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A Study on Reduction of Cooling Energy in Glazed Buildings

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Abstract: Large scale air conditioning applications are one of the major energy consumers in hot and humid countries like Malaysia. For building complexes such as those in a university, the cooling energy varies depending on the varying activities of students and staff. Some of these buildings are intentionally designed and built by architects for aesthetic values and those with building envelope that comprises large areas of glazing consequently face high energy cost of air-conditioning due to the high heat gain through solar radiation. Due to the present uncertainties in the cost and availability of local and global energy, along with the environmental problem related to global warming, studies on how to reduce cooling energy in highly glazed buildings are imperative. The objective of the present work is to study a few possible strategies to reduce energy consumption through the air conditioning systems in a highly glazed academic building. The strategies considered in the study are through forced reduction of air-conditioning load during lunch-time and during rain and also by switching off some of the lights during office hours. The study is conducted by computer simulation using EnergyPlus software which estimates the cooling energy of a building or areas. It is found in the study that the strategies for reduction of cooling energy have potentials and are practical for implementation in the buildings.

Key words: Air handing units, simulation, energy plus, energy management

INTRODUCTION

Although, blessed with sources of oil and gas reserves, Malaysia is going to be affected by the present trends of global energy and environmental problem. Energy supply is greatly subsidized in Malaysia but the scenario will change when it may become a net importer of crude oil by 2015. A more efficient energy usage and significant reduction in the released emission is therefore required. Space cooling with the use of air conditioners is practiced all year round in Malaysia and this accounts for 42% of total electricity energy consumption for commercial buildings and 30% of residential buildings (Saidur *et al*., 2009). Since the energy cost tends to increase further in the future, reduction in the energy used for cooling in built environment is a vital step to energy conservation in Malaysia; for example by looking at the operational point of view (Sulaiman and Hassan, 2011a).

Architectural designs of certain buildings seem to portray more on the aesthetics values but at the simultaneously fail to consider the climate situation in the country. Extensive use of glazing for buildings' perimeter walls which increases the cooling load by sun radiation, is an example of poor consideration in energy conservation since sun light is available all year round in Malaysia. Although little can be done on design when a building is completed and handed over, there are opportunities for energy conservation in the operation and maintenance aspects of the air-conditioning system. The total building electricity, for instance, can be reduced by 3% for every °C rise in the indoor air temperature (Lam, 2000).

In a recent report (Sulaiman and Hassan, 2011a), it was demonstrated that cooling energy can be optimized by cutting the supply of cool air to unoccupied rooms by proper scheduling or chilled water supply for building areas which are not facing the sunrise and of the usage of rooms. Reduction in cooling energy can also be achieved by delaying the start-up of Air Handing Units (AHU) usual also by shutting down the system 30 to 60 min earlier than (Sulaiman and Hassan, 2011b). In a work (Lee and Braun, 2007) using a demand-limiting strategy

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that employed an inverse building model trained with field measurements a 30% reductions in peak cooling loads was demonstrated.

In the present study, reduction in the cooling energy through three different strategies was studied individually. The first approach was by shutting off the chilled water supply valves at the AHU's during lunch time (identified as the "lunch mode"), with the consideration that most of the occupants would leave their workplace for lunch. In this case, the AHU blowers were maintained operating to sustain a comfortable environment among the small number of occupants. The second approach of reduction in cooling energy was by increasing the set point room temperature when it was raining (rain mode), taking advantage of the absence of sun and reduction in the ambient temperature. The third approach was by turning off some lights in the rooms which were readily bright due to the use of glazing as external walls. Space cooling energy due to the heat gain from lights is an important major component for commercial buildings having a larger ratio of interior zone. By turning of the lights would not just reduce the energy for lighting but would also decrease the cooling energy. The study was conducted by using computer simulation software, EnergyPlus.

DESCRIPTIONS OF BUILDINGS

In the study 16 buildings that were constructed next to each other within an academic complex in a university campus were involved, as illustrated in Fig. 1. The main functions of the buildings are offices, classrooms, laboratories and computer rooms. The buildings which have nearly the same size and shape, are labelled as Blocks 1 to 5 and Blocks 13 to 23. Blocks 6 to 12 would be built under a future development scheme. Each of the buildings has four floors with the exception of Blocks 5 and 15.

