Evaluation on Cooling Energy Load with varied Envelope Design for High-Rise Residential Buildings in Malaysia

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ABSTRACT

With the development of the economy in the recent years, Malaysia is maintaining a high economic growth and therefore, its energy consumption increases dramatically. Residential buildings are characterized by being envelope-load dominated buildings, hence are greatly influenced by the outside climatic conditions. Due to the hot humid climate of Malaysia, air conditioning system accounts for more than 45% of the total electricity used in the residential sector which is required to remove substantial amount of gained heat due to poor thermal envelope performance. This paper uses Ecotect software to analyze the impact of building envelope design on energy cooling load for residential building in Penang, Malaysia, which include area ratio of window to floor, exterior wall thermal insulation, and several kinds of shading system. This paper describes an integrated passive design approach to reduce the cooling requirement for high-rise apartments through an improved building envelope design. Comparing with the other passive strategies investigated in this paper, the results indicated that exterior wall thermal insulation is the best strategy to decrease both annual cooling energy load and peak cooling load which achieved a reduction of 10.2% and 26.3% respectively. However, the other passive strategies applied also have some marginal effect on decreasing the cooling load.

Keywords: *Energy efficiency; envelope Design; Residential building; Malaysia; Ecotect*

INTRODUCTION

Buildings, energy and the environment are key issues facing the building fraternity worldwide. With the increasing population and living standards, energy issue is becoming more and more important today because of a possible energy shortage in the future (Yilmaz 2007). In Malaysia, there is a growing concern about energy consumption, and its climate doesn't offer sufficient climate conditions to ensure thermal comfort all the year. However, electricity generation in 2006 was 96,000 GWh, which represents an increase of 328% from 22,400 GWh in 1990 (EIA 2009) This means Malaysia has a strong need and great potential to apply energy efficient strategies in lowering energy consumption in buildings.

Worldwide, the Worldwatch Institute estimated that buildings consume at least 40% of the world energy and 16% of the water used annually (Roodman and Lenssen 2005). Hence, energy growth in developing countries has been realized recently due to major developments in several sectors such as residential, commercial, and industrial and transportation. Commercial and residential buildings alone account for about 13.6% of total energy consumption and 48% of electricity consumption (Al-Mofleh, Taib et al. 2009). According to the Ninth Malaysia Plan, energy conservation culture must be inculcated. Buildings should be designed to optimise energy usage. Such resources need to be prudently and carefully utilised. The Malaysian government is adopting measures to reduce wastage by enhancing energy efficient buildings and increasing energy sufficiency (9th-Malaysia-Plan 2006). On this guideline, the government launched the National Green Technology Policy in August 2009. The objective of the policy is to provide direction towards management of sustainable environment. Moreover the 2010 budget earmarks 1.5 billion Malaysian Ringgit to promote green technology. Therefore, reducing energy use for space cooling in buildings is a key measure to energy conservation and environmental protection in Malaysia. It has also been reported that more than 40% of the energy consumed by Malaysian buildings can be reduced if energy efficiency is practiced and sustainable technologies are applied to building envelope (Azni Zain 2008). On other hand, the MS 1525 (MS_1525 2007) which is the Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings was developed as a guide for energy efficient measures in Malaysian buildings. The Malaysian standard also emphasized that passive method should be utilized before going to active method.

This paper describes an investigation of the effect of three passive design strategies, namely, window size, thermal insulation, and external shading devices on both the annual cooling load and peak cooling load on a high-rise apartment building in Malaysia. A general overview of the climate in Malaysia is given followed by reviews on previous research into the use of passive design strategies on high-rise buildings in hot-humid climate. The model used to simulate the passive strategies is then described, followed by the results and conclusions of the investigation.

