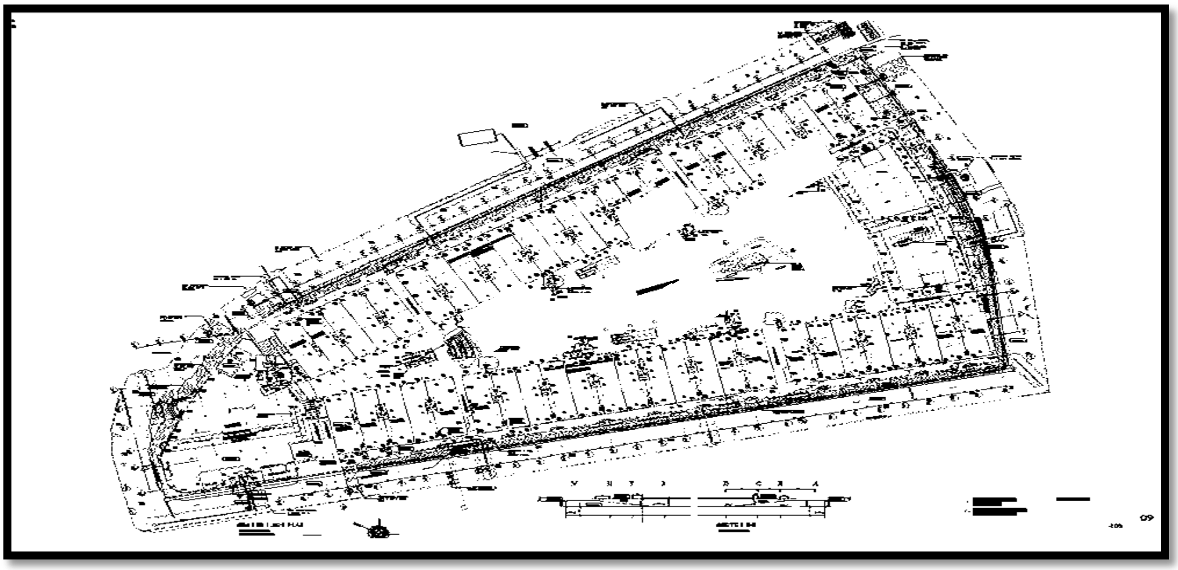

Fig. 18: Sectional axes to illuminance test points of measurment

4. POST OCCUPANCY AUDIT RESULTS

4.1 Air velocity results

The air velocity was taken at open air entry points of the ground floor. For simplicity purpose, the result is constrained at body level of the five points. Figures 19 and 20 show the air velocity results.

