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Analysis of Annual Cooling Energy Requirements for Glazed Academic Buildings

[1]Shaharin A. Sulaiman and [2]Ahmad H. Hassan
[1]Department of Mechanical Engineering, Universiti Teknologi PETRONAS,
31750 Tronoh, Perak, Malaysia
[2]Department of Engineering, Vinyl Chloride Malaysia Sdn Bhd,
24300 Kerteh, Terengganu, Malaysia

Abstract: The objective of the present study was to analyze the annual cooling energy of highly glazed academic buildings which are located in a university in Malaysia. The outcome of the study would enable further remedial actions in reducing the energy consumption of the buildings' air conditioning system. The study is conducted by computer simulation using EnergyPlus software to calculate the cooling energy of a selected building or areas. Comparison is made against the rated equipment load (i.e., the air handling unit) installed in the buildings. Since the buildings in the present study are not constructed parallel to each other the effect of building orientations with respect to the sun positions are also studied. The implications of shades such as venetian blind on the cooling energy are investigated in assessing their effectiveness in reducing the cooling energy, apart from providing thermal comfort to the occupants. In the aspect of operation, the present study includes the effects of reducing the set point air temperature and infiltration of outdoor air due to doors that are left open by the occupants. It is found from the present study that there are significant potentials for savings in the cooling energy of the buildings.

Key words: Cooling energy, air-conditioning, glazed buildings

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INTRODUCTION

Malaysia experiences rapid increase in energy consumption in the last decade due to its high economic growth and increase in the standard living of household (EIA, 2009). Energy is becoming more costly and the situation is worsened by the global warming as a result of green house gas emission. 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. A study on the factors affecting energy performance in buildings is necessary for a better understanding of the design and operational strategies related to energy conservation; these are possible with the use of energy simulation software.

At present, there is no legislation pertaining to building efficiency in Malaysia. Architectural designs of certain buildings seemed to portray more on the aesthetics values but at the same time failed to consider the climate situation in the country. The extensive use of glazing for buildings' perimeter walls, which results in higher cooling load due to sun radiation, is an example of poor consideration in energy conservation since sun light is available all year round in Malaysia. In many situations, lack of attention has been given to the aspects of operation and maintenance of the building.

As for the building owners, little can be done on the aspect of design to conserve energy when a building has already been constructed and handed over. On the other hand, there are energy conservation opportunities in the operation and maintenance aspects of the air-conditioning system. Overcooling, for instance, was investigated in Hong Kong (Lam, 2000) in which it was reported that there could be a 3% reduction in total building electricity use for every °C rise in the indoor design temperature.

In the present study, the cooling energy resulted from the as-installed system is studied and a few possible energy conservation mechanisms is studied for centralized air-conditioning systems of glazed buildings in a University. The study is conducted by using computer simulation software, Energy Plus (2010).

Corresponding Author: Shaharin A. Sulaiman, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 31750 Tronoh, Perak, Malaysia

Possible weaknesses in the aspect of air-conditioning operation are identified and potential solutions are simulated using the software.

DESCRIPTIONS OF BUILDINGS

The study involved 16 buildings that were constructed next to each other within an academic complex in a university campus, as illustrated in Fig. 1. Each of the buildings has four floors with the exception of Buildings 5 and 15. The buildings' aspect ratio is 3.1. The major functions of the buildings are as offices, classrooms, laboratories and computer rooms. The total air-conditioned floor areas for each building are approximately 4833 m^2. The building can be accessed 24 h a day by the staff, but the air-conditioning is only supplied 12 h per day, typically between 7 a.m. and 7 p.m. from Mondays to Fridays. On Saturday, a few areas are air-conditioned based on the requests by the occupants; this is normally 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 by a single layer of tinted glass with an overall U-value of 1.43 W m^{-2} K. Selected laboratories are constructed with double glass and the overall U-value of 0.72 W m^{-2} K. External walls that are not glazed and are composed 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. The indoor walls are also made of glass 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 air ducts in the buildings is equipped with a Variable Air Volume (VAV) system as means 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 have other energy saving mechanisms which were installed in the system during initial 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 LOADS

In the present study the building's cooling energy was simulated based on a few operational conditions or patterns using EnergyPlus. Hourly and annually cooling loads were calculated by 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).

The design data was based on that for Kuala Lumpur, which was available in the EnergyPlus database. The location of study, near Tronoh was situated less than 200 km to the North of Kuala Lumpur and had nearly the same ground elevation (62 m average) and climatic conditions. The outdoor design condition corresponded to dry bulb and wet bulb temperatures of 32.5 and 26.9°C, respectively. The daily temperature range of Dry Bulb (DB) temperature was 8.2°C. As for the indoor design condition, the dry bulb temperature was nominally set by the building operator to be 24°C with a relative humidity of 50% and these were within the range of values commonly practised in Malaysia (Leong, 2009). Controls of the indoor air temperature were done by thermostats.

Most of the buildings were used mainly as lecture rooms, laboratories and lecturers' offices. 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. In some cases, subject to requests by the occupants, the AHU's were turned off at 7.30 p.m., or later

Fig. 1: Aerial view of the academic complex

if requested by the occupants. The lecturers' offices, which were located on the highest floor, were generally fully occupied during the office hours. However, a number of lecture rooms and laboratories were not always occupied for various reasons.