LOCAL CLIMATE CONDITION OF PENANG, MALAYSIA

Penang is an island located North of Peninsular Malaysia at its west coast. Its local latitude is 5.35°N and longitude is 100.30°E. The local climate is the hot humid tropical characterized by a uniformly high temperatures, high humidity and abundant rainfall throughout the year. According to Malaysian Meterological Department (MMD 2009) Malaysia has a diurnal temperature range of minimum 23–27 °C and maximum 30–34°C thus, there is no particular hot or cold seasons. The annual rainfall is evenly distributed throughout the year, the relative humidity ranges from 74–86% although September to November may be considered the wettest months. On the other hand, according to 10-Day Agromet Bulletin, (MMD 2009) showed that, some places in Penang has the highest daily solar radiation of more than 6.1 kWh/ m^2 per day. Since at present, this energy cannot be explored efficiently, it creates discomfort and becomes a heat gain problem that needs to be extracted from the building space.

PREVIOUS ENERGY EFFICIENT STUDIES IN HOT-HUMID CLIMATE

There are few similar studies on energy efficient building and its thermal performance in Malaysia. The majority of these studies were focused in non residential buildings, such as offices, hotels etc, and few of those studies considered residential sector. (Saidur, Sattar et al. 2007; Daghigh, Adam et al. 2009; Saidur 2009). Unfortunately, new building envelope designs are developed to meet the client's requirements without much concern to the local climate and with no intention to conserve energy. This has undoubtedly disregarded the climate as a design determinant in building envelope design. As a result, these have contributed to an overall poor thermal performance of the buildings which became more dependent on artificial means to provide comfortable thermal environment at high energy consumption. There is only a limited amount of literature and research on energy-efficient apartment building design in hot and humid climates. The majority of these limited researches are found to be from Hong Kong, Taiwan and Singapore, but very limited in Malaysia. An analysis of the building energy consumption in Hong Kong (Lam and Li 1999) showed that the building envelope design accounts for 36.7% of the peak cooling load, which is directly related to building design which is the responsibility of architects and engineers. The remaining percentage is related to building operation, which is the owners and operators responsibility.

Cheung had conducted a study to reduce the cooling energy for high-rise apartments through an improved building envelope design (Cheung, Fuller et al. 2005). This study showed that annual cooling has an almost linear relationship to the solar absorptance which is the amount of solar energy that passes into a material of the building envelope. A 30% reduction in solar absorptance can achieve a 12% saving in required cooling energy. Al-Mofeez reported a study on energy saving from retrofitting a one-story house located in Dhahran, Saudi Arabia, which is in hot humid climate (Al-Mofeez 2007). The study shows that savings in electrical consumption due to building envelope reached 40.3% on average and 34.3% in peak months. (Bojic and Yik 2005) studied the dependence of space cooling loads of Hong Kong residential flats on the constructions of external and internal walls, and the location of thermal insulation layer in the walls and partitions using detailed simulation. The results show that insulating the envelope and the partitions would be effective in reducing the yearly space cooling load, by up to 38%, and could reduce by up to 16% the peak cooling demand, depending on the number and positions of insulation layers in the walls. Another study reported by (Yang and Hwang 1995) on the effect of external shading devices on cooling load under Taiwan climate. The results showed an annual savings of 12% of the cooling load can be experienced if external shading is properly installed. However, the study aims to make comparison between shading devices and thermal insulation effectiveness.

A study by (Yu, Yang et al. 2008) has been conducted to investigate the effects of building envelope components on cooling energy load in high-rise apartment in hot summer and cold winter zone of China. The results indicate that envelope shading and exterior wall thermal insulation are the best strategies to decrease the cooling energy which achieved a saving of 11.3% and 11.5%. Generally speaking, previous studies have focused only on either a particular envelope component in a generic building or on the overall effect of the whole envelope. There is a lack of comparative study of the relative efficiency and impact of passive design strategies.

METHODOLOGY

In this paper, the effect of the various passive and energy efficient design strategies on the cooling energy requirement have been evaluated for the main bedroom R1 from a high rise residential building called “The View” which is located in Penang, Malaysia. R1 now will be called the BASECASE model. Two variables were selected to represent the cooling energy, namely annual cooling load and peak load of the cooling system. Annual cooling load is defined as the output from the cooling system rather than the actual amount of energy consumed by the cooling system and the peak cooling load is defined as the maximum amount of heat that must be removed from a conditioned space in any single hour over the year to maintain a constant and comfortable temperature for its occupants (Cheung, Fuller et al. 2005). Three passive thermal design strategies were identified, namely, window to floor area ratio, thermal insulation for external walls, and shading devices.

