THE COMPARISON BETWEEN COMPUTER SIMULATION AND PHYSICAL MODEL IN CALCULATING ILLUMINANCE LEVEL OF ATRIUM BUILDING

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ABSTRACT

This research examines the accuracy of computer programmes to simulate the illuminance level in atrium buildings compare to the measurement of those in physical models. The case was taken in atrium building with 4 types of roof i.e. pitched roof, barrel vault roof, monitor pitched roof (both monitor pitched roof and monitor barrel vault roof), and north light roof (both with north orientation and south orientation). The results show that both methods have agreement and disagreement. They show the same pattern of daylight distribution. In the other side, in terms of daylight factors, computer simulation tends to underestimate calculation compared to physical model measurement, while for average and minimum illumination, it tends to overestimate the calculation.

Keywords: Computer simulation, Physical model, Daylighting, Illuminance, Atrium.

BACKGROUND

Recently computer abilities improve drastically in simulating the performance of building. It presents not only the visual aesthetic of building but also environmental analysis such as daylighting calculations, thermal building performances, acoustics, etc. Many studies have been conducted in order to investigate the behaviour of light and daylight in buildings. One said that computer simulation is a potentially cost effective method to evaluate a large range of design variants i.e. well index, surface reflectivity, etc.

Although research about daylighting prediction with computer simulation has been done for several times, discussions about the accuracy of computer simulation in predicting the daylight level is still questioned. There are many debates about the weaknesses of the computer simulation and the case for and against is not entirely clear (**Mardaljevic, et.al, 1998;11**). Meanwhile, physical models have been accepted as a reliable research tool adequately predicts daylight level are still having tendency to overestimate illuminance level in real building (**Cannon-Brookes,1997**).

As both methods have different weaknesses, it might be better for designer rightly see little to choose in what components or aspects one method is not limited than the other. By making a comparison between two methods for validation, a more reliable result can be achieved.

AIMS

This research is aimed to compare the illuminance levels of atrium building resulting from physical model measurements and those of computer simulations.

TECHNIQUES FOR PREDICTING DAYLIGHT LEVELS

There are three techniques that can be used to predict daylight levels in an atrium i.e. physical scale models, computer simulations, and analytical formulae.

Physical model study has been existed as the best method that adequately predicts illuminance levels in real condition. It is the quickest and simplest method of testing daylight levels in building. Although it seems costly for the initial expense as the model usually be tested under artificial sky, many designers have found it very beneficial to manipulate the components in atrium's daylighting and this is very useful at all stages of the design process. In addition, physical models provide not only daylight level data but also an impression of the effect achieved. In general, there are 3 types of daylighting models to establish the performance characteristics of a design i.e. massing models for studying the building's exterior and the surrounding environment, models for studying the performance characteristics of the building including daylight penetration and distribution, illuminance levels, glare and contrast, and models for studying individual apertures, including glazing, shading devices, and other characteristics of the aperture.

Many advantages can be taken from the use of models in studying daylighting. Models can be constructed for visual observations and aesthetic analysis. Besides that comparisons can be made between modifications of designs. In addition openings and windows area can be changed to test impacts of usable daylight. Illuminance levels resulting from different design schemes can be compiled and used to project energy savings. However limitations of scale models such as difficulties in scaling the materials may result errors in the quantitative measurements. Furthermore no error bands are either proposed or discussed moreover at small-scale models that tend to overestimate illuminance levels in real condition. Model simulations are measured under artificial sky instead of actual sky where conditions can be held constantly. Research conducted by **Cannon-Brookes (1997)** showed that physical models have also weaknesses in presenting the real building performances. It was said that dimensional accuracy, simulation of photometric properties, reflectance, transmittance, dirt and maintenance factors are all factors that effect the accuracy of physical models in presenting illuminance levels inside a building. Fenestration is the most likely cause of error as it is the element of building through which all the illumination reaching the point of measurement must pass. It causes to pay more attention to achieve dimensional accuracy. Besides that factor, it seems that interior may also be a source of error, especially if the models use high reflectance surfaces. In this study, the Externally Reflected Component (ERC) is considered as non-existent while the Internally Reflected Component (IRC) is limited from the roof structures. The very low reflectance internal surfaces of atrium limit the light received by the photocells.

