Impact Of Solar Radiation On High-Rise Built Form In Tropical Climate

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Abstract

This study investigates on the impacts of solar radiation towards high-rise building form, orientation and building envelope. High-rise building is exposed to overheating in the tropical climate or equatorial region. For a high-rise built form, vertical surface is most critically exposed to direct solar radiation. The computer program "Ecotect v5.2" was applied to simulate the intensity and distribution pattern of cumulative incident solar radiation on vertical surfaces. The simulation results reveal that south orientation is the most critical part to be protected than others parts. By combining different passive solar design strategies - core position, recessing space and self-shading envelope - intensity of solar radiation striking on the high-rise built form can be reduced up to 40%.

Keywords: Vertical Surface, Orientation, Building Envelope, Insolation.

1.0 INTRODUCTION

Since Malaysia (located at 3.1°N and 101.7°E) is in the tropical region, it is undeniable that we are facing a lot of problems in terms of sun and wind. Unlike the temperate climate, tropical region has summer all the time during the year which gain unnecessary excessive heat. Therefore it is more important to prevent solar radiation from overheating the building surfaces. Due to their height, building envelope of high-rise is exposed to the full impact of external temperatures and global solar radiation than low-rise buildings, which can be shaded by the roof. Therefore it is very important to understand of the influence of incident solar radiation on high-rise building.

This study therefore aims to explore on different passive solar design strategies for high-rise building in tropical climate in order to minimize the intensity of solar radiation that falls on the high-rise built form.

"Ecotect v5.2" environmental design tools [1] is a useful tool for architect to deal with during the preliminary stages of building design, which includes solar exposure, lighting, acoustic and so on.

Operating the "Ecotect v5.2" environmental design tools involve the following procedure:

a. Develop base case models.
b. Investigate the influence of solar radiation on base models.
c. Modify base model and repeat the simulation to investigate the impacts.
d. Repeat previous step until a satisfactory solution is reached.

2.0 METHOD AND BASE MODEL

2.1 ECOTECT 5.2v

"ECOTECT" is a software package with a unique approach to conceptual building design. It couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays. As a conceptual design tools, "ECOTECT" provides its own fast and intuitive modelling interface for generation event the complex building geometry. The model is editable. Tasks such as resizing or inclining walls, manipulating complex curves, rearranging zones, moving apertures or even adding and deleting surfaces are all straightforward.

For this study, "Ecotect v5.2" is used to simulate data for cumulative incident solar radiation on vertical surface on an hourly, daily and monthly basis. Solar insolation is always given as an average daily value in Wh/m². This selector determines the period over which the total daily value is averaged. The months over which the seasons are deemed to span depends upon the current the model latitude, used to differentiate between northern and southern hemisphere.

2.2 Performance Criteria

The main focus for this study is to investigate the intensity of solar radiation striking on external surfaces of high-rise building before it enter into the internal space of the building. In addition to solar exposure values for individual surfaces, it is also possible to display the distribution pattern of cumulative incident solar radiation (insolation) over the surfaces of an entire building. This can be particularly useful when considering the shading requirements on a building or assessing the best areas to place photovoltaic for maximum collection over any period throughout the year.

2.3 Features Of Climatically Interactive High-Rise Building

This study is divided into two main parts, which are the basic analysis of high-rise built form, and possible passive solar design strategies based on the basic analysis. Firstly, a base model is built in order to simulate the impacts of solar radiation towards the built form, orientation and basic form for high-rise building. The physical characteristics of the building are shown in Table 1. Secondly, 3 passive solar design strategies – core position, recessing space and self-shading envelope - have been simulated in order to compare the effectiveness of each strategy on different orientations, basic form and design days.

2.3.1 Base model

a. Built form

In order to compare the total solar radiation on high-rise and medium-rise built form, two blocks with a some scheme form are placed vertically and horizontally each, which are assumed as high-rise building and medium-rise building respectively. Total amount of solar radiation on exposed surfaces will be collected. [refer to Table 1(a)]

b. Orientation

Accordingly, the overall building orientation has an important bearing on reducing the amount of total solar radiation. The amount of indirect radiation falling on a surface is almost independent of surface orientation whereas direct radiation is highly dependant on orientation.