ASSESSMENT OF THE INSTALLED LOAD

In analyzing the system's cooling load, it was necessary to compare the equipments' rated cooling load to that calculated by the software. This would determine if there was significant overdesign or under design of equipment. Table 1 showed the rated equipment loads for AHU's at the right wing of Level 3 in Buildings 1, 5, 17, 21, 22 and 23, as specified by the design engineers. Also shown in Table 1 are the refrigeration load calculated by the EnergyPlus software for comparison. Although the study was done only for selected buildings the results were expected to be able to represent the other buildings.

It is observed in Table 1 that the equipments load varied although, they are basically of the same geometry and construction. The calculated load for Buildings 21, 22 and 23 had high refrigeration loads of over 87 kW each as compared to only 50-55 kW in Buildings 1, 5 and 17. This was likely due to the variation in the orientation of the buildings with respect to the direction of sun.

From the results in Table 1 it is shown that the installed AHU's were overdesigned by an average of 28%. It is obvious that the trend of the designer was to overdesign by at least 20%. Nevertheless, in Building1 the overdesign factor was nearly 50%, which was considered as very high. In practice, sizing of air-conditioning equipments is normally being overdesigned by 10-15% (Yu and Chow, 2000) due to factors such as future extensions, to overcome uncertainty in assumptions during sizing calculation phase and also due to clients' request. Although a system should be designed to be flexible, overdesigning is not a good engineering practice. The penalty of equipment over sizing is lower plant efficiency. If there is a possibility of future extension or change of usage, the system should be designed so that it will be easy and inexpensive to add equipment or change equipment.

Table 1: AHU loads of selected building

	B1	B5	B17	B21	B22	B23
Building orientation (N°)	155	90	160	52	32	14
Peak sensible cooling load (kW)	40.2	42.9	41.2	69.4	69.7	69.8
Refrigeration load (kW)	50.7	54.0	51.9	87.4	87.8	88.0
Equipment rated load (kW)	96.0	70.0	80.8	112.0	112.0	111.0
Overdesign (%)	47.0	23.0	36.0	22.0	22.0	21.0

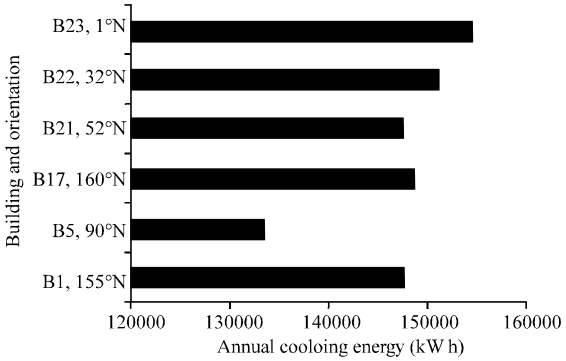

Fig. 2: Variation of simulated annual cooling energy for different building orientations

EFFECT OF BUILDING ORIENTATIONS

The effect of building orientation with respect to North towards the cooling energy requirement, such as those for Buildings 21, 22 and 23, were investigated. The indicated bearing reflects the position of the building with respect to the sun. EnergyPlus simulation was performed for all six buildings listed in Table 1. The simulation was made only for Level 3 (lecturers' offices) of those buildings due to similarity in the design and construction (e.g., wall material, floor area, internal heat gain) except for building orientation.

It is shown in Fig. 2 that Building 23 (14°N) experienced the highest annual cooling energy at about 155MWh, while the lowest is Building 5 (90°N). It is also observed in Fig. 2 that the closer a building orientation to 0°N the higher would be the cooling energy, as that for Buildings 23, as well as for Buildings 21 and 22. When a building is aligned in parallel with the North direction (0°N) the highest solar radiation through the glazed walls is experienced. This is due to the fact that solar radiation intensity received by a surface is the highest at right angle when the glass area is perpendicular to solar radiation. On the other hand, for Building 5, which was aligned nearly parallel to the East or West, the glazed wall area received the minimum amount of solar radiation, which resulted in a relatively lower annual cooling energy. Thus, it can be concluded that building orientation with respect to the sun is one of the factors that result in the variation of annual cooling energy in each building.

EFFECT OF WALL SHADES

Since the study involved highly glazed buildings, a common approach of reducing the heat gain through solar radiation would be by introducing internal shadings either internally or externally in a building. The effectiveness of a shading device is usually gauged by its shading coefficient or the ratio of the solar energy transmitted through a window to the incident solar energy. In the present study, blinds and internal shading devices were chosen for simulation as they are commonly used for typical buildings in Malaysia. Three types of chosen blinds were the High Reflectivity (HIREF), Medium Reflectivity (MIDREF) and Low Reflectivity (LOWREF) slats blinds. As for the shading devices, the High Reflectivity Low Transmittance (HRLT), Medium Reflectivity Low Transmittance (MRLT) and Low Reflectivity Low Transmittance (LRLT) shades were considered. Energy Plus simulation was done for Building 23 for all floors (Levels G, 1, 2 and 3).

