Available online at www.sciencedirect.com

SciVerse ScienceDirect

ELSEVIER

Procedia Engineering 21 (2011) 273 – 282

Procedia Engineering

www.elsevier.com/locate/procedia

2011 International Conference on Green Buildings and Sustainable Cities

The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics

Nedhal A. Al-Tamimi[a*], Sharifah Fairuz Syed Fadzil[a]

[a] *School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Minden, Penang, Malaysia*

Abstract

The present study focuses on the effect of shading devices on the indoor temperature of high-rise residential buildings in the hot–humid climate of Malaysia. Several methods can be employed to improve indoor thermal environment, including using a reflective glazing system, using light colors for external surfaces, and using the appropriate thermal properties of external walls and roofs. However, before using any of these methods, it is important to have an optimum shading device to reduce the solar radiation absorption that leads to an overheated indoor environment and an increase in cooling energy loads. Therefore, the main objective of the current paper is to find the extent of a building's solar heat gain and, consequently, the indoor air temperature that is influenced by the external shading devices. A computerized simulation tool (IES<VE>) is used to carry out the investigation, taking Penang as the empirical background of the hot–humid climate. The results indicate that egg-crate shading has a significant impact on decreasing discomfort hours compared with other shading types.

Selection and/or peer-review under responsibility of APAAS

Keywords: Shading Devices; Indoor Environment; Thermal Performance; IES<VE>; Malaysia

1. Introduction

In Malaysia, building surfaces exposed to the sun such as windows, walls, and roofs can admit heat from solar radiation, leading to an increase in the amount of energy needed for cooling purposes. To avoid the inflow of heat, whether direct or indirect, the surfaces on which the sun's rays fall must be protected. Emphasis must be given to shading devices because glazed windows are the main components which allow the penetration of incoming heat and consequently increases the risk of overheating [1].

* Corresponding author. Tel.: +60-12-4499-760; fax: +60-19-4644-393

E-mail addresses: nedhalali.rd08@student.usm.my; nedhalanywhere@yahoo.com

doi:10.1016/j.proeng.2011.11.2015

Therefore, the main objective of the present study is to determine the optimum external shading devices to reduce incoming heat and consequently reduce the risk of overheating which substantially contributes to energy consumption

The design of shading devices can be quite complex because its thermal evaluation demands extensive understanding of the mechanics of the sun's position and sun path diagrams. In tropical climates, however, building designers should keep solar radiation away from the transparent elements of the building's envelope. Figure 1 shows that all facades receive solar radiation from different angles all year round and that each orientation must be designed separately.

Nomenclature

IES<VE>	Integrated Environmental Solutions Virtual Environment software
MMD	Malaysian Meteorological Department
NS	No Shading case
BC	Base Case
VS	Vertical Shading case
HS	Horizontal Shading case
EC	Egg-crate Shading case
NV	Natural Ventilation

2. Previous Studies

Previous studies investigated the effect of shading devices and their impact on daylight quantity and distribution [2–4], energy use [5–7], and human comfort and perception [1, 8]. However, there is a lack of information on their effect on several types of indoor air temperature, especially when considering natural ventilation conditions during daytime and nighttime separately. Corrado reported that the appropriate external shading devices can control the amount of solar radiation admitted into a room, which could largely reduce cooling loads and improve indoor thermal comfort [9]. Each face of a building requires a different shading treatment because sunlight strikes each side from different angles. Exterior systems are typically known to be more effective than interior systems in blocking solar heat gain.

In 2007, Wong and Li [10] studied the effectiveness of window shading devices on cooling energy consumption for east and west windows in Singapore. The study shows that 2.62%–3.24% of the energy cooling load can be saved by applying a simple 30 cm-deep horizontal shading device to the window. When the depth of the window shading device is 60 cm, 5.85%–7.06% of the cooling load could be saved. When the depth of the shading reaches 90 cm, the cooling load of the room is reduced by 8.27%–10.13%. However, Wong and Li's study considered only east and west orientations, and did not take into account other parameters such as the width of the openings, height of the openings, horizontal shadow angle, and vertical shadow angle. The previous study by Yu on a high-rise residential building in Taiwan [11] indicated that envelope shading is the best strategy to decrease cooling energy consumption, which achieved savings of 11.3% on electric consumption.