In physical models measurement, there are two evaluation methods that should be considered i.e. photometric and photographic evaluation. Photometric evaluation concerns about the measurement of absolute illuminance in a space. This evaluation requires a number of different light meters which one to measure exterior illuminance continuously and the remaining to measure interior illuminance. With both exterior and interior illuminance measurement, daylight factors can be calculated. In order to measure a pattern of illuminance level inside a model there are:

- A single point measurement, which using only one probe in the model.
- A line measurement, which using a series of probes in a single row. Usually consists of minimum 3 point of measurements either parallel or perpendicular to the aperture
- Grid measurement, which using a series of probes that forms a grid.

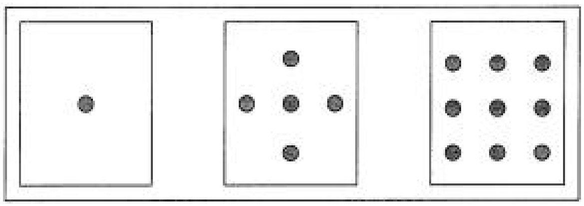


Figure 1. Point, Line, and Grid Measurement Schemes for Lying Out Station Points.

Photographic evaluation provides the record of daylight quality in a model. It concerns about how to take pictures inside a model that correctly present the quality of light in the space. In this, the choice of lenses is important either it is wide-angle lenses range from 21 mm to 28 mm or macro zoom lenses range from 28 mm to 75 mm.

The second technique for predicting daylight levels is computer programme. Computer programme have existed since programmable calculators first became available. Over the years, the computer has been developed well with faster speed, and bigger memory capacity in which offer more possibility for daylighting illuminance evaluation. Several lighting simulation programme such Radiance and Lightscape has been used for years and accepted to be reliable measurement tools. According to **Aizlewood (1997)** some possible sources of simulation errors could be resulted from:

- Geometry errors; the geometry of the computer models may not the same as the geometry of the physical model.
- Sky definition errors; the computer may have a mistake in implementing the CIE overcast sky
- Limitations and bugs in the algorithms
- Inappropriate ambient parameters; computer has ambient parameters, which is set to a

default values automatically. However users may set the parameters

- Errors in the definitions of surface properties, which are set in a computer may not accurately reflect the reflectance of the physical models

Another way to estimate daylight in an atrium are analytical formulae. Analytical formulae also called mathematical modelling offer several advantages over physical models. It allows the design team to make quick analyses of various aperture configurations in order to gauge the sensitivity of a design concept to changes in room shape, aperture size, aperture location, or come other variable. Most of analytical formulae are available in computerized form, allowing fast and inexpensive analyses of a wide range of concepts that would be too time-consuming and costly to build and test properly with physical scale models. It can be used to determine lighting system performance (daylighting plus electric lighting) over an extended period of time – such as a month or a year. This cannot be accomplished with a physical scale models.

However they have also disadvantages such as the simplifying assumptions that allow the analytical formulae to be used as simple manual design tools often limit their usefulness and reduce their accuracy in comparison to actual building performance or to physical models performance. The more advanced and extensive mathematical modelling techniques the more complex to be used manually to analyse a design concept and can only be used readily in some form of computer analysis. All analytical formulae are limited by the number of cases that have been studied. Some analysis of daylighting concepts only can be done with physical models. Above all, many architects, engineers and lighting designers are not comfortable working with complex formulae or an unfamiliar set of algorithms when trying to analyse a daylighting concept.

ATRIUM MODELS

A 1:50-scaled model was used to investigate daylighting performance of atrium building i.e. daylight distribution and illuminance level influenced by its roof design. The model which was made of 12 mm MDF and cardboard, had internal size about 720 mm x 640 mm x 300 mm with a Plan Aspect Ratio (PAR) of 0.3, a Section Aspect Ratio of 1.67 and a Well Index (WI) of 1.09. The internal sides of the model were painted with black matt colour to minimise internal surface reflections (about 2%). In the other side the external walls were painted with white gloss to maximise external surface reflectance (about 85%).