The BASECASE Model

The View (Twin Towers) condominium Figure 1. is located in Penang Malaysia at Gelugor district. The residential scheme consists of two towers (A, B) each 29-storey high with three units on each floor. The two towers are connected by a sky-bridge at the fourteenth floor and both towers have a total of 164 units. The View has been developed and constructed by Ivory Properties Group, which completed the project construction in 2007. Due to the site considerations such as Penang Bridge and the sea view, the building has been oriented to southeast i.e. tower A, and northeast i.e. tower B. The floor area of each unit is approximate of 184 m^2. The view residential design is selected as it exemplifies the trend of modern residential design which has mostly glass façade that can be contradictory to energy efficient building design in the tropics. The extend of energy saving using the three strategies can be compared to the basecase model which is also oriented to the south- west direction which is considered as a worst case orientation scenario in the tropics (Fairuz Syed Fadzil and Sia 2004). For the purpose of cooling load investigation a south west oriented room (R1) is selected as shown in figure 1. The total floor area of the R1 is 28.3 m^2.

The Simulation Tool ECOTECT

Many computational applications have been developed to support the energy and environmental performance of buildings (Mahdavi and El-Bellahy 2005). Ecotect program is a building design and environmental analysis tool that covers a broad range of simulation and analysis functions required to understand how a building design will operate and perform (Ecotect 2009). Ecotect allows designers to work easily in 3D and to apply tools necessary for an energy efficient and sustainable future. It is an environmental design tool which includes an intuitive 3-dimensional modeling interface with extensive performance analysis functions covering shading, thermal, lighting, acoustic, energy, resource use and cost aspects. Ecotect provides performance analysis which is simple, accurate, interactive and visually responsive (Crawley, Hand et al. 2008). Thus, Ecotect is appropriate tool for energy performance assessment and suitable for the present case study to simulate the cooling load energy of the R1 which has two external walls.

Building Envelope Modification Approach

The three passive design approaches investigated and simulated in this paper are as follows:

Window to floor area ratio (WFR):

The effect of increasing south-west and north-west area ratio of window to floor area of the main bedroom R1 from 30% as a BASECASE to the minimum area allowed by the Malaysian Uniform Building By Law UBBL i.e. 10%, and to the