In Singapore, Wong Nyuk [12] studied the effects of shading devices on temperature. The study shows that horizontal shading devices reduce indoor temperature by 0.61 to 0.88 °C. The vertical shading device reduces the temperature by 0.98 °C in another study by Yang and Hwang [13], who investigated the influences of external shading on energy savings in a Taiwanese building. The study by Yang and Hwang showed that direct air conditioning power consumption readings indicate an average savings of 25% if external shading is properly installed.

On other hand, Tzempelikos and other researchers reported that shading devices can lead to big energy savings when they are applied in combination with the appropriate glass type, enabling them to modify the thermal effect of windows to a great extent [14–15].

3. LOCAL CLIMATE CONDITION OF PENANG, MALAYSIA

Penang is an island located north of Peninsular Malaysia at its west coast. Its local latitude is 5.35o N and its longitude is 100.30o E. The local climate is hot–humid tropical characterized by uniformly high temperatures, high humidity, and abundant rainfall throughout the year. According to the Malaysian Meteorological Department [16], Malaysia has a diurnal temperature range at a minimum of 23–27 oC and a maximum of 30–34 oC. Thus, there is no particular hot or cold season. Annual rainfall is evenly distributed throughout the year, and relative humidity ranges from 74% to 86%, although September to November may be considered the wettest months. Figure 2 shows the maximum, minimum, and average dry bulb temperatures and average relative humidity for the Penang area, where the present case study is located.

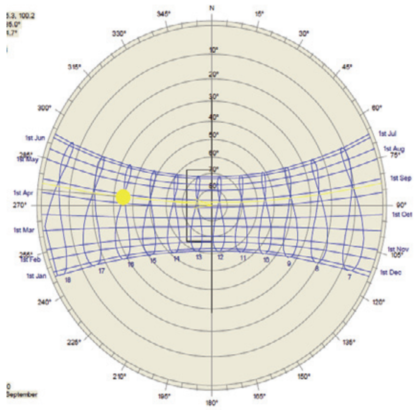


Fig. 1. A stereographic sun path diagram for Georgetown (latitude 5.3°) (Source: Weather Tool Software)

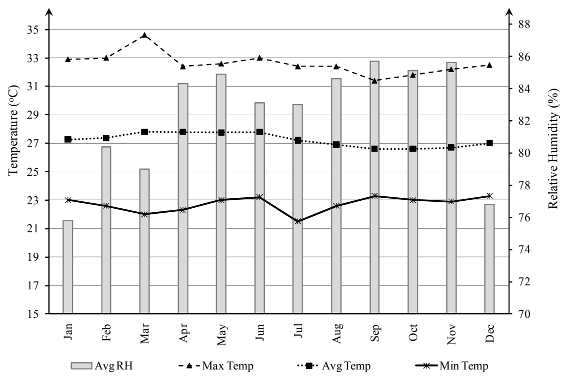


Fig. 2. Max, min, average dry bulb temperature and average relative humidity in Georgetown (Source: Weather Tool Software, average of 30 years data)

According to the 10-Day Agromet Bulletin, MMD [16] showed that some places in Penang have the highest daily solar radiation of more than 6.1 kWh/m2 per day. At present, this energy cannot be explored efficiently, thus creating discomfort and becoming a heat gain problem that needs to be removed from the building space

4. METHODOLOGY

Environmental simulation method is the norm in any research involving building physics [11, 17–19]. For the purpose of investigating the effects of external shading devices on indoor air temperature, the present study used computer modeling techniques that have been widely promoted as an effective and reliable tool to optimize the design process for buildings. However, to carry out successful computerized building simulations, accurate and reasonable input data for the buildings and climate are essential [20].

To enhance accuracy of the simulation, several studies suggested that simulated results must be compared with measured data and several input parameters affecting the simulation discrepancies were tuned [21–22]. This procedure is usually known as the calibration of the simulation model.

To calibrate the building simulation, IES<VE> simulation results were compared with fieldwork data. The methodology was pursued in three phases. The first phase was the data collection from the field. The second phase was the verification and validation process, which included a model of the external shading device similar to the real one used in a residential unit. The results of the field measurement were then compared with those of the simulations. The last stage involved simulating the five proposed models (Figure 3). The width of the various investigated shading devices was fixed at 600 mm, as recommended

Fig. 3. The alternative designs for the three types of shading devices (Source: Author)

by many studies conducted in the tropics, taking into account day lighting and aesthetic considerations, as well as the view angle requirements from the internal spaces [23].