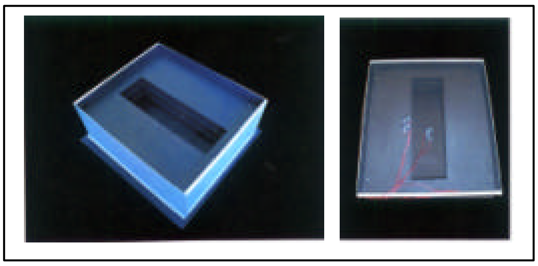
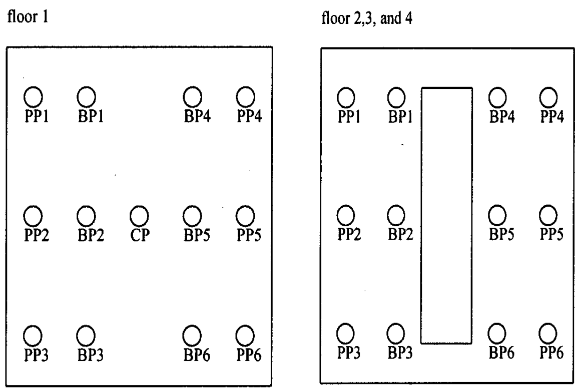


Figure 2. Physical Model of Atrium

It is important to know that the effect of clear glazing was ignored since no benefit in realism could be achieved by using glazing in the model. Maintenance losses, called efficiency factor, which is caused by imperfectly clean surfaces and will reduce reflectance and transmittance have been ignored too. The model was tested under 2x2 m artificial sky and measured using illuminance meter. In every measuring task, two photocells were located side by side in identical positions on each floor. Photocells number 12 and 8 were located on the 1^{st} floor, number 10 and 17 were on the 2^{nd} floor, number 6 and 12 were on the 3^{rd} floor and number 8 and 4 were located on the 4^{h} floor. In each floor, these photocells were placed on 2 main positions called balcony and perimeter position, which were distributed in 12 points of measurement. All points had a distance of 1 meter from either the balcony or the perimeter, and illuminances were measured horizontally about 1 meter above the floor.



PP = perimeter point, BP = balcony point, CP = central point

Figure 3. Cell Position in the Atrium Models

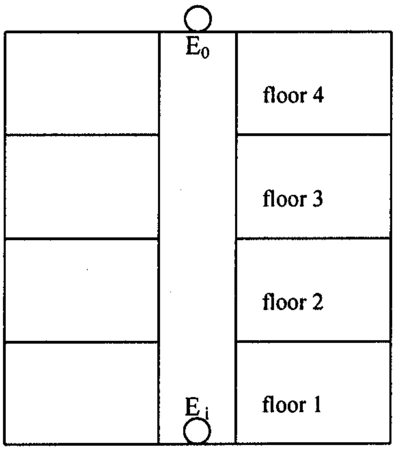


Figure 4. Atrium Model's Section

The types of roof proposed are pitched roof, barrel vault roof, monitor roof (both monitor pitched roof and monitor barrel vault roof), and sawtooth roof.

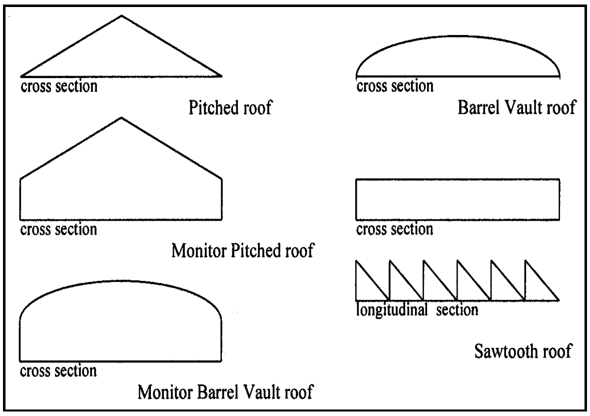


Figure 5. Types of Roof Proposed

COMPUTER MODELS AND SIMULATING

In order to minimize geometry errors, all models of atrium were made in 3D modelling software (read: AutoCAD ver.2000) exactly the same size as the physical models. Although computer software gives possibility to set the materials on the model, this was not done due to the lack of computer software in providing the similar material properties with those of the physical models. In that case, then the material reflectance was set based on the colour reflectance. All black-parts of models was set to 0.02 reflectance reference, and white-parts to 0.85.

For computer models, the materials have reflectance as below :

- Floor reflectance	2%
- Interior walls	2%
- Exterior walls	85%
- Ceiling	2 %
- Roof	85%

The next step was setting the camera in an identical position for each floor.