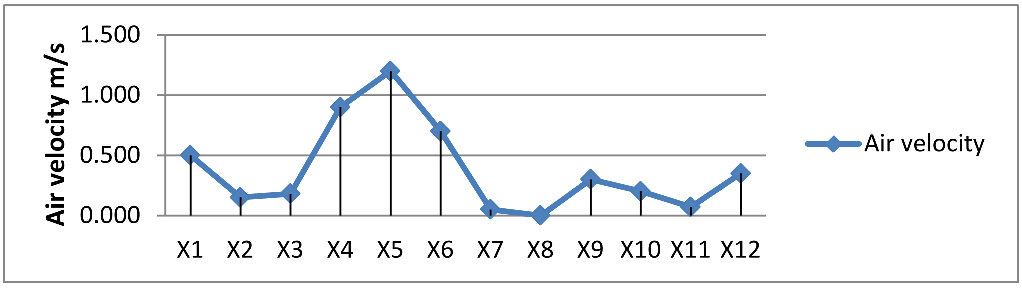

Fig. 19: Air velocity reading for 29/05/2011 – 2PM

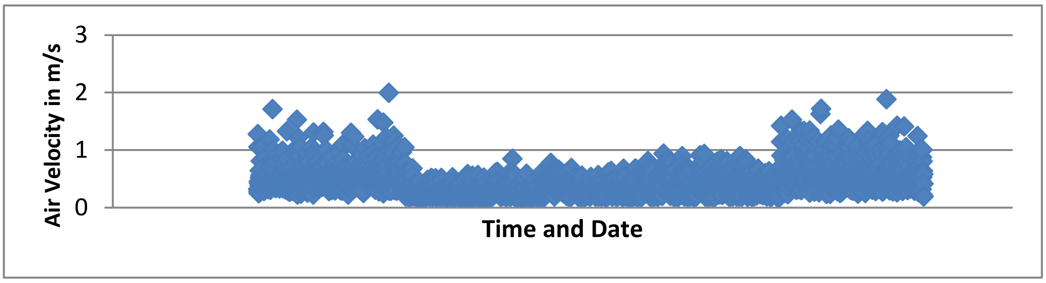

Fig. 20: Air velocity profile at middle of space u8 courtyard from 8th - 9th Sept 2011

4.2 Illuminance measurement results

The result of measurements of indoor horizontal illuminance can be highlighted as in Figures 21 and 22:

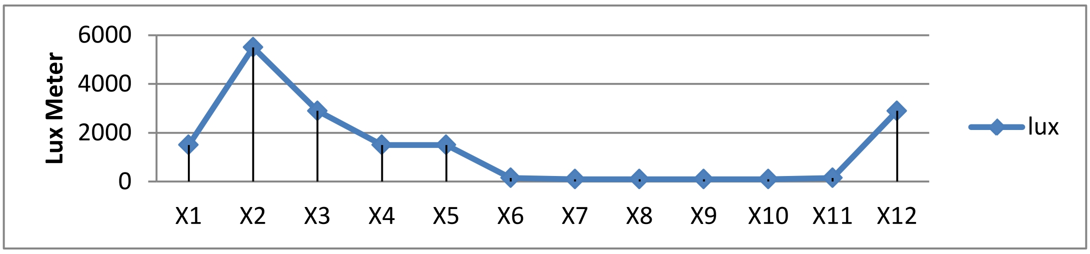

Fig. 21: Measurements of indoor horizontal illuminance on the 29/05/2011 - 11AM

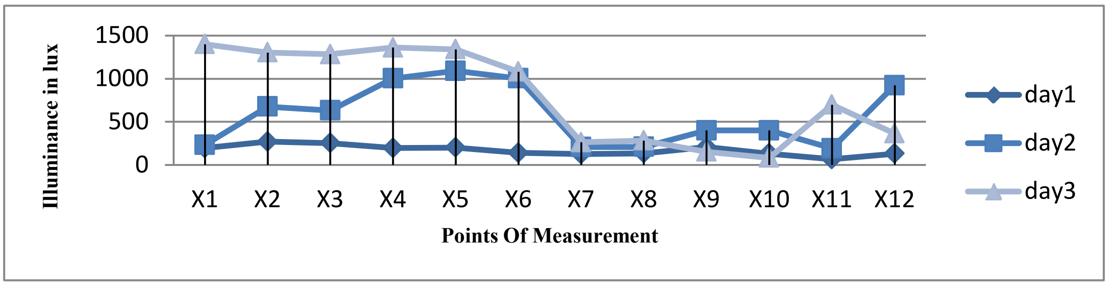

Fig. 22: Measurements of indoor horizontal illuminance on March 18 & 20, 2012 and April 8, 2012

4.3 Temperature audit result

Temperature results for the post occupancy can be shown in the following Figures and Table 2:

