DAYLIGHT MODELLING AND THERMAL PERFORMANCE OF ATRIUM OF NEW MECM BUILDING AT PUTRAJAYA

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ABSTRACT

A low energy office (LEO) building has been designed for the Ministry of Energy, Communication and Multimedia (MECM) at Putrajaya, Malaysia. The LEO building was designed to incorporate renewable and energy efficiency strategies. Several window designs were considered for the new showcase building. To ascertain that innovative window designs achieve the low energy consumption objectives, a study was done to analyse and compare the effect of several adaptations of the punch-hole window designs on the illumination levels of the indoor spaces of the office building. Architectural scale models were used under a sky simulator to analyse the impact of those window designs on indoor illumination. A scale model of the atrium section of the building was also studied to assess the daylighting performance of the atrium. Again, a sky simulator designed and built to conform to the tropical sky model, was used for the purpose. However, naturally-ventilated atriums are not commonly found in hot-humid climates. Therefore, this paper presents the results of the daylight modelling and the thermal performance of an atrium designed to consume low energy. The daylighting performance was determined for each floor of the 5-storey structure using the daylight factor method. The calculation of the absolute indoor illuminances was done using solar and daylight modelling. The thermal performance was evaluated using Computational Fluid Dynamics (CFD) simulations using Climate Model Year Data and architectural parameters as input. The thermal performance was analysed based on temperature differences and airflow characteristics. It was found that the atrium provides indoor lighting for the office spaces within the recommended levels. The temperature differences, airflow distribution and velocities also indicate that indoor thermal comfort is not compromised despite of the energy minimizing considerations. The results of this work have actually been incorporated in the design of a low energy MECM government office of which the construction is in the last stages of completion in Putrajaya, Malaysia.

This paper also presents the recommendations made on the possible improvements to the basic design in order to optimize natural daylighting and natural ventilation while protecting the building façade from solar thermal penetration.

Keywords : *Daylighting, low-energy office building, punch-hole window designs, atrium design, Computational Fluid Dynamics (CFD) simulations*

INTRODUCTION

The fundamental objective in designing a modern energy efficient low-energy office building is to provide the occupants with thermally and visually comfortable indoor environment by using an atrium space as a thermal buffer space and daylight collector [1]. Good daylighting in the atrium can be achieved by properly controlling the intensity and distribution of available daylight to meet the lighting design criteria. The indoor environment of many office spaces is influenced by both daylight and artificial lighting. Characteristics of windows and their shading efficiency affect the daylight indoors. The window design is a key facade element and should have energy efficient features to accommodate the visual impact required by the office building's occupants [2]. The Low Energy Office building for the Ministry of Energy, Communications and Multimedia in Putrajaya uses punch-hole windows to reduce glare and solar gains.

Moreover, daylight availability, configurations of fenestration system and atrium well, wall surface reflectance and light collecting system of adjacent spaces as the most important parameters that would determine the intensities of incoming daylight and solar radiation as well as the spatial distribution of daylight in the atrium space and the adjacent spaces. Glare problems and solar heat gains within the atrium space during the daytime may be resulted from improper decisions on these parameters [3].

The new MECM office building built at Putrajaya by the year 2004 is intended to be an exemplary, energy efficient office building that considers both energy efficient and passive features right from the design stage. The office building is to be a show case project aimed at setting a new standard for sustainable building design in Malaysia; thus signifying clearly Malaysia's support in promoting Renewable Energy and Energy Efficiency as well as her strong commitment in addressing the issue of climate change and ensuring sustainable development in the country. It is targeted that the energy consumption of the building be between 100 - 135 kWh/m^{2}year as opposed to the 250 - 300kWh/m^{2}year for a typical building. Among the passive energy efficient features incorporated in the building are building orientation, landscaping, naturally ventilated atrium, enhanced wall insulation by using alternative building materials and daylighting. The size of the atrium is approximately 80 m in length and 40 m wide with the long axis facing north-south directions. Level 4 has office spaces on the left while a lansdcaped rooftop terrace lies on the right of the atrium

In order to properly address the effect of key design parameters on atrium daylighting, not only measurements and calculations of illuminances are considered but analyses on luminance distributions on interior spaces must be conducted. In this respect, this research focuses on the daylighting performance of a four storey atrium in a low-energy office building design for the Ministry of Energy, Communication and Multimedia (MECM) currently being built at Putrajaya, Malaysia [2].

The Overall Design

The overall building layout and the façade design have been developed to incorporate suitable Energy Efficient features. The chosen overall building design lends itself to cost effective energy use, energy efficiency [4] through both:-

- Architectural design (passive solar strategies) which includes building orientation, insulation of walls and roofs, use of `punched' windows design with heat reflecting glazing and `light shelves', naturally cooled atrium and functional landscaping at selected locations.
- Mechanical and electrical (M&E) design (active energy management strategies).The active components of M&E services are reinforced to allow enhanced energy management capabilities for the building.

Window Design, Shading and Orientation

From an energy point of view, windows contribute negatively to the energy consumption of a building due to the fact that solar radiation through window increases the cooling load. However, windows also provide daylight to the building. Provided that artificial lighting along the perimeter of the building is controlled according to daylight availability, the use of daylight contributes to reducing the consumption of electricity for lighting, which in turn also reduces the cooling load. Diffuse light therefore contributes both to improving the working environment and to reducing electric lighting and the cooling load. Direct sunlight will typically provide more light than needed near the windows [4].