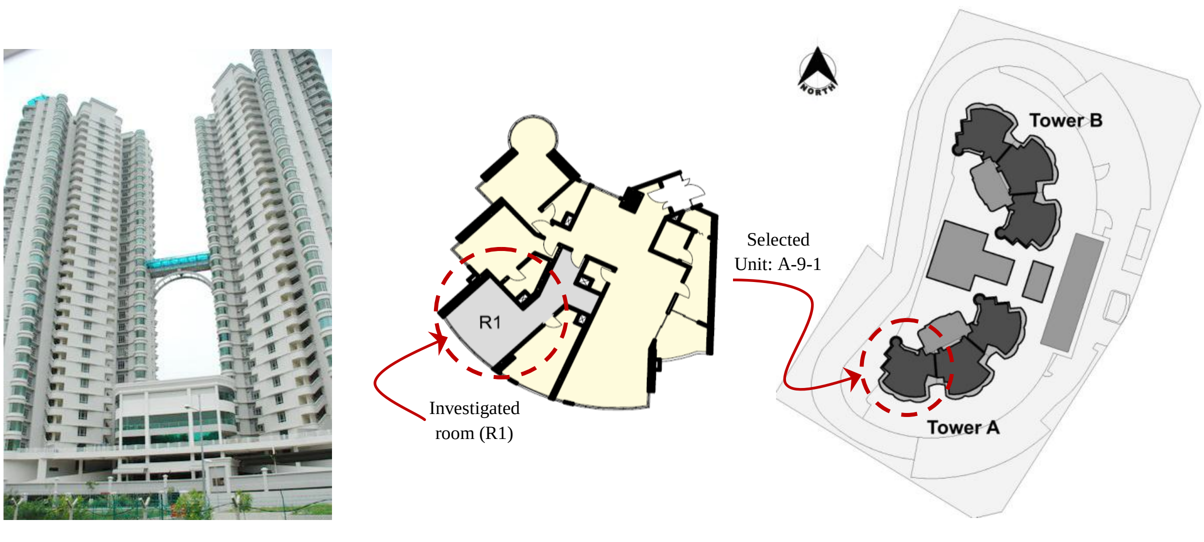


Figure 1. The View (elevation, typical floor plan of the units showed the investigated room), Penang

maximum area allowable on the two directions of the room façade i.e. 80% in steps of 10% as shown in figure 2. are investigated.

Thermal insulated walls:

Thermal insulation material such as extruded polystyrene (EPS) has been developed in the recent year to be widely used in new building for energy efficient building design requirements (Yu, Yang et al. 2008). The external wall layers, dimensions and their characteristic used for simulation are shown in table 1. The effect of insulation on cooling load is evaluated by increasing the thickness of EPS in steps of 25mm to a maximum thickness of 100mm.

External shading devices:

External shading type in this paper was egg crate shading (i.e. overhangs and fins). The length of both horizontal overhang and vertical fins was varied from 0mm (No Shading) to 120mm as a maximum in steps of 30mm as shown in figure 3.

The Occupied Schedule

The BASECASE unit was assumed to be occupied by two persons. The room also assumed to be fully air conditioned from 10 p.m. to 7 a.m. from Monday to Friday and from 11 p.m. – 9 a.m. in weekends. The set zone of spaces thermal comfort was set accordance to MS-1525 as (18^{o}C – 26^{o}C dry bulb temperature and 60% of relative humidity) with a minimum rate of air change per hour during occupied period.

The unit also assumed to be naturally ventilated during unoccupied daytime hours. The energy output data of the R1 is presented in this paper, which is assumed to be reflected the overall scenario of the whole building. The weather file of Georgetown, Penang has also been selected for evaluation through simulation process.

RESULTS AND DISCUSSIONS

Area Ratio of Window to Floor (WFR)

The curve of annual cooling load as well as the peak cooling are shown in figure 4. With the increase of south-west area ratio of window to floor, the cooling load is increased linearly from WFR 10% to 40%. The increased in the cooling load in this period is 1.3% in each 10% increment in WFR. The jump in the cooling load occurred when WFR increased from 40% to 50% to reach 8% of the room's cooling load. This sudden increase happened because of the new opening in the other direction of the room façade i.e. north-west window. Consequently, increases of the cooling load rises smoothly to reach 1.1% with every increment in WFR. On the other hand, the peak cooling load is increased linearly when WFR is increased. The results showed that, the annual cooling load and the peak cooling of the BASECASE room with WFR 30% can be minimized to 2.7% and 31.3% respectively by decreasing the windows area ratio WFR to 10%.