Square form with equal surfaces at four sides is chosen in order to determine the vertical surface that received maximum solar radiation. [refer to Table 1(a)]. There are 4 different wall orientations - north, south, east and west - consist in this study.

c. Basic building shape

Square and rectangular is the regular form for high-rise building in order to achieve net-to-gross area efficiencies, make the construction & structural design as economical as possible and something for aesthetic value. This study the main concern is the influences of solar radiation against different building form.

Four basic forms: square, rectangular, triangular and cylinder with same amount of vertical surfaces area have been chosen. The building shape that received the minimum solar radiation would be chosen for further analysis, Table 1(b).

d. Four-design days

Four-design days (21^{st} Mac, 21^{st} June, 21^{st} Sep. and 21^{st} Dec) have been determined in order to find out the most critical orientation and distribution pattern of solar radiation on vertical surfaces [refer to Table 1(c)]. Based on the analysis from (4.3), cylinder had been chosen as the ideal form in order to minimize the total solar radiation striking on the vertical surface.

Table 1 Base model, which shows the physical characteristics of the high-rise building.

Constant Factor	(a) Built form & orientation	(b) Basic Building Shape	(c) Four-Design Day
Form	Square	Varies (square, rectangular, triangular & cylinder)	Cylinder
Floor area	900 m²	Varies	1046 m²
Total Vertical Surface	12,000 m²	12,000 m²	12,000 m²
Orientation	East, north, West & south	East, north, West & south	East, north, West & south
Floor to floor height	4m	4m	4m
No. of storey	25 storey	25 storey	25 storey
Materials	Solar collector	Solar collector	Solar collector

2.3.2 Design Parameter for passive solar design strategic

a. Core position

Position of service core is important in the design of the tall building. The service core not only has structural ramifications, it also affects the thermal performance of the building and its views. In the tropics, cores should preferably be located on the hottest sides of the building. Cores can provide buffer zones, insulating internal spaces [2].

b. Recessing space

Recessing space provides shade for building. A window can be totally recessed to form a balcony or a small skycourt. Placing the recessing space at on hot elevations permits glazing to these is to be full height clear panels [2].

c. Self shading envelope

Self-shading envelope is generated by building shape in a way the building facades are self-shaded or partial self-protection from solar radiation during a required period to achieve passive cooling for building in tropics [3].

The shading period between 10.00 to 16.00 solar time. The period is limited to the 4 hour around noon so as to avoid very inclined facades. Additional shading devices should be considered to prevent significant solar gains before 10.00 and after 16.00. The required protection angles for east and west elevations are 40^{o} and 45^{o} from the zenith.

3.0 CLIMATE FOR HIGH-RISE BUILDING IN TROPICAL CLIMATE

3.1 Global climatic conditions in Kuala Lumpur, Malaysia

All simulation is calculated based on the Malaysian climate data. The calculated data were obtained from the ECOTECT 5.2v - weather file for, Kuala Lumpur Latitude: 3.12; Longitude: +101.6; Time zone: +8.

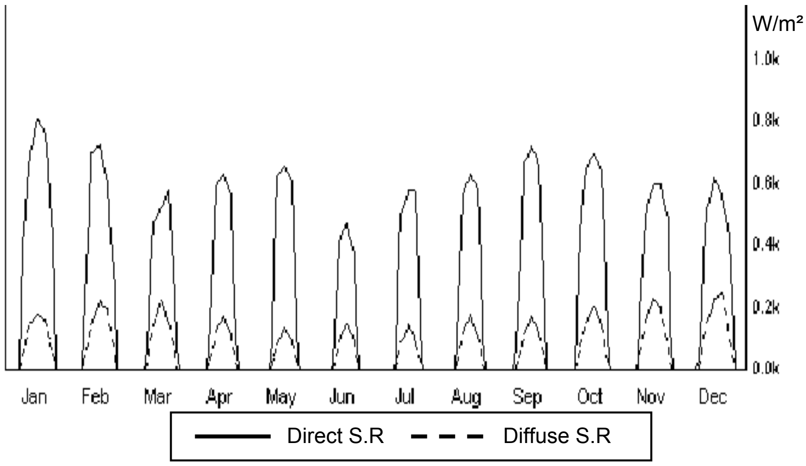
3.1.1 Solar radiation

Characteristics of warm-humid equatorial climate like in Malaysia vary significantly through out the day. This is mainly due to the formation of clouds creating sky patches and resulting in obstruction of the sun. Therefore the solar radiation penetration is not constant and the intensity of the solar radiation from the sky vault is a combination of direct sun, clear sky portion and from the cloudy portion. [4]

The monthly average daily solar radiation in Malaysia is 4000-8000 Wh/m^2 with the monthly average daily sunshine duration ranging from 10 hr to 13.5 hr, (Table 2). Graph 1 shows that high solar radiation occurs more frequently during October to November and January to February, while low solar radiation for May to June.