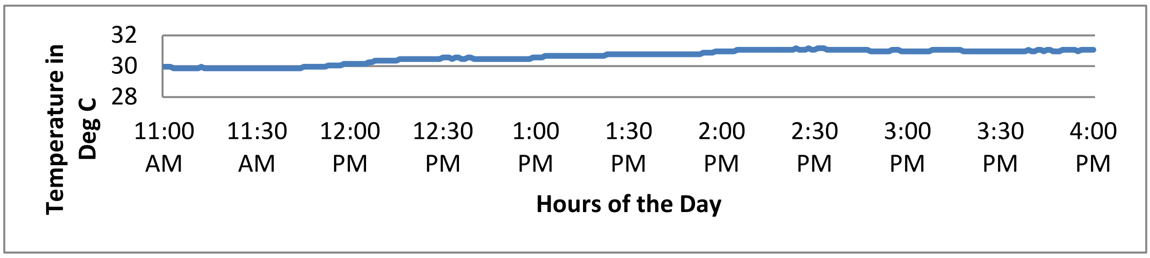

Fig.23: The reading for point 1 on the 30th of May

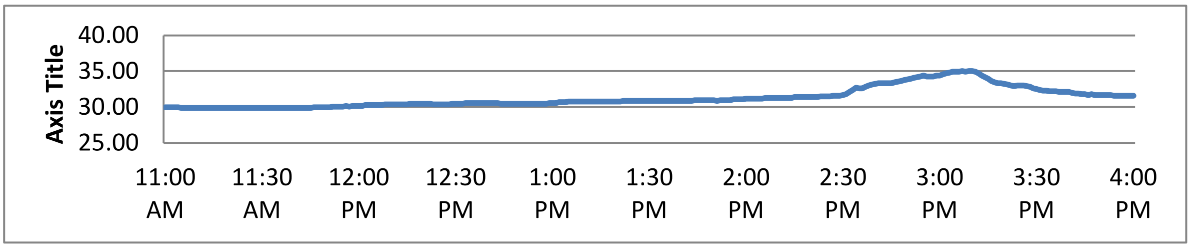

Fig. 24: The reading for point 2 on the 30th of May

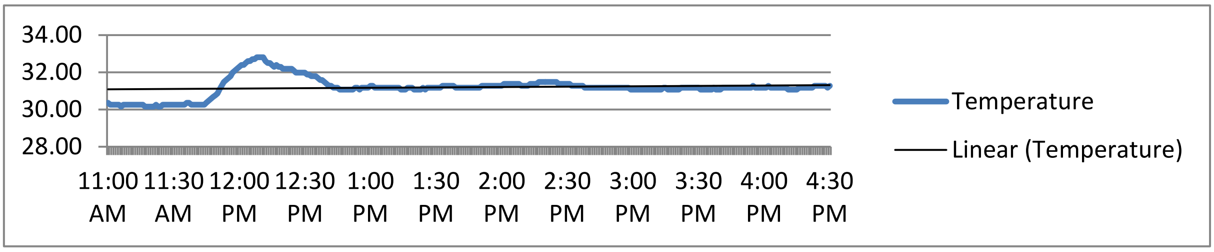

Fig. 25: The reading for point 3 on the 30th of May

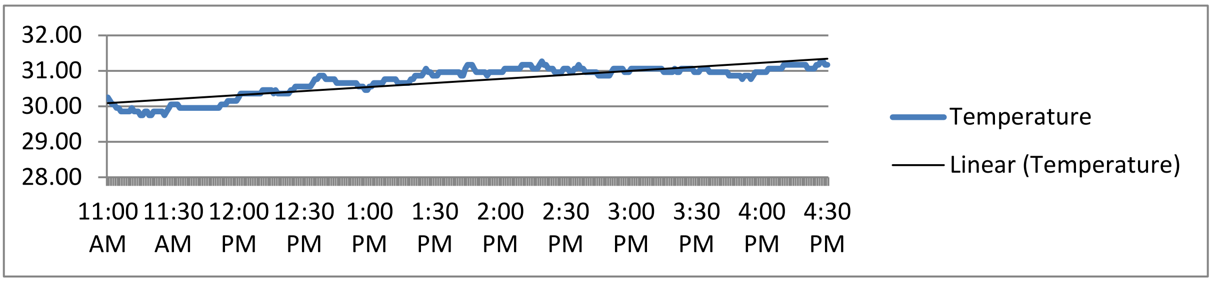

Fig. 26: The reading for point 4 on the 30th of May

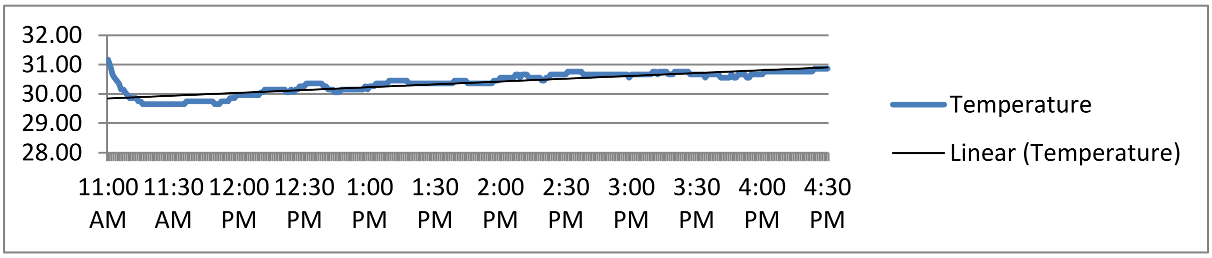

Fig. 27: The reading for point 5 on the 30th of May

Table 2: Outdoor and inside temperature on March 18 & 20, 2012 and April 8, 2012

Time	Inside	Outside
18/3/2012	30.1°C	32.4°C
20/3/2012	29.9°C	31.8°C
8/4/2012	29.4°C	31.3°C

5. PERFORMANCE AND OBSERVATIONS

5.1 Daylight Lux level

For all audit phases, the lighting conditions were well above expectations when compared to the simulation at working plane. At all test-points, the final results recorded more even distribution of daylight, with high levels being concentrated in the center. This distribution gradually declines towards western façade and gradually increases towards eastern façade. Table 3 and Figure 28 reveal the final results of measurements for indoor horizontal illuminance.