The top-most floor which is the most occupied area, comprises the lecturers' offices. For each building, the typical aspect ratio is 3.1 and the total air-conditioned floor areas are approximately 4833 m^2. The building could be accessed 24 h a day by the staff. The official working hours is between 8.00 a.m. and 5.00 p.m. and most AHU's are operated approximately between 7.30 a.m. and 5.30 p.m. from Mondays to Fridays. At certain areas the AHU's are normally turned off at 7.00 p.m. as requested by the occupants. On Saturdays, a few areas are air-conditioned depending on requests by the occupants; usually for selected laboratories and lecturers' offices.

The external walls of the buildings, including the doors, are nearly fully glazed with aluminium frames. Most of the walls are constructed with a single layer of tinted

Fig. 1: Aerial view of the academic complex

glass with an overall U-value of 1.43 W m^{-2} K^{-1}. Selected laboratories are constructed with double glass and the overall U-value of 0.72 W m^{-2} K^{-1}. External walls that are not glazed are composed of a layer of Medium Density Fibre (MDF) board of a layer of Medium Density Fibre (MDF) board which is sandwiched by Corian® solid panels (DuPont, 2010). The total thickness of the composite wall is 200 mm and its overall U-value is 0.72 W m^{-2} K^{-1}. The indoor walls are also made of glasses of the same heat transfer properties. The floor slab is 300 mm thick concrete. The ceiling finish is 13 mm gypsum board.

Each of the buildings has two wings of occupied areas; each is served by an Air Handling Unit (AHU). The buildings' air-conditionings uses the Variable Air Volume (VAV) system as a mean to vary and reduce the energy consumption based on the varying load of the air-conditioned area. Descriptions of the VAV system can be found in various references; e.g. (Pita, 2001). The buildings also had other energy saving mechanisms which were installed in the system during construction such as the variable speed drive for the blower's motor of the AHU, heat recovery wheels and motorized valve for modulation of chilled water supply.

SIMULATION OF COOLING ENERGY

Computer simulations were conducted to predict the effects of shutting off the chilled water supply valves of the AHU's during lunch time. The other simulations were performed to estimate reductions in the cooling energy as a result of increasing the set point room temperature in the event of rain, when there would be no solar heat gain. The building's cooling energy was simulated based on a few operational conditions using EnergyPlus version 3.0 (EnergyPlus, 2010), a building energy simulation software developed by the US Department of Energy, based on its previous energy analysis software; i.e., BLAST (Building Loads Analysis and Systems Thermodynamics) and DOE-2.

The EnergyPlus software was developed to model thermal loads, lighting, ventilating and other energy related systems. The simulation program is based on the heat balance method which allows for simultaneous calculation of radiant and convective effect at both interior and exterior surface during each time step. With this method, all heat balances on the outdoor and indoor surfaces and the transient heat conduction through the building construction are taken into account (Eskin and Turkmen, 2008).

Indoor and outdoor design conditions: The Kuala Lumpur design data being the next available information in the Energy Plus database was used in the present study. The location of study, near Tronoh, is situated less than 200 km to the north of Kuala Lumpur and has nearly the same ground elevation (62 m average) and climatic conditions. The outdoor design condition corresponds to dry bulb and wet bulb temperatures of 32.5 and 26.9°C, respectively. The daily temperature range of Dry Bulb (DB) temperature is 8.2°C. As for the indoor design condition, the dry bulb temperature is nominally set by the building operator to be 24°C with a relative humidity of 50% and these are within the range of values commonly practiced in Malaysia (Leong, 2009). Controls of the indoor air temperature are done by thermostats.

Measurement of light intensity: In the present study, simulation was conducted under the condition that some of the lights were turned off to provide just enough illumination in the lecture rooms. Measurement of light intensity was done using the Sanwa LX 3131 lux meter in order to check for sufficient luminous intensity in the lecture rooms. The device was capable to measure up to 10,000 lux with accuracy of ±10% at full scale. Measurements were performed at selected points at an elevated height of 1000 mm from the finished floor surface.

RESULTS AND DISCUSSION

The reductions in cooling energy due to the three different approaches are presented.