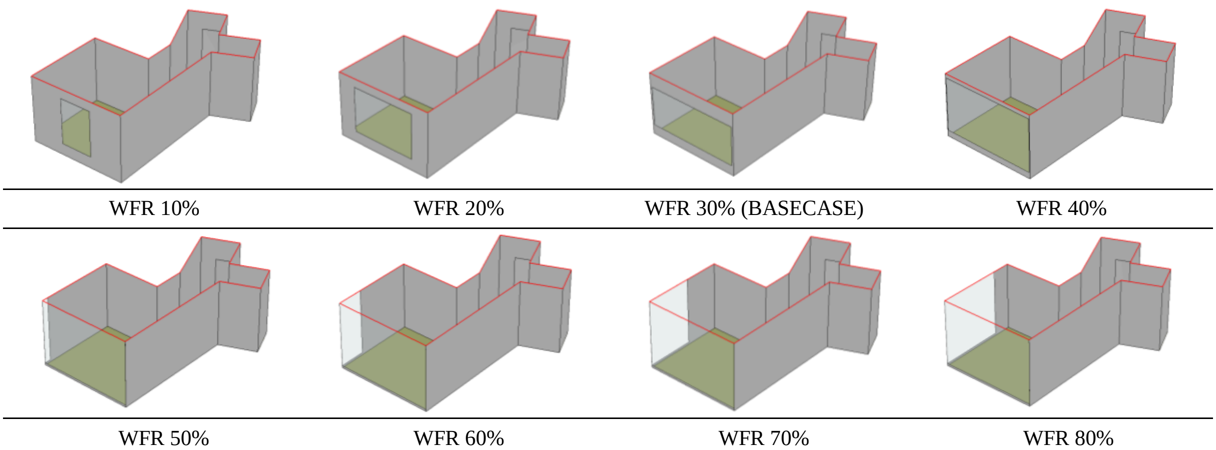
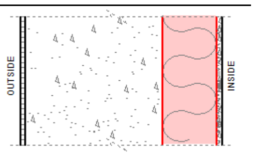


Figure 2. Steps of change WFR in the external façade of R1

Table 1. External wall composition with insulation inside

Layer description	Thickness (mm)	Density (Kg/m^3)	Specific heat (KJ/Kg.K)	Thermal conductivity (W/m.K)	Figure
Cement/Sand Plaster	10	1250	1.09	0.72	
Reinforced Concrete	250	1600	6.57	1.44	
ESP insulation	25 – 100	28.8	1.21	0.03	
Plaster/Cement board	10	950	0.84	0.17	

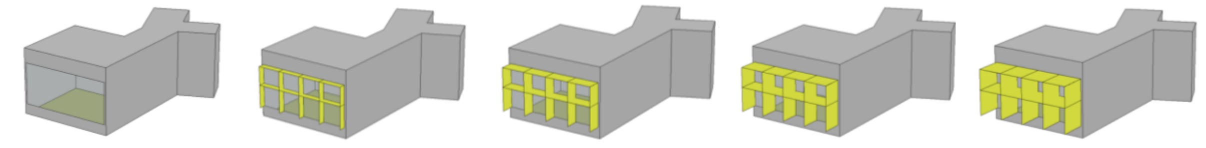


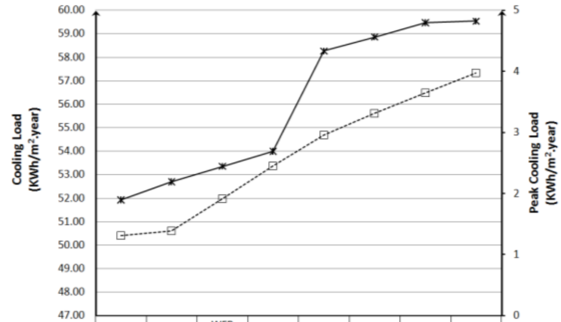
Fig.3. Steps of change shading devices length of R1

Exterior Wall Thermal Insulation

The introduction of thermal insulation can effectively reduce both the annual energy cooling and peak load of the cooling system. As shown in figure 5, the introduction of 25mm thick insulation on the inside reinforced concrete produces a reduction of 8.5% and 20.5% in the annual cooling load and peak load respectively. Changing the thermal insulation of the external wall from 25mm to 50mm reduces the annual cooling load and peak load by 1.2% and 4.1% respectively. It can be seen that, the thicker the insulation the greater reduction in both annual cooling energy and peak cooling load. However, the results showed that, using thermal insulation thicker than 50mm is not economical as the effectiveness of the extra insulation is found to be stagnant.