Punch-hole Window Designs

Punch-hole windows are windows that are set back from the building façade to create a shading device surrounding the opening itself. The windows of the Putrajaya building are 2,400 mm high with a light shelf attached in the middle of the opening (see Appendix for photographs of the models). A summary of the window dimensions are given in Table 1.

Table 1 : Punch-hole window dimensions with height of 2400 mm

Window Type	Depth of shading (Light shelf) in mm	Depth of setback in mm
Open	0	0
Punch-hole 1	1000	1000
Punch-hole 2 (opaque)	650	0
Punch-hole 2 (transparent)	650	0

METHODOLOGY

Daylight Modelling For Punched-hole Window Design

The indoor environment of many office spaces is influenced by both daylight and artificial lighting. Characteristics of windows and their shading efficiency affect the daylight indoors. The window design is a key facade element and should have energy efficient feature to accommodate the visual impact required by the office building's occupants [2]. For this study, four types of punch-hole window designs were tested for their daylighting performance. The daylight factor method was used. Graphical daylighting design aids such as three-dimensional daylight factor contours and linear daylight factor distributions were produced for the models tested. The results of each punch-hole window design were then compared with that of an open window.

The models were placed under the artificial sky which was built to simulate the luminance distribution of the Malaysian sky to test the illuminance distribution inside the window scale models [5]. The exterior and interior illuminances at designated points (interval of 5cm) were measured using sensitive photometers for three types of punch-hole window scale models (scale of 1:10).The floor area of the models measured 40cm by 50cm, whereby a total of 90 equidistant points were marked on the floor board where measurements were made. The daylight performance of each window was tested (using a scale model and a sky simulator) along the central axis of the window [6] as in Figure 1.

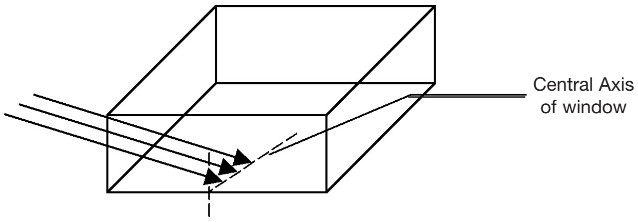

Figure 1: Scale model of open window showing positions along its central axis where measurements of illumination were made.

Daylight Modelling For Atrium Design

A physical model was used in this work to measure the daylight distribution inside the atrium and in adjacent spaces of each of the four floors of the atrium. The Megatron Architectural Model/Daylight Factor Lightmeters (AML/DFM), designed for architectural models tested under artificial skies, was used as the major measuring instrument. It consists of an outcell to measure the exterior illuminance and 12 incells for measuring the interior illuminances simultaneously. This method is an established method for daylight design [7]. A 1:50 scale model (as shown in Figure 1) of the atrium was constructed and used under an artificial sky. The artificial sky was adjusted to simulate the typical Malaysian sky type [8]. The standard daylight factor method was used to determine the ratio of interior illuminance and exterior illuminance at equidistant points at intervals of 5 cm on each floor of the scale model. The estimated indoor illuminance was then calculated using solar and illuminance data [9].

Figure 2 : Architectural scale model of the atrium

Thermal Analysis

FLOVENT, a 3-dimensional CFD modeling software specifically designed and optimized for modeling airflow in the built environment was used as the tool for simulating the airflow, temperature distribution and the thermal analysis of the atrium. Furthermore, CFD simulations would be the best option to predict and analyze the thermal performance of buildings in the design stage. To design a naturally ventilated atrium for a hot and humid climate like Malaysia, is a challenge as the country does not have great temperature differences between indoors and outdoors. Thus, the height of the building and the temperature difference between the heights is crucial to create the stack effect. In this building, a solar thermal flue is incorporated at the roof top of the 12 meter high glass atrium to create a stack effect. The flue faces east, to maximize sun exposure and will be heated up as much as possible. The air will then be forced to rise due to the reduced air pressure zone at the solar heated spaces of the flue, creating an up draught and air movement within the atrium space [10].

There were limitations to the dimensions and construction of the flue due to architecturally aesthetic reasons and rules laid out by the Putrajaya Development Center. Modelling was carried out for a fixed flue height of 4.0m but for two different widths of 0.85m and 1.0m. While the two possible flue construction ensemble studied were for the east facing flue wall with and without a layer of 150mm of concrete. The main area of interest would be the occupied space of the atrium i.e. the lobby area which opens up to the atrium. All simulations were conducted under worst case conditions based on the Climate Model Year data [11] i.e. hottest month (month of March), with no wind, and for different times of the day, namely at 10:00 am, 12:00 pm and 2:00 pm. If the thermal analysis showed positive results under worst conditions, then it will definitely be better results for any other ambient conditions. Simulations were also conducted for the month of December (when the sun lies lower in the sky and is not directly facing the flue), as well as for cloudy and clear sky conditions. For all the cases studied, the airflow and temperature values as well as its distribution patterns were predicted and air change rates calculated.