Camera 1 was placed on the 1st floor at a coordinat:
Origin x = 27.1m y = 9.2m z = 2.95m
Target x = 17.5m y = 40.9m z = 2.95m

Camera 2 was placed on the 2nd floor at a coordinat:
Origin x = 27.1m y = 9.2m z = 6.7m
Target x = 17.5m y = 40.9m z = 6.7m

Camera 3 was placed on the 3rd floor at a coordinat:
Origin x = 27.1m y = 9.2m z = 10.45m
Target x = 17.5m y = 40.9m z = 10.45m

Camera 4 was placed on the 4th floor at a coordinat:
Origin x = 27.1m y = 9.2m z = 14.2m
Target x = 17.5m y = 40.9m z = 14.2m

After the camera and material properties were set, then a lighting simulation programme called Lightscape was used to calculate and simulate daylighting inside the models. The calculation was set for calculating illuminance level in 4 months a year i.e. March, June, September, and December. Daylighting process was set to exterior and interior so that the computer calculates the illuminance both inside and outside of the atrium.

ANALYSIS AND RESULTS OF EXPERIMENT

Results from the physical models measurement and computer simulations are compared based on factors such as Daylight Factors and Distribution of Light within the atrium models including average illumination, minimum and maximum illumination.

Daylight Factors

In terms of Daylight Factors, the physical models show a range from 5.06 % to 30.15 %, whereas computer simulation ranges from 4.19 % to 21.26 % (table 1).

Tabel 1. Daylight Factors for Physical Models and Computer Simulation (%)

	No roof	Roof type 1	Roof type 2	Roof type 3	Roof type 4	Roof type 5	Roof type 6
Physical models	30.15	24.12	5.06	24.81	5.08	6.49	6.43
Computer simulation	21.26	20.20	5.72	19.71	5.69	4.19	4.19

The table shows that calculations from computer simulation are lower than that from physical models. The differences range from 0.61 % to 8.89 %.

Effect of Photocell Positions in Physical Models

The distribution of light across the atrium floors can be deduced from the 12 recording positions, which due to the amount of the atrium floor provided 48 recorded-points of illumination. The position of photocells inside the models gives a great effect to illuminance level both for the balcony position (BP) and perimeter position (PP). Figure 6 and 7 presents the illuminance level influenced by the photocells positions in atrium. For the BP, which consists of 6 points of measurement, it is clear that each position has different level of illuminance. Positions in the middle of the balcony, BP2 and BP5, have the highest level of illuminance among the other positions. It also can be said that the increase of illuminance level for all positions are linear from floor 1 to floor 4.

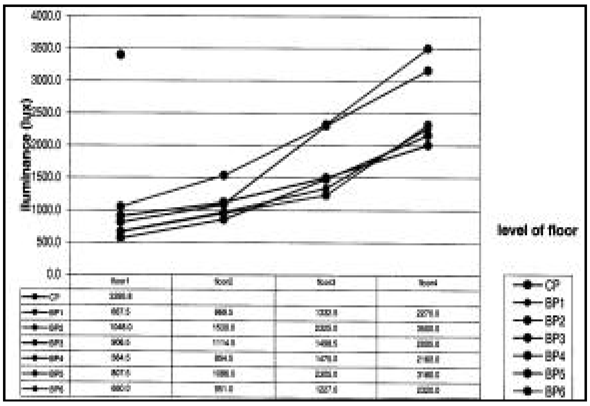


Figure 6. Illuminance Level for Balcony Position

Meanwhile the perimeter position shows slight differences. For PP, the illuminance levels increase constantly only from floor 1 to floor 3, whereas floor 4 has a very high illuminance compare to the three others. The highest illumination for floor 4 are in the middle of the PP shown by PP2 and PP5.

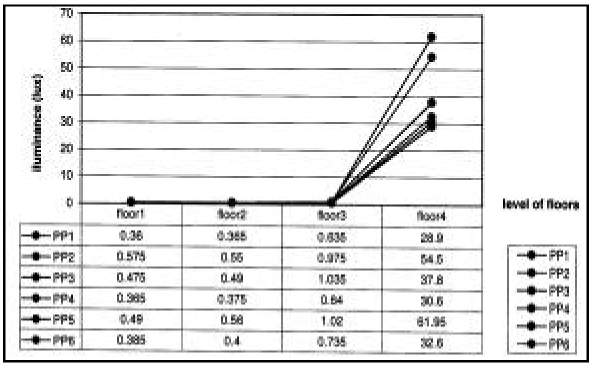


Figure 7. Illuminance Level for Perimeter Position

Effect of Photocell Positions in Computer Simulation

Calculations from computer simulation support those from physical models. It shows that different positions have different illuminance. In computer simulation, the level of illumination is shown by different colours, from dark blue for low illuminance to red for high illumination. From figure 8 it is clear that the further the photocell position from the lightwell, the lower the illuminance level and its colour becomes dark blue. The highest illumination is also shown in the middle of the floor.