Lunch mode: From a survey among the lecturers which was conducted throughout the study, 90% of the respondents usually leave their office during lunch hour

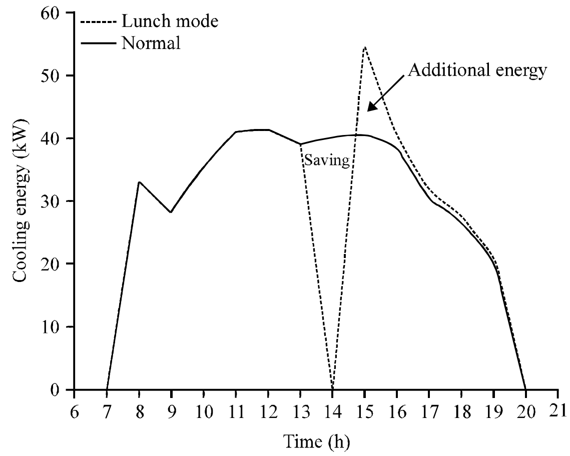

Fig. 2: Variation of cooling energy with time for block 17 with and without lunch mode setting

(1.00 to 2.00 p.m.) to have their lunch elsewhere and the remaining 10% would normally stay in the office. Since most of the lecturers' offices would be empty during lunch hour, the proposed approach of shutting off the chilled water supply valves to the AHU's between 1.00 and 2.00 p.m. would seem practical for energy saving.

Figure 2 shows the typical variation of estimated cooling energy for the lecturers' rooms in Block 17 with time, with and without shutting off the chilled water supply valve during lunch hour, represented by the dashed line and continuous line, respectively. The energy saving is represented by the area within the V-shape zone as indicated in the Figure. Due to heat gain during the lunch hour, the cooling energy is shown to be higher than usual at approximately 3 p.m.; after about 4 p.m., the difference is shown to be small. Nevertheless, the net energy saving is shown to be higher than the additional energy and hence the lunch mode approach is demonstrated as feasible.

Shown in Fig. 3 is a bar chart of the annual cooling energy for lecturer rooms with and with and without shutting off the chilled water supply valve during lunch hour. Generally, the difference is shown to be small in the chart. The annual cooling energy under normal operation mode was estimated to be about 1,976,928 kWh. However, with the lunch mode setting, the estimated annual cooling energy was approximately 1,943,560 kWh which was equivalent to about 1.7% of saving. For a large system as in the present study, the saving would contribute to a saving of RM 11,345 year^{-1} if a rate of RM 0.34 kWh^{-1} were adopted. The actual rate would be higher if inefficiencies of converting the electrical energy into mechanical energy were taken into account. With no capital investment such approach would be considered as practical.

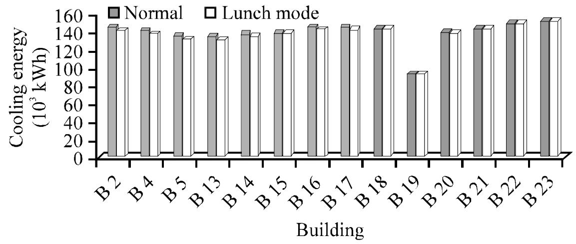

Fig. 3: Annual cooling energy of various buildings with and without lunch mode setting

Table 1: Daily rainfall at the Kg Gajah weather station

	No. of rainy days			
Months	Light (1-10 mm)	Moderate (11-30 mm)	Heavy (31-60 mm)	Very heavy (>60 mm)
January	3	5	3	13
February	4	4	5	11
March	2	3	5	8
April	2	3	2	0
May	3	2	1	0
June	2	3	2	0
July	4	0	2	0
August	3	2	0	0
September	2	3	2	2
October	3	4	4	6
November	4	3	6	18

(MMD, 2009)

Rain mode: Malaysia receives an average of 2409 mm (94.8 in) of rainfall per year or 201 mm (7.9 in) per month. The number of rainy days in Peninsular Malaysia ranges from 10 to 21 days (MMD, 2009). Table 1 shows the daily rainfall distribution between January 2009 and November 2009 for the Kg Gajah weather station.

Data from the Kg Gajah weather station was chosen because it is situated in the same district with the location of the present study. The total number of rainy days is 154 out of the 334 days (11 months). Obviously Table 1 implies that the proposed rain mode can be applied to the buildings at the present location of study.

To make sure that the occupants would be comfortable during rainy day, the set point temperature was increased to 26°C which was 2°C higher than that of the normal setting. The actual time of rain would be difficult to predict. For simplicity, computer simulation was conducted under the condition as if it would be raining for one hour at 4.00 p.m. every day throughout a year. Although, just a rough assumption, rain normally occurs in the area of study in late afternoon.

A typical result of cooling energy reduction through the rain mode for Block 18 is shown in Table 2. With an increase in the set point temperature by 2°C when it rains would reduce the cooling energy by approximately 370,000 kWh or 36%. The energy saving would be equivalent to RM 125, 800 (assuming an energy cost rate of RM 0.34 kWh^{-1}).