Table 3: Lux values for the building

Location		First day	Second day	Third day	Average
Working plane		2582.7	2549.3	1109.9	2080.6
Second floor	Minimum	172.0	292.7	176.8	213.8
	Maximum	286.0	323.5	191.5	267.0
Third floor	Minimum	220.0	228.5	135.5	194.7
	Maximum	256.0	337.5	222.0	271.8
Fourth floor	Minimum	176.0	299.6	177.8	217.8

	Maximum	286.0	376.4	209.5	290.6
Roof		2690.0	3607.5	1015.0	2437.5

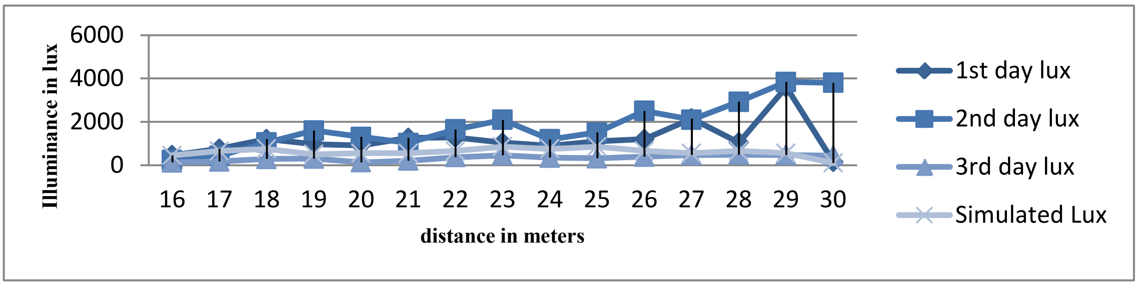

Fig. 28: Comparison between on-site measurement and simulated measurement

As for the lux level conditions at floor corridors, the simulation shows values that are close to 50 lux. The real minimum values were observed to be around 194 at the darkest spot. Those levels are well above the recommended average illuminance levels for corridors.

5.2 Air velocity

The results for air velocity were non-conclusive following the nature of the first audit; they may change once the mall operates. Regardless, the following results (Table 4) can be taken as an indication on how the building will behave under similar conditions.