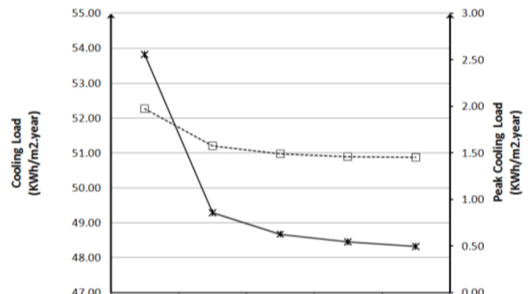
Shading System

A shading device cuts part of the solar heat gain so that the total heat flow is actually reduced, not only delayed. In hot and humid areas, the solar gain constitutes a major portion of the perimeter zone air-conditioning (AC) load of a building (Yang and Hwang 1995). The effect of shading system on annual cooling energy requirement and on peak cooling load are shown in figure 6. The simulation results indicate that the longer the shading the greater reduction in both annual cooling load and peak cooling load. The minimum effect was with lower shading length of 30cm which recorded a saving in annual cooling load about 1.2%, this cooling load reduction has been increased by almost double using shading length of 60cm to reach about 2.34%. The results also indicated that use of shading devices with a length more than 60cm is not economical as the effectiveness of the extending shading length starts to stagnate. The reduction of annual cooling load for 90cm and 120cm shading length was 2.47% and 2.56% respectively. Besides that, the maximum reduction in the peak cooling load occurs was 22.15% with a maximum length of shading devices of 120cm.



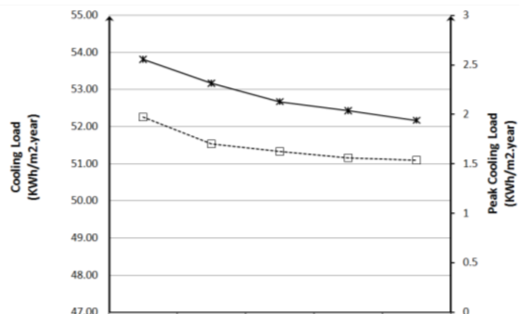
	WFR 10%	WFR 20%	WFR 30% (Basecase)	WFR 40%	WFR 50%	WFR 60%	WFR 70%	WFR 80%
Cooling Load	51.92	52.69	53.36	54.00	58.26	58.86	59.47	59.53
Peak cooling	1.315	1.386	1.914	2.45	2.959	3.314	3.644	3.975

Figure 4. Annual required cooling energy and peak load for various area ratio of window to floor



	BASECASE no insulation	25mm insulation	50mm insulation	75mm insulation	100mm insulation
Cooling Load	53.821	49.284	48.675	48.461	48.33
Peak cooling	1.97	1.58	1.49	1.46	1.45
Reduction in cooling load	0.00%	8.43%	9.56%	9.96%	10.20%
Reduction in peak cooling	0.00%	20.17%	24.38%	25.90%	26.31%

Figure 5. Annual required cooling energy and peak load for various external wall thermal insulations



	BASECASE	30cm Shading	60cm Shading	90cm Shading	120cm Shading
Cooling Load	53.821	53.171	52.677	52.43	52.174
Peak cooling	1.973	1.701	1.626	1.563	1.536
Reduction in cooling load	0.00%	1.20%	2.34%	2.47%	2.56%
Reduction in peak cooling	0.00%	13.79%	17.59%	20.78%	22.15%

Figure 6. Annual required cooling energy and peak load for different integrated shading length

This paper used Ecotect software to analyze the thermal behaviour of high-rise residential building under Malaysian tropical climate. The effect of some building envelope factors on cooling energy load has been investigated, those factors include: 1) window to floor area ratio 2) external wall thermal insulation 3) different kind of shading devices. The main findings of this paper are summarized as follows:

- Exterior wall thermal insulation is found to be the best strategy to decrease both cooling energy load and peak cooling load which achieved a reduction of 10.2% and 26.3% respectively.
- Any increase in window floor area ratio (WFR) has a large effect on the cooling system. With increased glazed area, annual cooling load rises steadily (1.3% increase in cooling load with every 10% increase in WFR).
- External integrated (overhangs and fins) shading has a limited effect on the cooling load.
- Finally, the simulation results in general indicated that there is a large potential to decrease the cooling load of the high-rise apartment in Malaysia by considering the passive concepts for the building envelope. The designers and engineers can apply the strategy selectively with minimal cost and relatively high efficiency in the early stage of building design.

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