Flue/Solar Chimney Calculations

To investigate the effectiveness of the flume in creating air movement, particular attention is given to the occupied spaces on the ground floor and the areas around the flume. The occupied zone is taken to be the space covering a height of 1.7m from the ground floor. The ventilation rate was calculated using the formula [12]:

$$V = \frac{N \times \text{Room Volume}}{3600}$$

N = number of air changes per hour ventilation rate (m3/s)
V= ventilation rate(m^2/s)
CFM = 16.6 Av.√(H dT)
CFM = ventilation rate in cubic feet per minute
AV = cross sectional area of the flume (sq.ft)
H = height of the flume (ft)
dT = temperature difference (ºF)

RESULTS AND ANALYSIS

Daylighting Analysis of Punch-Hole Window Design

a) Open Window without Glazing

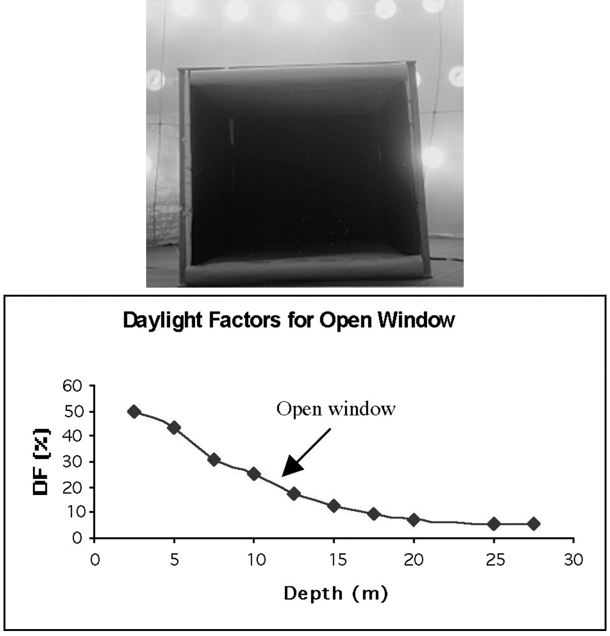

Figure 3: Daylight Factors for Open Unglazed Window

The daylight factors measured along the central axis are shown in Figure 3. The daylight factor (DF) drops from 50% to 5%. At the 10m position from the window, the DF is 25%. If the design daylight is taken at 10,000 lx, this point will have an indoor illuminance of 2,500 lx. At 25 m depth, the illuminance will be 500 lx. An open, unglazed window will provide sufficient natural lighting. If a glazing of 50% transmittance is used then all the illuminance values would be halved. For example, the indoor illuminance at the depth of 25 m would be 50% of 500lx which is only 250 lx.

(b) Punch-Hole Window 1

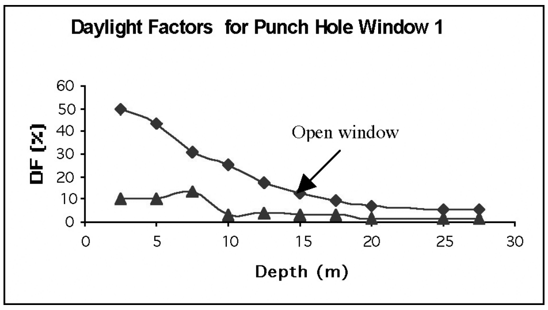

Figure 4: Daylight Factors for Open Unglazed Window and Punch-Hole Window 1

With this window design, the DF is reduced drastically from 50% to 10%. The lightshelf helps to increase the DF at a depth of 7.5m. At the 10m position, the DF is less than 5%. Here supplementary lighting is needed beyond the 7.5m depth. The comparison DF charts are given in Figure 3. All DF values would be reduced according to types of glazing used.

(c) Punch-Hole Window with Opaque Sunshades

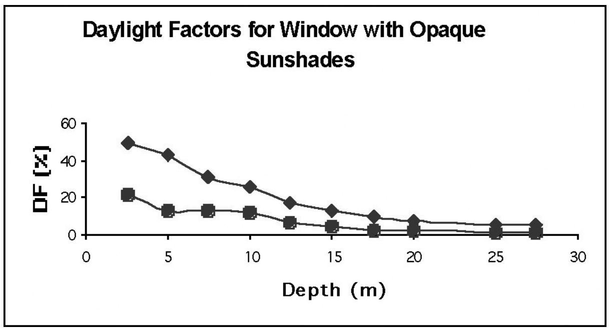

Figure 5: Daylight Factors for Punch-Hole Window with Opaque Sunshades

The opaque sunshades reduce the DF from 50% to 20% near the window. At 10m depth, the DF is 10% or 1000 lx if the daylight design criteria is used. This may be reduced to 500 lx if 50% transmittance glazing is used. Beyond this point the DF tapers off to almost 0%.

(d) Punch-Hole Window with Transparent Sunshades

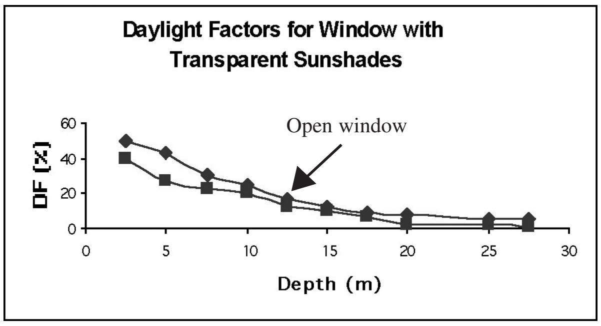

Figure 6: Daylight Factors Punch-Hole Window with Transparent Sunshades

Transparent sunshades reduce the DF to only 40%. The 10m depth has a DF of 20%. Beyond that the DF values are almost equal to that produced by the open window.