The effect of shading devices on indoor air temperature was investigated annually in terms of the following:

- The min, max, and mean annual air temperatures.
- The number of hours that indoor air temperature recorded annually (365 * 24 hrs = 8760 hrs) was predicted to be below the upper limit of comfortable temperature in Malaysia, i.e., 28.6 ^{o}C

4.1.The base case model

The View condominium (Figure 4) is located at the Gelugor District, Penang, Malaysia. The residential scheme consists of two towers (A and B), each tower 29 stories high with three units on each floor. The two towers are connected by a sky bridge at the 14th floor, and have a total of 164 units each. The floor area of each unit is approximately 184 m^2. The View's residential design was selected for this study because it exemplifies the trend of modern residential design, which has a façade mostly made of glass, in contrast to the energy-efficient building designs in the tropics. To investigate the effects of external shading devices on indoor air temperature, a southwest-oriented room (R1) located in the ninth floor of the tower (A) is selected, as shown in Figure 5.

4.2.Fieldwork

Environmental field data were collected at 10-minute intervals by monitoring the indoor/outdoor temperature, MRT, and air velocity using a data logger, i.e., BABUC/M. A series of continuous environmental data measurements was undertaken in Room R1 for the period between April 7 and 29, 2009. The collected data were used for calibration purposes to ensure the validity and the reliability of the developed simulation model. The data collected were in two different conditions: unventilated (with windows closed) and naturally ventilated (with windows open)

4.3.Thermal modeling tool

Many computational applications have been developed to support the energy and environmental performance of buildings [24]. The thermal performance of the building was investigated using the Integrated Environmental Solutions Virtual Environment software (IES-VEVersion 6.1.0.1), which is a well-established tool for analyzing the dynamic responses of a building based on the hourly input of weather data [25]

Virtual Environment (IES) consists of different modules, and each module performs specific calculations such as “Apachesim” for thermal simulation, “Radiance” for lighting simulation, “Mechanical” for mechanical simulation, and “SunCast” for solar shading analysis. Only three modules of the package were used to carry out the investigation, namely, ModelIT, SunCast, and Apache.

The full building model was constructed as shown in Figure 6. However, to reduce modeling complexity and closely exemplify the base case in high-rise building, with floors above and below, two complete units were modeled for both levels (upper and lower the base case unit).