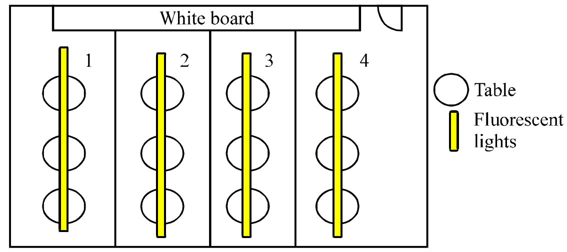

Fig. 4: Lecture rooms layout from top view for lecture room during normal operation

Table 2: Savings in cooling energy for block 18 by adjusting the set point temperature to 26°C

	Set point temperature	
	24°C	26°C
Annual cooling energy (10^6 kWh)	1.02	0.65
Reduction		36%

Reduction of lighting: In the lecture rooms, the lights are tabulated in rows depending on the size of the rooms. Figure 4 shows typical room's lighting layout. The room's size is 14× 8.5×3.4 m (H). The wall which has the white board receives natural lights through a full-length glazed wall above the white board, with the height of 1.0 m. The room comprises of 12 round tables which are arranged in three columns, as shown in the Figure. Each of the columns of tables is illuminated by an array of fluorescent lights (Zones 1 to 4). The fluorescent lights comprise of the 18 and 38 W types of lamps. Although, the room can accommodate about 80 students, some classes have smaller number of students of around 20 students. As the students are free to choose their seats during lectures, means all lights will normally be switched on to make sure the luminance level is suitable for the occupants.

Figure 5 shows the arrangement of on-off settings for the lightings in the lecture room of Figure 4 if the number of students less were than 20. In such situation, only the lights of Zones 2 and 3 would be turned on and the students would be required to occupy the shaded tables. The standard illumination level for general building areas, as recommended in Malaysia Standards MS 1525 is around 300-400 lux (Malaysian Standard MS1525, 2007). Inspection of the illumination level in the vicinity of the occupied tables under such setting was found to be satisfactorily above the standard values although the readings varied from points to points in the room and therefore the potential energy savings were estimated using different configurations, with a ballast factor of 1.25 and cooling load factor of 1.0.

Table 3 is summary of the lighting configurations and reductions in heat gain for the lecture room. As indicated

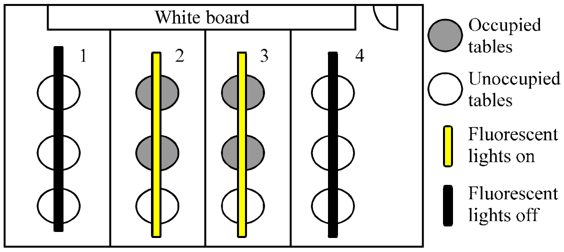

Fig. 5: Proposed on-off setting for lighting the lecture room of that depicted in Fig. 4

Table 3: Lighting configurations and reductions in heat gain for the lecture room depicted in Fig. 4 and 5

Zones turned on	Light power (W)	Quantity	Load (W)	Total Load (W)	Saving (%)
1, 2, 3, 4	38	32	1520	1700	
	18	8	180		
1, 2, 3	38	24	1140	1275	25
	18	6	135		
2, 3	38	16	760	850	50
	18	4	90		
2	38	8	380	425	75
	18	2	45		

by the shaded row in Table 3, if only two columns of lights were turned on (Zones 2 and 3), the saving would be 50%.

The actual saving in energy depends on the hours of operation of the room. If on a day, for example, five hours of lectures were involved, would mean a saving of 4.25 kWh which would be equivalent to RM 1.44 day^{-1} just for one room. Thus, it is shown that due to the presence of sufficient natural lights through the glazing, turning off some of the lights in the lecture rooms can contribute to significant saving of the cooling energy.

CONCLUSIONS

A study on the effects of a few approaches to reduce the cooling energy in highly glazed academic buildings was performed, among others by using EnergyPlus software. From the study, the followings can be concluded:

- The proposed setting to shut of the chilled water supply into the AHU during the lunch mode was observed as feasible as the number of staff who would remain in the office would be less than 10%. The estimated saving in the annual cooling energy was 33,368 kWh or about 1.7%. Since no capital investment is required, the approach would be considered as practical
- Increasing the set point temperature during the rain should be considered as an opportunity for a place that is blessed with consistent rain throughout the year. In the present study, by raising the set point temperature by 2°C when it rains would reduce the annual cooling energy by approximately 370,000 kWh or 36%
- Optimization of lightings in a lecture room should be practice since it may contribute in saving energy. In the present work a 50% reduction in the cooling load was observed if the number of occupants is small (20 persons)

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