Absolute Illuminance

The actual hourly illuminance can be estimated for each position along the axis perpendicular to the plane of the window. The hourly exterior illuminnace for the Klang Valley, Malaysia is shown in Table 1.

The interior illuminance can be calculated easily from the relationship :

$$\text{Interior Illuminance} = \frac{\text{Exterior Illuminance}}{100} \times \text{DF \%} \quad \text{(lux)}$$

The sun is over the equator in March and maximum daylight is available then. The month of December witnesses the lowest illuminance levels due to higher rainfall rather than changes in seasons. The mean daylight levels are represented during the month of August. Table 2 shows the interior illuminance at 10m deep at specific time and months [13].

Table 2: Hourly Illuminance for the Klang Valley, Malaysia

Time (hrs)	March	August	December
6:00	0	0	0
7:00	7274	6967	4497
8:00	24459	22167	17142
9:00	43200	38437	30974
10:00	60839	53669	44018
11:00	74579	64524	54190
12:00	82105	70919	59764
13:00	82105	70919	59764
14:00	74579	65495	54190
15:00	61696	53669	44018
16:00	43857	38437	30974
17:00	24872	21757	17512
18:00	7274	6967	4497
19:00	0	0	0
	Maximum	Mean	Minimum

Table 3: Interior illuminance (in lux) at 10 m deep

Type of Windows	Open Window	Punch-Hole 1	Punch-Hole 2	Window with Opaque Sunshades	Window with Transparent Sunshades	
March 7am	2,546	218	255	800	1,455	
March 12 pm	**20,500**	**2,460**	**2,870**	**9,020**	**16,400**	**Maximum**
August 7 am	11,742	209	244	766	1,393	
August 12 pm	17,730	2128	2,482	7,801	14,,184	
December 7am	**1,124**	**525**	**613**	**495**	**900**	**Minimum**
December 12 pm	14,941	1,793	2,092	6,574	11,953	

Direct sunlight will typically provide more light than needed near the windows, and consequently the thermal impact that goes with the sunlight will also be unnecessarily high, even though the electrical lighting is offset. Futhermore, the sunlight creates glare problems. The shading system for the building shall therefore be optimized to avoid direct sunlight, but also to allow maximum diffused light into the building. In the MECM Building, the windows are primarily orientated to the North and the South. This orientation receives less direction sunshine, and only shallow out shading is required to shade off the sun. East and west orientations receive more sun, and the sun is more difficult to shade off due to the low sun angles for the radiation in the morning and in the afternoon. Exterior shading is most efficient, as the sun is stopped before it enters the building. The recommended shading design for the various facades and the two types of shading is summarized in Table 4:

Table 4 : Shading Design For The Various Facades [4]

Orientation	Degrees From north	Shading type shading	Depth of	Notes
NE	25	Punched Hole Window	650 mm	For a 2.400 mm high window with light shelve in the middle
		Louver/curtain wall	370 mm	For a distance between louvers of 1000mm
SE	115	Punched Hole Window	1000 mm	For a 2.400 mm high window with light shelve in the middle
		Louver /curtain wall	820 mm	For a distance between louvers of 1000mm
South	200	Punched Hole	650 mm Window	For a 2.400 mm high window with light shelve in the middle
		Louver /curtain wall	370 mm	For a distance between louvers of 1000mm
North	0	Punched Hole Window	650 mm	For a 2.400 mm high window with light shelve in the middle
		Louver /curtain wall	370 mm	For a distance between louvers of 1000mm
NW	295	Punched Hole Window	1000 mm	For a 2.400 mm high window with light shelve in the middle
		Louver /curtain wall	820 mm	For a distance between louvers of 1000mm

Daylighting Analysis for Atrium Design Ground Floor

It was found that the highest daylight factor (DF) of 71.2 % obtained at the centre of the atrium ground floor which receives much of the daylight from the atrium roof top and the front entrance [14]. The daylight factor however decreases slowly at average DF of 33 %, gradually tapering to an average of 3 % as the distance increases to 15 m from the centre of the atrium. The front entrance of the ground floor receives much daylight with a high DF of 54 % at the entrance and then decreasing gradually to 30 % at a distance of 17.5 m from the centre. Relatively some daylight is received at the lift lobby area, with a DF of about 0-10 % as shown in Figure 7.