5. RESULTS AND DISCUSSION

5.1. Calibrating the base case model

Fig. 4. The View residential building, Penang

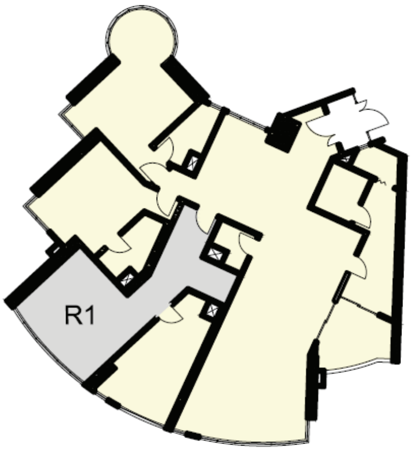


Fig. 5. Typical floor plans of the unit showing the investigated room

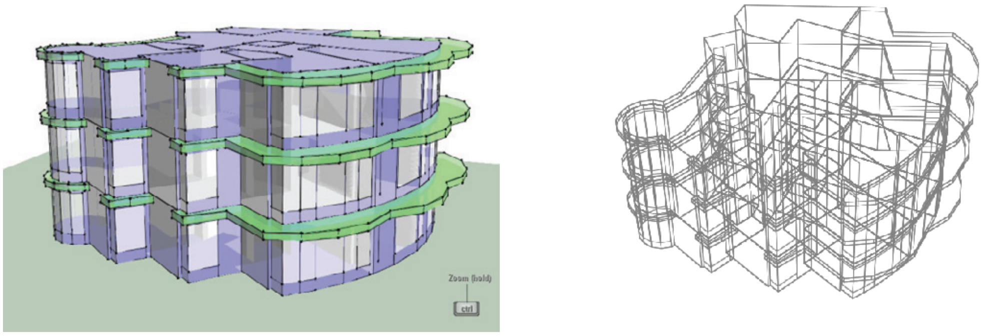


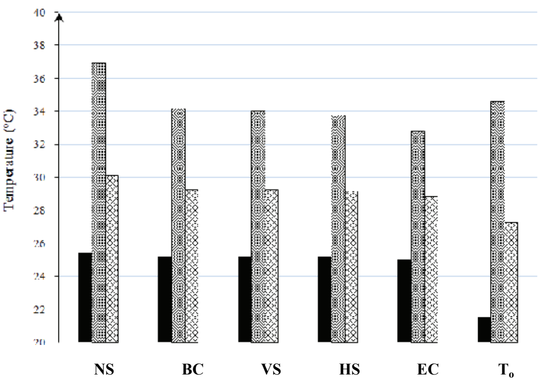
Fig. 6. Base Case Model (3 levels) using IES<VE>

The simulation output was compared with the fieldwork results for the indoor/outdoor temperature pattern for two consecutive days in the selected room (R1) under ventilated and unventilated conditions. Statistical analysis for the present study was carried out between the field measurement readings and the simulation results IES<VE> of the indoor/outdoor air temperature for the room in different ventilation conditions and dates using SPSS v.16. Results showed that the Pearson correlation test between the simulated indoor air temperature (Ti) in the unventilated and ventilated room R1 with the field readings were 93% and 91%, respectively. Thus, the results proved the validity and reliability of IES<VE> for use in further simulations for building envelope modifications.

5.2. Annual thermal performance of varied shading devices

Further simulations to investigate the effect of shading devices, as shown in Figure 3, were carried out under ventilated and unventilated conditions. Simulation output are shown in Figures 7 and 8, which rank the annual effect of varied shading devices on indoor temperature behavior from worst to best. Alternatively, Tables 1 and 2 show the improvement in indoor conditions based on the number of comfort hours in the varied types of shading used in unventilated and ventilated rooms, respectively. Overall, the results showed that in unventilated rooms, the egg crate has a significant impact on reducing indoor air temperature. The results in Figures 7 and 8 show that a maximum reduction of 5.1 and 1.4 oC in indoor temperature could be achieved by adding egg crate shading devices to un-shaded windows in unventilated and ventilated rooms, respectively. However, the average annual reductions of temperature under the same conditions were 1.3 and 0.4 oC in unventilated and ventilated rooms, respectively.

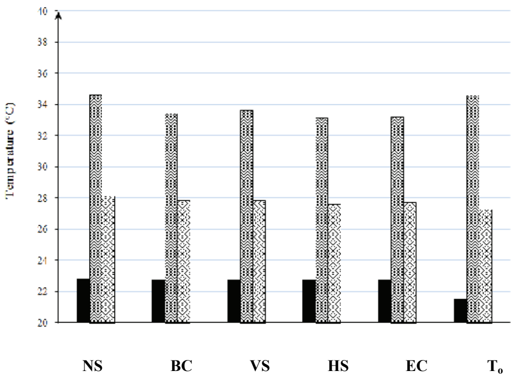
The effect of shading devices may vary during daytime and nighttime. Tables 1 and 2 separate the two distinct periods for comparison, and show the number of comfort hours with the indoor air temperature and the percentages to the total annual hours in unventilated and ventilated rooms, respectively. In an unventilated room, adding egg-crate shading could result in an increase in the number of hours with temperatures less than 28.6 oC from 1821 to 3947 hours, respectively, with an improvement of 117%. In this case, the annual percentage of the full day that To and Ti (in NS and EC cases) were found to be less than Tc were 68%, 20.8%, and 45%, respectively. In the absence of NV, there was not much difference in the percentage of comfort hours achieved by vertical and horizontal shading devices in the annual full day, daytime, or nighttime period. However, the maximum improvement in indoor conditions was achieved using the egg-crate shading type.