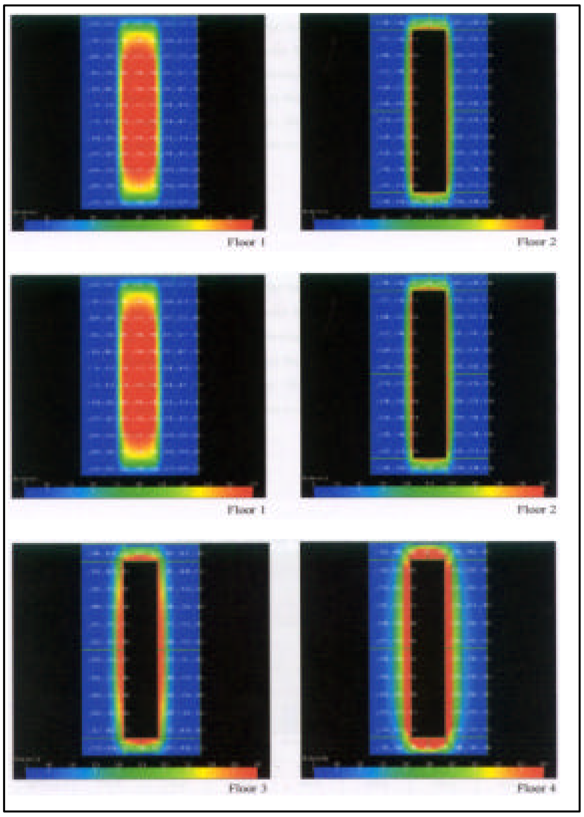
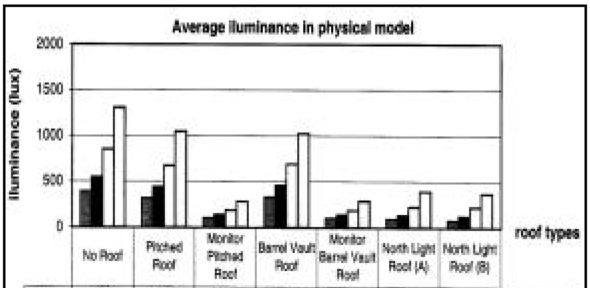


Figure 8. Illumination Across the Floor in Computer Simulations

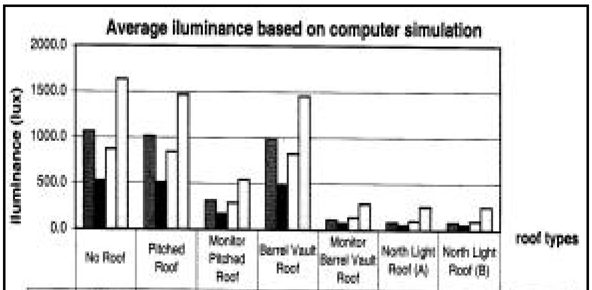
Comparison of Average Illuminance

In terms of average illuminance, results from physical models show the same tendency for all roof types in which the higher the floor, the higher the average illuminance value across the floor (figure9). However results from computer simulations showed differences. The average illumination of the 2nd , 3rd and 4h floor shows a similar increase, but the 1st floor gives a different pattern. The 1t floor has even higher average illumination than floor 2 and 3. This is caused by the way of computer programme in calculating the illumination between floor 1 and the other floors. It seems that the computer programme calculates the average illuminance based on the width of surface area of models. As the 1st floor has wider surface area than floor 2 and floor 3, then it has higher illumination. In this case voids of floor 2 and 3 have been ignored. Comparing the average illumination, it can be said that calculation from computer simulation is slightly higher than that of physical models.