Table 4: Summary of air velocity audit

Location		First day	Second day	Third day	Average
Ground floor	Main entrance	0.25	0.42	0.23	0.30
	Point 1	0.62	0.74	1.22	0.86
	Point 2	0.40	0.25	0.14	0.26
	Point 3	0.22	0.27	0.47	0.32
	Center	0.72	0.75	0.88	0.78
Second floor	Minimum	0.21	0.14	0.23	0.19
	Maximum	0.25	0.42	0.34	0.33
Third floor	Minimum	0.14	0.08	0.14	0.12
	Maximum	0.20	0.24	0.28	0.24
Fourth floor	Minimum	0.29	0.22	0.14	0.22
	Maximum	0.09	0.14	0.07	0.10
Roof		0.47	0.34	0.31	0.37

As shown from the data, maximum air velocity recorded was 1.63 m/s, a speed considered at the upper range of comfort but is acceptable in hot and humid conditions. On the other hand, the average air velocity in the building was 0.47 m/s, a speed considered quite stagnant and unpleasant in warm condition, but is acceptable in cool conditions.

5.3 Temperature results

The temperature at the plaza confirmed the previous simulation. Although the simulation temperatures were not impressive, they are still considered within the comfort level. It was also predicted that the plaza will eventually have better temperatures when the fountains, air circulation systems , and spot cooling points (entrances) operate. The audit also shows that for a variation of time and external weather conditions (ranging from rain and cloudy days), internal temperatures (at peak time of 2pm in the day) may range from 28 ℃ to 30 ℃. Regardless, air velocity and temperature have no correlation in change. Table 5 shows the summary of recorded temperatures.

Table 5: Temperature summary

	Working plane temperatures		Average	
Minimum	29.85	29.13	27.39	28.79
Maximum	32.28	30.13	27.87	30.09
Average	30.82	29.83	28.36	29.67
	Roof level temperature		Average	
Minimum	30.46	30.46	26.98	29.30
Maximum	35.12	32.50	26.98	31.53
Average	33.49	31.49	28.53	31.17

The audit also found that at 2pm, an average of 29.7° C was observed at body level in the majority areas within the plaza. This coincided with the acceptable thermal comfort range based on 60-70% RH (Relative humidity) and sufficient air flow under Malaysian climate. However, these temperatures may also be affected by airflow and relative humidity conditions. Comfort levels in the tropics can thus be improved by increasing airflow through mechanical means.

6. CONCLUSION

Thermal consideration of outdoor environments in large cities is essential as it adds value to urban space. Because comfort contributes to people's life, thermal comfort then, contributes to the quality of a space. The comfort conditions within these spaces are affected by urban design parameters, morphology of buildings, characteristics of surrounding surfaces and spaces, in addition to occupant activities. Therefore, understanding of convective and radioactive exchanges through the actions of wind, as well as the differences in temperatures and pressures can contribute towards enhancing a microclimate necessary for urban life patterns in the tropics.

Hence, strategic design was undertaken that involved 'breaking the roof section and overall area' into 'smaller strip of glass and metal deck roof'. This will reduce heat penetration to the space and will allow the latter to 'breathe'. Jack roof effect will help to provide an outlet for the trapped heat under the roof covers. Glass roof with low-e properties will help to prevent heat from entering the space in addition to allowing sufficient daylight. To assist the cooling further, water features and air circulation systems were strategically placed.

Until today, no air-conditioning is used in this space and the retail mall visitors were delighted to experience breezy and cool atmosphere. One of the visitors commented in her blog:
'...Apa yangaku perasan, dekat dalam ni takde menggunakanaircond.Maybe dalam shop
lot tu diorang gunaaircond. Dekat luar2 ni, terasa cam berada dekattepi pantai. Berangin dan xterasa bahang p

anas.Padahal kat luar tu panas terik…' Translation *"what I can see definitely from this shopping centre is… the internal area of the shops use air conditioning, but the common areas.. It feels like near the beach… you can't feel the heat radiation at all, whereas the outside is intense heat…"* The project represents a strategic usage of simulation and visualization tools in energy efficient design. On completion of the building, two phases of Poe confirmed that the simulation tools closely reflected the actual environment within the commercial centers.

7. REFERENCES

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