	NS	BC	VS	HS	EC	T_o
Min. Val.	25.45	25.17	25.19	25.18	25.04	21.5
Max. Val.	36.93	34.18	34.04	33.78	32.8	34.6
Mean	30.13	29.27	29.26	29.17	28.85	27.28

Max Ti Difference (EC-NS) = (36.93-32.8) = 5.1 °C

Fig. 7. Annual min, max, and mean temperatures with varied shading devices in an unventilated room



	NS	BC	VS	HS	EC	T_o
Min. Val.	22.8	22.75	22.75	22.73	22.73	21.5
Max. Val.	34.61	33.4	33.62	33.14	33.17	34.6
Mean	28.1	27.84	27.83	27.64	27.7	27.28

Max T_i Difference (EC-NS) = (34.61-33.17) = 1.4 °C

Fig. 8. Annual min, max, and mean temperatures with varied shading devices in a ventilated room

Table 1. Annual effect of shading system on improving indoor temperature in an unventilated room

Code	Shading System	Number of Hours < 28.6 ^oC			% hours of T_c/year		
		Full Day	Daytime	Nighttime	Full Day	Daytime	Nighttime
NS	No Shading	1821	683	1138	20.8%	15.6%	26.0%
BC	Base Case	3135	1098	2037	35.8%	25.1%	46.5%
VS	Ver. Shading	3171	1135	2036	36.2%	25.9%	46.5%
HS	Hrz. Shading	3319	1184	2135	37.9%	27.0%	48.7%
EC	Egg Crate	3947	1408	2539	45.1%	32.1%	58.0%
	T_o	5969	2366	3603	68.1%	54.0%	82.3%

Table 2. Annual effect of shading system on improving indoor temperature in a ventilated room
Code Shading System Number of Hours < 28.6 oC (Tc) % hours of Tc/year

Co de	Shading System	Number of Hours < 28.6 ^oC (Tc)			% hours of Tc/year		
		Full Day	Dayti me	Night time	Full Day	Dayti me	Night time
NS	No Shading	5295	1674	3621	60.4 %	38.2 %	82.7 %
BC	Base Case	5619	1850	3769	64.1 %	42.2 %	86.1 %
VS	Ver. Shading	5655	1877	3778	64.6 %	42.9 %	86.3 %
HS	Hrz. Shading	5848	1995	3853	66.8 %	45.5 %	88.0 %
EC	Egg Crate	5868	1949	3919	67.0 %	44.5 %	89.5 %
T_o		5969	2366	3603	68.1 %	54.0 %	82.3 %

On the other hand, in ventilated rooms, little improvement on comfort duration was recorded compared with unventilated rooms. In this case, the results showed no difference in the effect of both egg-crate and horizontal devices on improving the annual number of comfort hours, which were about 66.8% and 67%, respectively. The figures also show the thermal performance of varied shading types during daytime and nighttime separately. The results indicated that the egg crate has a significant impact on decreasing the annual discomfort hours during daytime.

6. Conclusion

External shading devices such as overhangs, louvers, and egg crates should be encouraged as architectural elements to protect building envelopes and occupants from solar radiation in Penang, which has the highest radiation level in Malaysia. Shading devices in both ventilated and unventilated rooms have a significant impact on improving internal thermal conditions. However, egg-crate devices are the best in reducing indoor air temperature and decreasing the number of discomfort hours because of their configuration (i.e., combination of overhangs and fins devices), which avoids solar radiation from varied sun angles. Therefore, comparing the rooms EC with the rooms BC, the improvement in the number of the comfortable hours (i.e., less than 28.6 oC) was found to be 26% and 4.7% in unventilated and ventilated conditions, respectively. Consequently, egg crate has a more positive impact in slowing down the daily solar heat gain in a tropical climate.

Acknowledgment

The authors would like to acknowledge University Science Malaysia (USM) and the Postgraduate Research Grant Scheme No. 1001/PPBGN/843055 for supporting the present research, and IVORY Properties Group representing The View, Penang, for all the assistance and cooperation given.

References

[1]Datta G. Effect of fixed horizontal louver shading devices on thermal perfomance of building by TRNSYS simulation. *Renewable Energy* 2001; **23(3–4):** 497–507.

[2]Dubois MC. I*mpact of Solar Shading Devices on Daylight Quality: Simulations with Radiance.* Division of Energy and Building Design: Lund University, Sweden;2001.

[3]Syed Fadzil SF and SJ Sia. Sunlight control and daylight distribution analysis: the KOMTAR case study. *Building and Environment* 2004: **39(6):**713–717.