Table 2 Monthly average daily global solar radiation and solar hours for Kuala Lumpur, Malaysia. (Source: ECOTECT 5.2v - weather)

Month	Solar radiation (Wh/m^2)	Solar hours
Jan.	10146	13.0
Feb.	8821	13.0
Mac	6690	12.0
Apr.	6287	11.0
May	6072	10.5
Jun.	4353	10.0
Jul.	5499	10.8
Aug.	6231	11.0
Sep.	7233	11.5
Oct.	8240	12.3
Nov.	8487	13.9
Dec.	8242	13.7
Avg.	7191.8	11.9



Graph 1 Monthly diurnal averages for solar radiation in Kuala Lumpur, Malaysia. (Source: ECOTECT 5.2v - weather file)

3.1.2 **General climatic data**

Heavy rain, constantly high temperature and relative humidity characterize the Malaysian climate. Generally chances of rain falling in the afternoon or early evening are high compared with that in the morning. The country experiences more than 170 rainy days. Ambient temperature remains uniformly high throughout the year. Average ambient temperatures are between 26.0^{0}C to 30^{0}C with relative humidity of 80-88%, and never falling below 60% [5]. The cloud pattern can be highly variable due to the high humidity and unpredictable weather, especially during the monsoon season.

3.2 **Intensity Of Solar Radiation Striking Vertical Wall Surface**

The position of the sun determines the intensity of solar radiation striking on various surfaces of a building. The amount of solar radiation striking a given surface of a building, wall or roof changes constantly as a result from the changing position of the sun. The diurnal and annual patterns of the sun's motion in the sky depend on the latitude of the location in question (distance, north or south, from the equator).

In the field of architecture and engineering the model adopted in ASHRAE [6] is widely used. The following calculations of the solar radiation on horizontal and vertical surfaces are based on the ASHRAE clear sky model.

3.2.1 Horizontal surfaces

a) Beam (direct) radiation (I_{bh}) is given by

$$I_{bh} = I'_{BN} \cos \theta$$

b) Diffuse radiation (I_{diff}) is given by

$$I_{diff} = C(I'_{BN})$$

Where for horizontal surface C is the diffuse sky factor

c) The total solar radiation (I_t) on horizontal surface is

$$I_{th} = I'_{BN} \cos(\theta_h) C(I'_{BN})$$

The incident angle θ is related to solar altitude (β), surface solar azimuth (γ) and surface tilt angle (ζ).

$\cos(\theta) = \cos\beta\cos\gamma\sin\zeta\sin\beta\cos\zeta$

When the surface is horizontal; $(\zeta) = 0^0$

$$\cos\alpha_h = \sin\beta$$

For vertical surface; $(\zeta) = 90^0$

$$\cos\alpha_v = \cos\beta\cos\gamma$$

Where θ_v is the angle of incidence on vertical surface.

3.3.2 Vertical surface

a) Beam (direct) radiation (I_{bv}) is given by

$$I_{bv} = I'_{BN} \cos(\cos\beta\cos\gamma$$

b) Diffuse sky radiation (I_{diffv}) given by

$$I_{diffv} = C(I'_{BN}) F_{ss}$$

Where F_{ss} is the angle factor between the surface and the sky, is given by

$$F_{ss} = (1+\cos\zeta)/2$$

For vertical surface $\cos(\zeta) = 0$

c) Ground reflected radiation (I_r) given by

$$I_r = I_{t;\theta}\, k_g\, F_{sg}$$

Where $I_{t;\theta}$ is the total horizontal radiation strikes the ground surface ($\theta=0^0$). k_g is reflectance of the ground and F_{sg} is the angle factor between the surface and the sky, is given by

$$F_{sg} = (1-\cos\zeta)/2$$

d) The total global radiation on vertical surface is (I_{tv}) given by

$$I_{tv} = I_{bv} + I_{diffv} + I_r = I'_{BN} \cos(\cos\beta\cos\gamma) + C(I'_{BN}) F_{ss} + I_{t;\theta}\, k_g\, F_{sg}$$