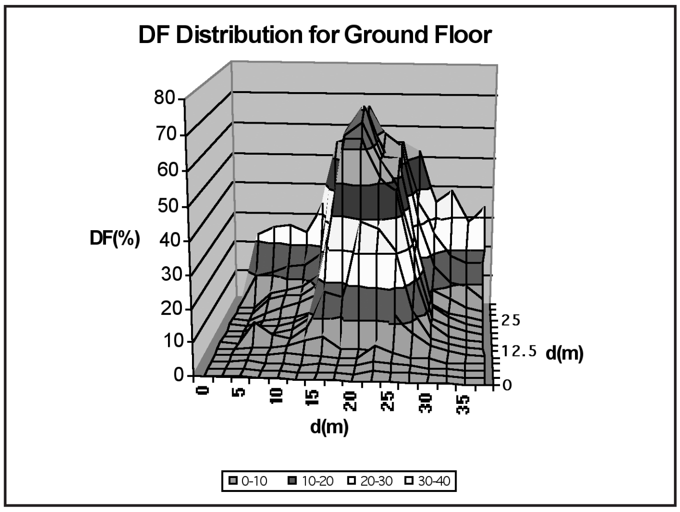

Figure 7: Daylight Factor Distribution on Ground Level of Atrium

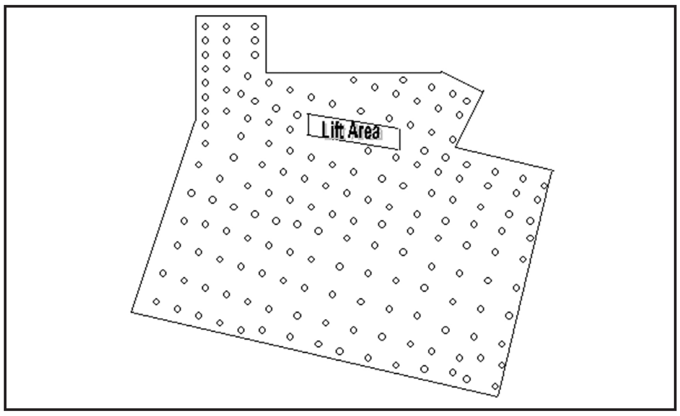

Figure 8: Ground Level Floorplan showing the inner cells placements

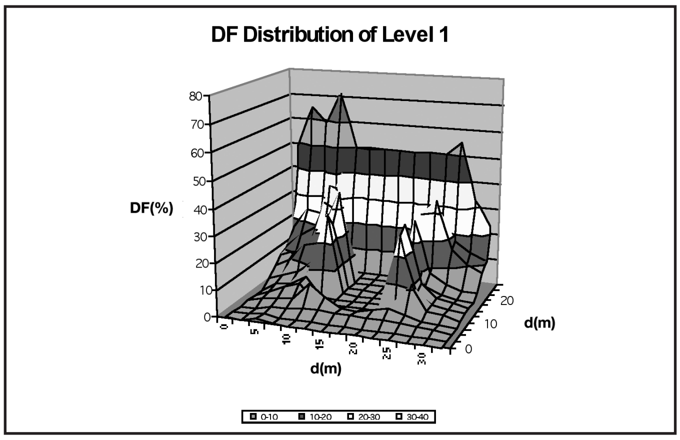

Figure 9: Daylight Factor Distribution on Atrium Level 1

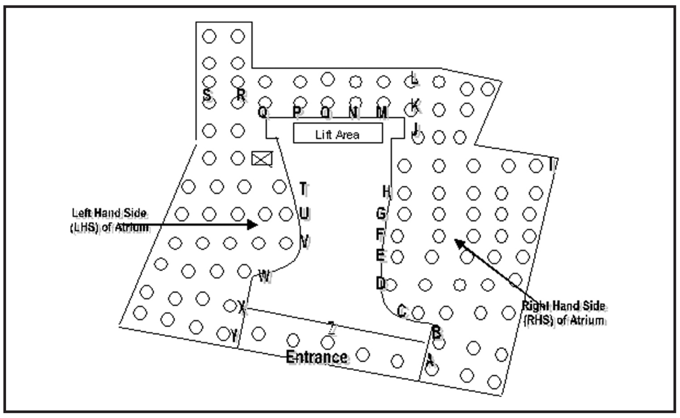

Figure 10: Floor Plan of Levels 1-3 of Atrium

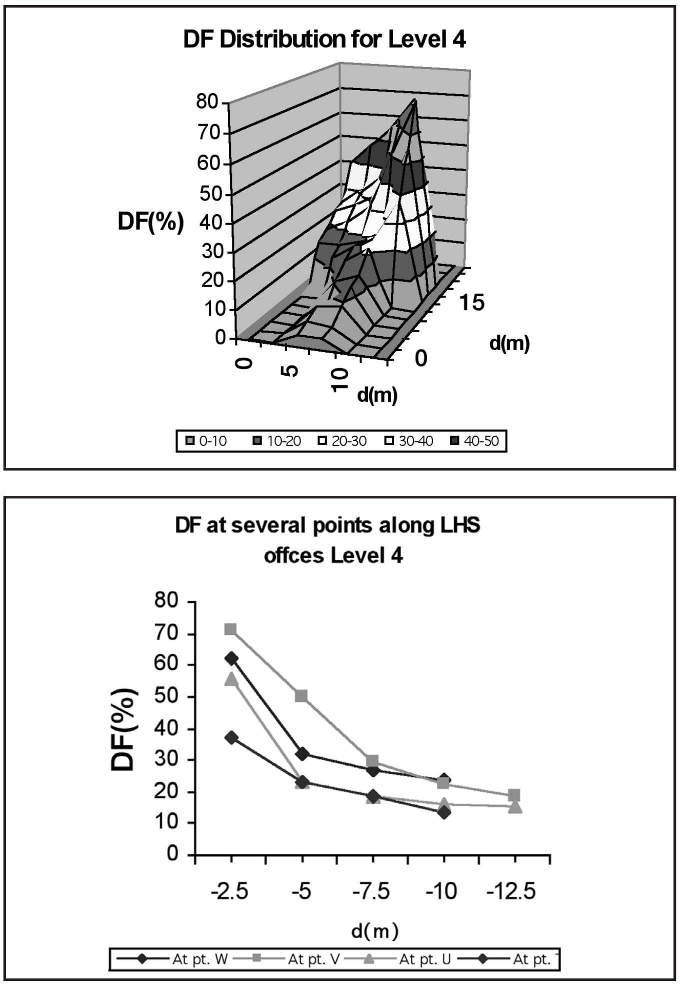

Figure 11: DF Distribution for Level 4 where the atrium ends.