[4]Abdulmohsen A. *Visual and Energy performance of Light shelf Daylighting Systems for Office Buildings in a Hot and Arid Climate. Dissertation 1995*, Texas: Texas A&M University.

[5]Datta, G. and A.A.M. Sayigh, A Trnsys Simulation to Study Effect of External Fixed Horizontal Louver Shading Devices on Sizing of Cooling and Heating Systems for Buildings.*World Renewable Energy Congress VI*, Pergamon: Oxford;2000, p. 1796–1799.

[6]Raeissi S. and M Taheri. Optimum overhang dimensions for energy saving. *Building and Environment*1998; **33(5)**: 293–302.

[7]Alzoubi, H.H. and A.H. Al-Zoubi, Assessment of building façade performance in terms of daylighting and the associated energy consumption in architectural spaces: Vertical and horizontal shading devices for southern exposure facades. *Energy Conversion and Management*;**51(8)**:1592–1599.

[8]Bessoudo, M., et al., Indoor thermal environmental conditions near glazed facades with shading devices - Part I: Experiments and building thermal model. *Building and Environment* 2010;**45(11)**: 2506–2516.

[9]Corrado, V., V. Serra, and A. Vosilla. Performance analysis of external shading devices, in *Proceedings of PLEA* 2004. Netherlands;2004.

[10]Wong, N.H. and S. Li, A study of the effectiveness of passive climate control in naturally ventilated residential buildings in Singapore. *Building and Environment* 2007;**42**: 1395–1405.

[11]Yu, J., C. Yang, and L. Tian, Low-energy envelope design of residential building in hot summer and cold winter zone in China. *Energy and Buildings* 2008. **40(8)**: 1536–1546.

[12]Wong Nyuk, H. and D.I. Agustinus. *Effects of External Shading Devices on Daylighting and Natural Ventilation, 8th International IBPSA-2003*. Netherlands;2003 ,p. 475–482.

[13]Yang, K.H. and R.L. Hwang. Energy Conservation of Buildings in Taiwan. *Pattern Recognition* 1995;**28(10):** 1483–1491.

[14]Tzempelikos, A., et al., Indoor thermal environmental conditions near glazed facades with shading devices - Part II: Thermal comfort simulation and impact of glazing and shading properties. *Building and Environment* 2010;**45(11)**: 2517–2525.

[15]Gratia, E. and A. De Herde, The most efficient position of shading devices in a double-skin facade. *Energy and Buildings* 2007; **39(3)**: 364–373.

[16]MMD, Records of Meteorological Data. 2009, Malaysian Metrological Department.

[17]Ji, Y., K.J. Lomas, and M.J. Cook, Hybrid ventilation for low energy building design in south China. *Building and Environment* 2009; **44(11)**: 2245–2255.

[18]Samirah Abdul, R. and K.S. Kannan. *Air flow and thermal comfort simulation studies of wind ventilated classrooms in Malaysia. Renewable Energy*. 8(1-4): p. 264–266.

[19]Chua, K. and S. Chou, Evaluating the performance of shading devices and glazing types to promote energy efficiency of residential buildings. *Building Simulation* 2010; **3(3)**: 181–194.

[20]Guan L. *The Implication of global warming on the energy performance in indoor Thermal environment of Air-Conditioned office buildings in Australia*. Faculty of Built Environment and Engineering. Queensland University of Technology;2006.

[21]Haberl, J.S. and T.E. Bou-Saada, Procedure for calibrating hourly simulation models to measured building energy and environmental data. *Journal of Solar Energy Engineering* 1998. **120(1)**: 193–208.

[22]Sreshthaputra A, J Haberl, and MJ Andrews. Improving building design and operation of a Thai Buddhist temple. *Energy and Buildings* 2004; **36(6):** 481–494.

[23]Liping, W. and W.N. Hien, The impacts of ventilation strategies and facade on indoor thermal environment for naturally ventilated residential buildings in Singapore. *Building and Environment* 2007; **42(12)**: 4006–4015.

[24]Lam, J.C. and D.H.W. Li, An analysis of daylighting and solar heat for cooling-dominated office buildings. *Solar Energy* 1999; **65(4)**: 251–262.

[25]IES<VE>. Integrated environmental solutions <Virtual Environment>. available through: http://www.iesve.com 2010 [cited 13 Dec 2010].