4.0 ANALYSIS OF DISTRIBUTION AND AVAILABILITY OF CUMULATIVE INCIDENT SOLAR RADIATION (INSOLATION) OVER THE VERTICAL SURFACES

4.1 Built Form

Influence of total incident solar radiation on square vertical built form and medium-rise horizontal built form indicated that vertical built form received 14.6% more solar radiation than low-rise building. Further results showed vertically (high-rise) it received 83.6% of total insolation from its vertical surfaces (wall or window) while medium-rise (placed in horizontally) collected 51.9% of total insolation from its horizontal surfaces (roof). For medium-rise building, horizontal surface (roof) should be most critical surface with highest solar exposure. But for high-rise, vertical wall is most critical surfaces to be protected from overheating.

4.2 Orientation

Simulation of the same square built form (high-rise) with orientation zones: east, north, west and south showing that the most critical vertical surfaces to protected from overheating is south surface, followed by east, north and west. South-orientated wall contributes 28.3% of the total insolation received by the vertical surfaces, (Table 3). Due to the tilt of the earth's axis (23.5^{o}), the area receiving the maximum solar radiation moves the north and south. So the most critical building orientation that needs to be protected is the south surface, especially during the tropic Capricorn (winter solstice).

Table 3 Total of insolation on vertical wall for different orientation.

Full year	Average daily total (Wh/m^2)
East	5228
North	3937
West	4471
South	**5384**
Total	19020

Table 4 Total of insolation on vertical wall for different building form.

Basic form	Average daily total (full year)	
	(Wh/m^2)	%
Square	19201	0
Rectangular	18105	5.7%
Cylinder	**11278**	**41.2%**
Triangular	13105	31.7%

4.3 Basic Building Shape

The results show that the cylinder form collected lowest amount of solar radiation while square form received the highest amounts of solar radiation [refer to Table 4]. The cylinder form reduces 41.2% of incident solar radiation compared to the square form. Further in all tested built forms top of the vertical surfaces received more solar radiation than the bottom. Distribution pattern of solar radiation on vertical surfaces is different for different building form. Therefore this indicates that the height of the vertical surface changes with incident solar radiation.

4.4 Four-Design Day

Table 5 shows the total amount of solar radiation on vertical surfaces. The cylinder form is made of 36 similar-sided polygons that looked almost circular from afar. The vertical wall that facing southeast received largest amount of solar radiation during 21st Dec, while the vertical wall facing northwest collected least solar radiation.

Figure 2 shows the combination of distribution pattern of solar radiation on vertical surfaces on the selected design days, most of the south and east wall must be protected of solar exposure. The top two floor of the cylinder high-rise received more than 6000Wh/m^2 while the 3 floors that near to the ground received less than 1500 Wh/m^2.

Table 5 Total of insolation on vertical wall for 4-design day.

Orientation	Average Daily Total Of Insolation (Wh/m^2)			
	21-Mac	21-Jun	21-Sep	21-Dec
East	3316	2556	6337	7363
North	3904	2739	5836	4095
West	3905	1685	3766	5842
South	4578	1561	6503	9611
Total	15703	8541	22442	26911