Levels 1-4

Figure 10 shows the floor plan for Levels 1 to 3 of the atrium. The circles indicate the points where interior illuminance were measured. A high and uniform DF of 50% was obtained at the centre of the front entrance at Level 1. Level 1 has an average DF of 26% measured along several points (points A to H; points J,K,M,N,O,P,Q; points T to Y on Fig.10) gradually declining to an average DF of 3% at a distance of 15 m away from the centre of the atrium. The lift lobby area has low DF of between 0-10% on all floors. The front part of the atrium has high and uniform DF of 55% on Level 2. The highest DF of 30% was obtained along the perimeter of the spaces adjacent to the atrium, gradually decreasing to an average DF of 1% as the distance increases to 15.5 m from the centre. The highest DF on Level 3 was 60% while Level 4 recorded a high of 70%. For Levels 3 and 4, the DF was 18% at 15 m away from the atrium. The atrium ends at Level 4. These DF values clearly indicate that the atrium provides more than sufficient daylight for the office spaces even at 15 m deep. The minimum DF for visual comfort in offices is only 2%. Therefore, the lift lobbies receive sufficient daylight even without electric lighting. In absolute terms, the minimum illuminance at the lift area could be 10 lx at 7 a.m. and a maximum of 800 lx at 1 p.m. At the entrance or the front portion of the atrium, the total minimum daylight may be 700 lx and maximum of 56,000 lx. This figure is excessive, but it must be mentioned here that these estimated figures represent bare daylight without any glazing. Excess lighting also means excess solar energy penetrating into the building walls and surfaces and this should be minimised. To avoid glare, "overlighting" and overheating, tinted glazing or shaded windows were suggested for the building.

Atrium's Thermal Performance Analysis

The following gives an overall analysis of the CFD investigations carried out in this study. The results of the simulations predicted that there are no substantial differences with regards to airspeed, temperature and air changes for flue widths 0.85m and 1.0m and for east facing flue wall with and without 150mm of concrete. Stack temperature differences of between 3°C to 7°C was predicted for all cases between the ground floor and the solar flue and this was found to be sufficient to create an air movement of between 0.05 m/s to 0.06 m/s (see Figures 11 and 12) in the occupied spaces of the ground floor below the atrium. It should be noted that an airspeed of 0.01 m/s is sufficient to create some feeling of comfort. Moreover, it should be noted again that this airspeed is predicted for the case where there is no outdoor wind.

The mean temperature in the occupied spaces of the ground floor was found to be either the same or only about 0.1°C to 0.3°C higher than the outdoor temperature, as would be expected for naturally ventilated spaces. This is portrayed in Figures 14 and 15 Thus, if relying only on natural air movement, interior temperatures would be favorable only in the early mornings and late evenings. The presence of wind can increase the interior airspeed but it will not lower the interior temperature.

During cloudy days, the stack temperature difference was predicted to decrease, subsequently decreasing the air change rates (from a range of 8 to 10 ACH to a range of 6 to 8 ACH). Air speed also decreased slightly by 0.01 m/s. This is also the case for the month of December, when the east flue wall is not facing the sun directly but with an insignificant reduction of less than 0.01 m/s. However, for the month of December, simulations predicted that the temperature in the ground floor becomes higher than the outdoor after 12 noon. This is probably due to the glass wall which covers the front of the atrium. In the month of December, this front glass wall becomes a high source of heat entry from the sun. The smoke