	No Roof	Pitched Roof	Monitor Pitched Roof	Barrel Vault Roof	Monitor Barrel Vault Roof	North Light Roof (A)	North Light Roof (B)
Floor1	388.1	311.2	101.3	324.5	99.8	93.2	78.5
Floor2	542.4	436.9	140.8	454.8	139.6	132.6	123.2
Floor3	847.3	669.9	188.1	689.9	188.9	227.4	221.6
Floor4	1305.1	1044.3	279.7	1020.9	287	388.9	366.2

Figure 9. Average Illuminance in Physical Mode

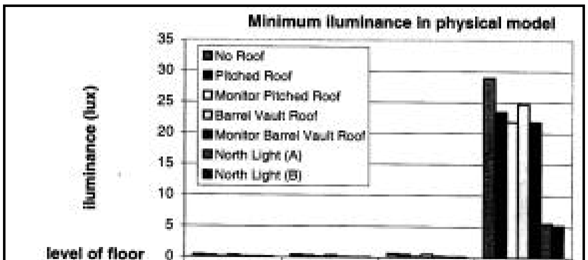


	No Roof	Pitched Roof	Monitor Pitched Roof	Barrel Vault Roof	Monitor Barrel Vault Roof	North Light Roof (A)	North Light Roof (B)
Floor1	1064.5	1009.9	309.6	969.9	107.9	84.1	84.1
Floor2	524.4	508.6	171.7	475.7	75.1	55.3	55.3
Floor3	869.1	841.5	289.3	823.6	135.9	98.6	96.6
Floor4	1636.2	1467.8	538.7	1454.2	284.0	252.7	252.8

Figure 10. Average Illuminance in Computer Simulation

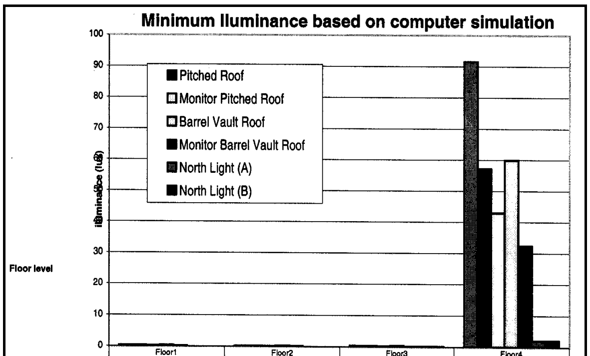
Comparison of Minimum Illuminance

Contribution of daylight to the space adjacent to the atrium varies according to the location of the room within the height of the building. A room located at the atrium floor level is mainly illuminated by light reflected from the floor, whereas a room located near the atrium roof receives most light directly from the sky. This can explain why the minimum illuminance value of floor 4 is much higher compares to the floor 1,2 and 3 as seen in figure 11 and figure 12. Floor 1,2 and 3 received most light from internally reflected light from the surfaces, which in this case have a very low reflectance. As a result most light is absorbed by the surfaces and only a small number was reflected. In the other hand floor 4 received most light from the sky. From figure 11 and figure 12, it can be said that results from physical models and computer simulation both have an agreement.



	Floor1	Floor2	Floor3	Floor4
No Roof	0.36	0.365	0.635	28.9
Pitched Roof	0.295	0.295	0.51	23.45
Monitor Pitched Roof	0.08	0.1	0.195	21.85
Barrel Vault Roof	0.31	0.315	0.54	24.75
Monitor Barrel Vault Roof	0.08	0.11	0.21	21.8
North Light (A)	0.07	0.07	0.125	5.5
North Light (B)	0.06	0.07	0.13	5.2

Figure 11. Minimum Illuminance in Physical Models



	Floor1	Floor2	Floor3	Floor4
No Roof	0.27	0.15	0.25	91.47
Pitched Roof	0.28	0.16	0.25	57.09
Monitor Pitched Roof	0.12	0.09	0.14	42.9
Barrel Vault Roof	0.28	0.18	0.28	59.86
Monitor Barrel Vault Roof	0.05	0.04	0.08	32.29
North Light (A)	0.03	0.03	0.05	1.95
North Light (B)	0.03	0.03	0.05	1.95

Figure 12. Minimum Illuminance in Computer Simulation

CONCLUSION

The comparison and analysis presented above reveale that there are still gaps between the results from physical models and computer simulations. Both physical models and computer simulation have agreement and disagreement in calculating illuminance level across the floor in atrium building. Computer simulation and physical models both show an agreement in distributing of daylight across the atrium floor. However, in terms of daylight factors, computer simulation underestimates the calculation from physical models. In order to make an acceptable comparison between both methods, a modifying factor should be used. Meanwhile for average illuminance, computer simulation slightly overestimate calculation compared to physical models.

Based on what presented above, it is recommended to conduct a further study to investigate factors that cause differentiation between computer simulation and physical models so that it can be minimised.

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