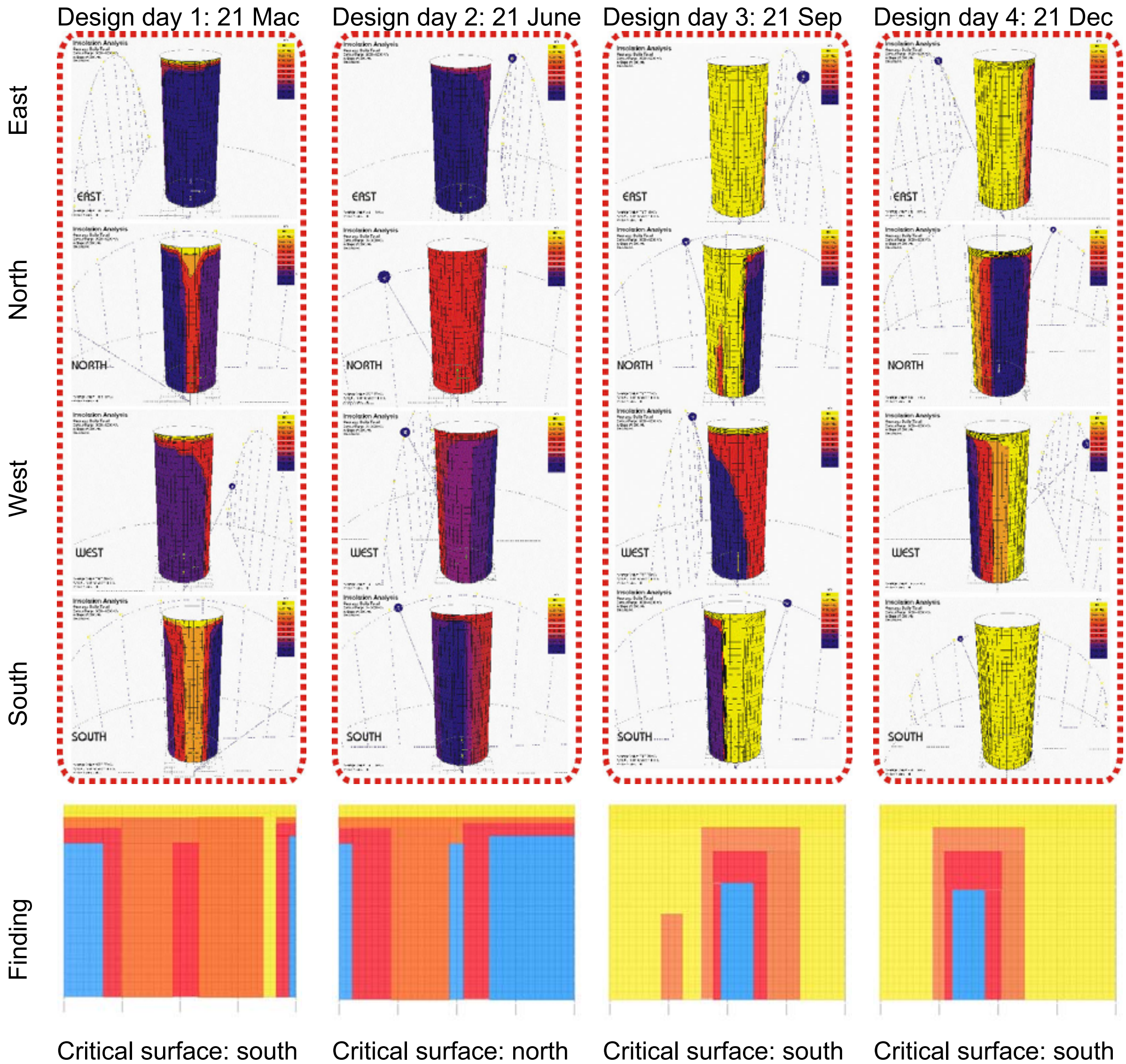


Figure 1 Distribution pattern of solar radiation on high-rise built form based on 4-design day by computer simulation

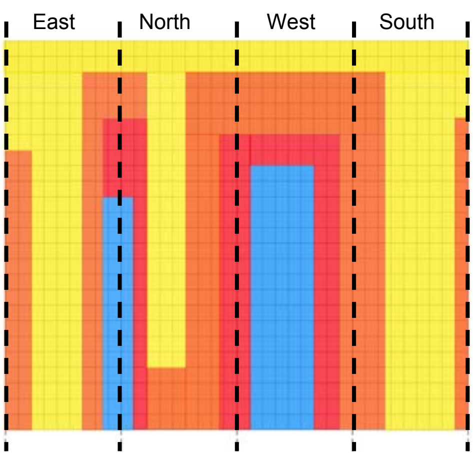
Legends

Most critical area (minimal 2.0 x > S.R)

Critical area (1.5> x>2.0 than average S.R)

Critical area (1.0> x>1.5 than average S.R)

Less critical area (x<1.0 than average S.R)



Legends

Most critical area (minimal 2.0 x > S.R)

Critical area (1.5> x>2.0 than average S.R)

Critical area (1.0> x>1.5 than average S.R)

Less critical area (x<1.0 than average S.R)

Figure 2 Analysis for Distribution pattern of solar radiation on high-rise built form.

5.0 PASSIVE SOLAR DESIGN STRATEGIES

5.1 Core position

The best position of core, which can acts, as buffer zone for high-rise building is south orientation. It reduced the 27% of total solar radiation, followed by the southeast orientation (26%) and east orientation (25%).