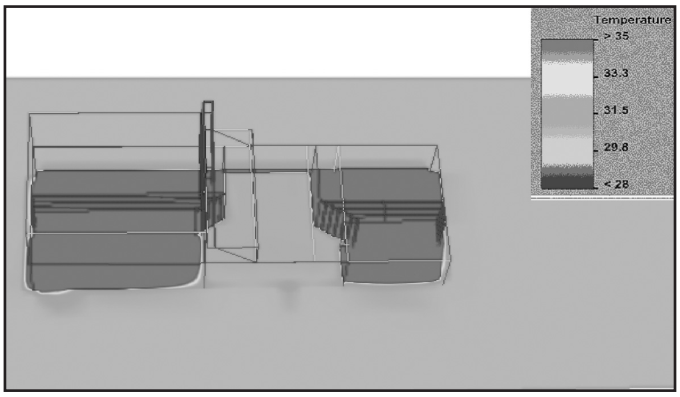

Figure 12: Temperature Distribution : Y Plane

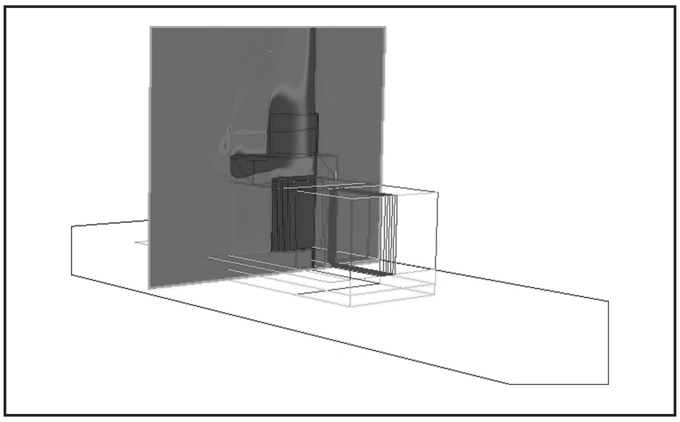

Figure 13: Temperature Distribution : X Plane

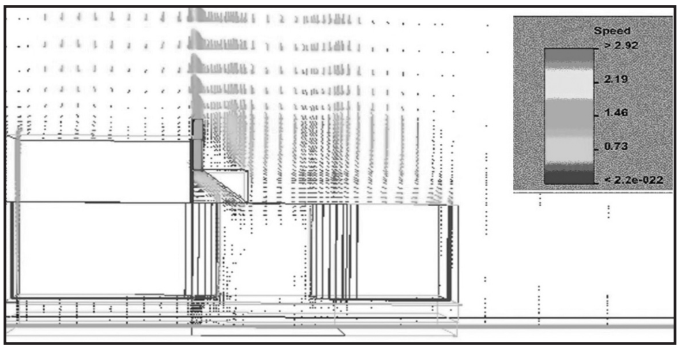

Figure 14 : Velocity Profile : Z Plane

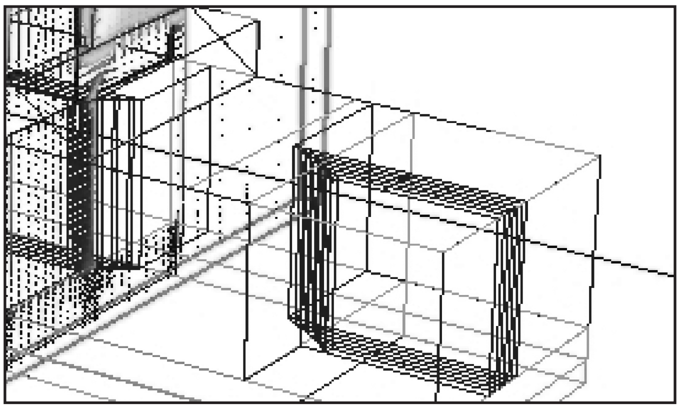

Figure 15 : Velocity Profile : X Plane

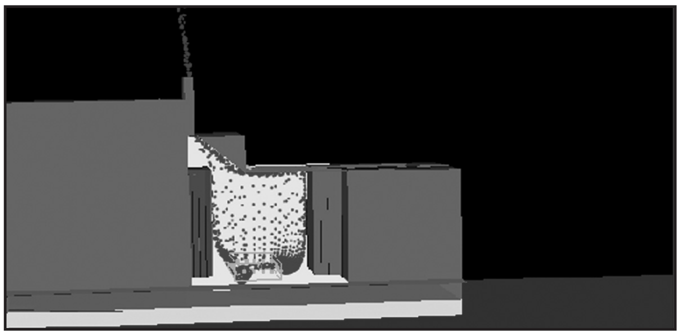

Figure 16 : Smoke Particle Distribution

particle distribution visual in Figure 16 shows that although the airspeed is low, the air movement is well distributed. Figures 11 to 16 are simulation graphics for one particular case i.e. for flue of width 0.85m and with 150 mm layer of concrete wall, clear skies in the hottest month of March at 2:00 pm.

CONCLUSIONS AND RECOMMENDATIONS

This paper has described first and foremost the physical modeling technique to investigate the daylight performance of punch-hole window designs with different types of shading devices. It was found that the window with transparent sunshades has the best DF distribution with respect to open window. The shading elements must be positioned such that daylight is reflected deep into the office building while preventing direct sunlight heating the window. For the punch-hole window design, it is anticipated that there is a shading element (light shelf) in the middle of the window. The light shelf is recommended to have a diffusing white surface, in order to diffuse light into the building through the upper part of the window. The light shelf must have the same depth as the rest of the "punch-hole" shading. However, towards the window, there can be a gap of up to 100 mm. The combination of punch-hole window with shading devices or glazing would accommodate the occupants' request for optimization of the daylight for unobstructed visual from the inside while maintaining minimal heat gain through the windows. The results of this study were used in the design process of the punch-hole windows and their shading devices for the low-energy office MECM building at Putrajaya with the design and build concept. For the LEO Building, two type of window façades are used. The punch-hole window facades in the lower floors, and curtain wall windows with exterior shading louvers in the upper floors. Towards the east, shading is deeper to protect against the low morning sun. The windows constitute 25 – 39 % of the façade area, depending on orientation. The western façade has virtually no windows. The window glazing is a 12mm thick light green tinted glazing.

The results have also shown that the atrium provides adequate natural lighting up to about 10 m away into the office spaces. However, the solar penetration will also bring with it unwanted heat gains. This could be addressed by providing shading without compromising on the lighting needs. It was proposed that shading be provided by using a retractable translucent canvas to reduce sunlight penetration into the atrium and to avoid glare in the adjacent office areas. The canvas should have a high shading coefficient, proposed to be 80-85 %. It is recommended that a solar sensor be placed above the level of the canvas to control the shading device.

The canvas should be pulled when the radiation exceeds 300 – 500 W/m^2 and it shall be pulled back when the radiation is 100 – 200 W/m^2 lower than the adjustable set point. It is also recommended that the use of clear glazing and light-colored interior walls in offices adjacent to the atrium to reduce the brightness ratio with respect to atrium light levels. The structural support systems and glazing frames should be used to create shade and shadow and to reduce the high luminance level "hot spots" on the east-facing wall (entrance) of the atrium.

However, the results of the CFD simulations portray the positive effect of the flue and consequently the success of the building design in providing air movement in the naturally ventilated atrium. Although airspeed is low, but it should be noted that the physical daylight modeling investigations have shown that the atrium provides indoor lighting for the office spaces within the recommended levels. These results indicate that the passive design strategies that are incorporated in this low energy office building are effective. Indoor thermal and visual comfort was not found to be compromised despite the energy minimizing considerations. Apart from these two strategies, landscaping and shading devices will also be included in the building design and this can further enhance the interior climate of the building. As both the recommended indoor temperature range from 23^{o}C to 26^{o}C and the recommended relative humidity 60% - 70% parameters are lower than outside air, full acclimatization is normally required for the working areas, in order to satisfy optimal human comfort and working conditions. In the LEO Building, intake of outside air is controlled according to CO_2 level of the indoor air, and thereby controlled according to the occupancy level. The more people in the building, the more fresh air intake is required for optimum quality of the indoor air.

The importance of the involvement of an energy conscious design team right from the design stage is an important aspect that is overlooked and missing from the current design process. It is hoped that this low energy office building will be an eye opener and example to all involved in the building industry - from the architects, engineers, interior designers right down to the contractors. Cooperation between all is crucial to ensure a proper designed energy efficient and energy conscious building which can reduce or minimize active energy-consuming measures and their associated environmental problems.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Material and Mechanical Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia for the test facilities, the Danish Cooperation for Environmental Development (DANCED) and the Ministry of Energy, Communications and Multimedia, Malaysia and the Institute of Research, Development and Commercialization, Universiti Teknologi MARA for sponsoring this research project.

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MEWC Low Energy Office (LEO) building
(formerly known as MECM LEO Building)
Putrajaya Malaysia

APPENDIX

In September 2004, the Ministry of Energy, Water & Communications (MEWC) have moved to its own 17,800 m2 building in the Federal Government Administrative Capital, Putrajaya, situated between Kuala Lumpur and the new Kuala Lumpur International Airport.

The Government of Malaysia wants their new Ministry of Energy building to be a showcase building for energy efficiency and low environmental impact, and design support from the Danish Agency for Development Assistance – DANIDA (formerly known as DANCED) program was requested and granted. The building shall demonstrate integration of the best energy efficiency measures, optimised towards achieving the overall best cost/effective solution.

Danish experts have since January 2001, in cooperation with Malaysian architects and engineers, optimised the overall design of the building and its energy systems for minimum energy consumption. A computerized design tool was introduced as a key instrument in the optimization of the building design and the design of the energy systems. In August 2002 the detailed design of the building has been finalised, and Putra Perdana Construction Sdn Bhd has started construction.

An ambitious goal was set for the energy efficiency of the building: Energy savings of more than 50% compared to traditional new office buildings in Malaysia should be achieved at an extra construction cost of less than 10%, giving a payback period of the extra investment of less than 10 years.

The cost target of maximum 10% extra costs for the energy efficiency measures have been confirmed through the recent Design and Built tender. The computer modelling using the Energy-10 computer software have predicted more than 50% energy savings. A subsequent energy monitoring follow up program is planned. The energy monitoring during use will add vital credibility to the predictions, that major energy savings and environmental benefits can be achieved in the building sector of Malaysia.

DESIGN AND PERFORMANCE OF THE MECM LEO BUILDING

The new MECM LEO building demonstrates the feasibility of the energy efficiency measures according to the new Malaysian Standard MS 1525:2001 "*Code of Practice on Energy Efficiency and use of Renewable Energy for Non-residential Buildings*". Following this code, the LEO building must have an energy consumption less than 135 kWh/m^{2}year. The predictions are, that the LEO building will have an energy index close to 100 kWh/m2year . This is a very good performance compared to typical new office buildings in Malaysia and the ASEAN region, having an Energy Index of 200 – 300 kWh/m^{2}year.

The energy efficiency measures that are expected to contribute to achieving the goal of an Energy Index of 100 kWh/m^{2}year are :

- Creation of a green environment around and on top of the building.
- Optimisation of building orientation, with preference to south and north facing windows, where solar heat is less than for other orientations.
- Energy efficient space planning.
- A well insulated building facade and building roof.
- Protection of windows from direct sunshine and protection of the roof by a double roof
- Energy efficient cooling system, where the air volume for each building zone is controlled individually according to demand
- Maximise use of diffuse daylight and use of high efficiency lighting, controlled according to daylight availability and occupancy
- Energy Efficient office equipment (less electricity use and less cooling demand)
- Implementation of an Energy Management System, where the performances of the climatic systems are continuously optimised to meet optimal comfort criteria at least energy costs

Site photos as 15th August 2003