5.2 Recessing space

Deep or total recess (vertically) provides shade on the building's facade. Based on the analysis from Figure2, the vertical walls of a cylinder have been recessed by 1.8m for critical area and 3.6m for most critical area (Figure 3). The result showing that recessed space for south and north facades, the total amount of insolation can reduce by 57-60%. This may because of the altitude of sun position which range form 0^o to 66.6^oN / 60.4^oS. By the same recessing space, east and west orientated wall only achieving reduction between 17-36%, table 6(b). Low sun angle caused decreasing the effectiveness of total recess' method at east-west wall.

East North West South

Finding

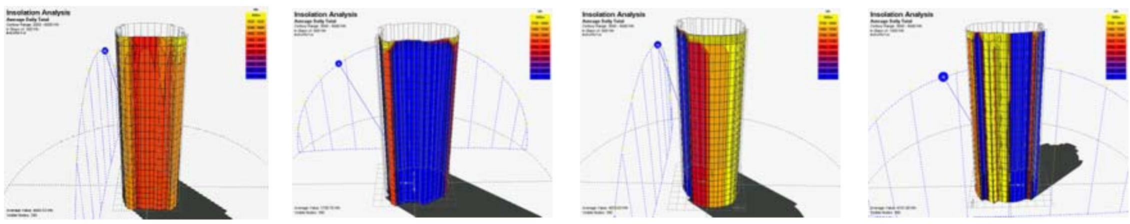


Figure 3 Solar radiation distribution pattern on high-rise built form based on 'recessing space' method.

5.3 Self shading envelope

For high-rise building, the sloped building façade can protect from direct solar radiation but it will cause structural problem. Therefore alternatives provided to reduce the slope of the façade and still can protect the façade from overheating by the noon sun. Table 6(a**)** showing the percentage of reduction of solar radiation on different orientation for self-shading envelope. By this method, amount of solar radiation can be reduced around 40% for all vertical walls. However, east and west orientations are more suitable for applying this method. Figure 4 shows the protection of building by self-shading concept.

Table 6 (a),(b) Passive solar design strategies

	Design day - 21 December				
	Constant factor	(a) Self-shading envelope		(b) Recessing space	
	(Wh/m^2)	(Wh/m^2)	%	(Wh/m^2)	%
East	7363	4541	30%	4682	36%
North	4095	2284	44%	1758	57%
West	5842	3386	40%	4860	17%
South	9611	6180	40%	4151	60%
Total	26911	16391	39%	15451	57%

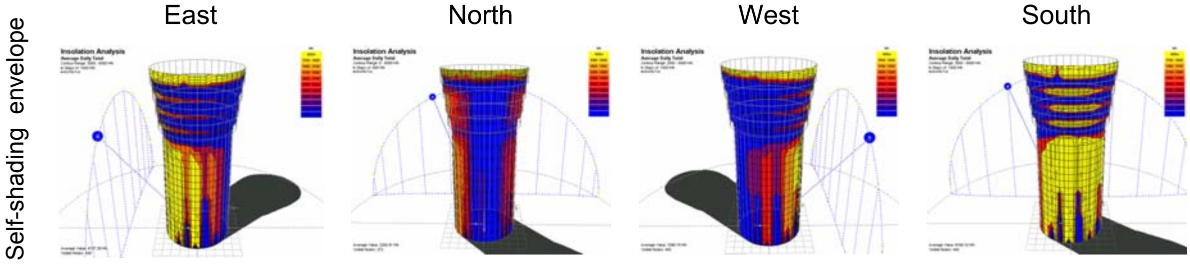


Figure 4 Distribution pattern of solar radiation on high-rise built form based on 'recessing space' method

6.0 CONCLUSION

"Ecotect v5.2" is a useful design tool which provides an accurate and easy way to simulate the level of solar exposure and insolation analysis on vertical surfaces for high-rise built form. For a low energy high-rise building, solar radiation towards vertical surface, orientation, building shape and building envelope are exposed more directly on high-rise building than other buildings. The result of analysis shows the importance of protection for the south-orientated wall, influences of solar radiation distribution pattern towards high-rise building's facade design. These studies allow us to determine how the high-rise built form could be ideally achieved when the solar radiation is taken as the main concern in high-rise building design.

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