The simulation results indicate that blinds and shades with high reflectivity material give the highest reduction of base case cooling load. Table 2 shows the percentage of reduction in the annual cooling energy for all types of blinds and shades. It is shown in Table 2 that the highest saving in the annual cooling energy can be achieved by installing the HRLT shades; i.e., reduction by 26.5% which accounts for 181,783 kW h. As for window blinds, a reduction of 14.2% in the annual cooling energy can be achieved by installing HIREF type of blinds and this is equivalent to 97, 203 kW h of cooling energy. Both types of shadings yield high energy savings due to their high reflectivity and low transmittance properties against the solar incident energy.

EFFECT OF SPACE OVERCOOLING

Space overcooling is caused when the actual air temperature in the conditioned space is lower than the designated set point value. In this study, the set point temperature for the buildings was 24°C, which was within the indoor design temperature recommended by ASHRAE Standard 55. Nevertheless, it was usual that the control room staff received instant requests from some of the occupants to reduce their room temperatures; mainly at the time when the sun was facing their rooms. Even though the change in the temperature set point should be made by the control room operator for only one room or zone, it was common that the operator would reduce the set point temperature for the whole floor, usually to 20°C. As a result, other occupants who were readily feeling comfortable started to feel colder and uncomfortable. Through interviews with a number of the occupants, it was discovered that most of them would rather remain silent about the situation and thus the problem prolonged. This was evident when a number of them started to wear additional clothing such as coats or sweaters in offices. Similar problems were also reported in Hong Kong (Lam, 2000), where many commercial premises were being over-cooled by 2-4°C.

Shown in Table 3 is the annual simulated cooling energy for a Building 23 as a result of different set point temperatures; i.e., 20, 22 and 24°C. The increases in cooling energy are calculated relative to the energy required at a set point temperature of 24°C. It is shown in Table 3 that a reduction in the air temperature from 24 to 22°C and 20°C will cause increases in the cooling energy by 36% and 68%, respectively. In term of cost, these are equivalent to RM 146, 880 and RM 278, 920 per year, respectively. The cost calculation is based on the standard commercial electric tariff rate of RM 0.397 for every kW h (TNB, 2010). It must be highlighted that in reality due to inefficiencies of motors and energy conversion system, the actual costs are expected to be higher than those listed in Table 3. This shows that overcooling of a space involves huge amount of additional energy and cost and thus should be avoided in the first place. Apart from the issue of operating cost, overcooling should also be avoided in order to provide a room temperature that is within the level of comfort of most occupants.

EFFECT OF OUTDOOR AIR INFILTRATION

Infiltration load is one of the elements of space cooling load. Normally, in design phase, designers will incorporate infiltration load based on the level of air tightness of a building. However, in actual daily usage, additional infiltration load may be imposed to the system through door or windows openings. In analyzing the severity of the addition of cooling energy from such air infiltration, a simulation of cooling energy

Table 2: Comparison of various AHU loads for a typical building

	Annual cooling load reduction (%)					
	Blinds			Shades		
Floor level	HIREF	MEDREF	LOWREF	HRLT	MRLT	LRLT
3	16.6	-9.4	2.4	34.6	18.5	-2.4
2	20.0	2.6	10.5	33.0	19.9	7.2
1	18.9	1.2	9.2	32.5	18.6	5.9
G	3.6	-4.9	-1.1	9.8	3.2	-2.7
Total load reduction	14.4	5.0	-2.7	26.5	14.4	1.8

Table 3: Effect of set point temperature on Building 23

Set point	24°C	22°C	20°C
Annual cooling energy (KW h)	1026	1396	1729
Increase in energy (%)	-	36	68
Equivalent cost (RM)	-	146,880	278,920

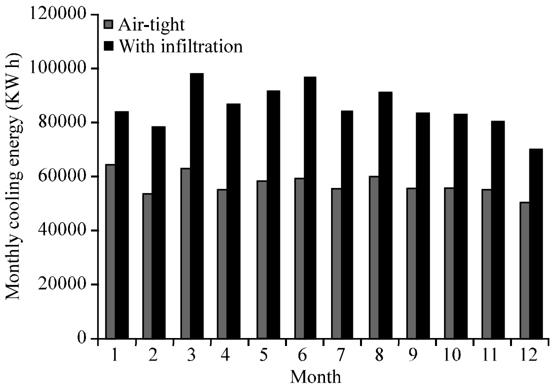

Fig. 3: Variation of simulated monthly cooling energy for building 23 if the doors are left open with infiltration rate of 1.0 cfm ft^{-1} of door area

was performed for Building 23 with the assumption that each floor has one door opened during the day time (8 a.m. to 5 p.m.). The value of infiltration was taken as one cubic foot per minute per square foot of the door area (Pita, 2001).

From the simulation computed by EnergyPlus, annual cooling energy for Building 23 was increased from 685, 160 kW h to 1, 026, 043 kW h as a result of infiltration load from the door openings. The increase is about 49.7% which would cost an additional RM135, 330. Therefore, the results in Fig. 3 imply that the infiltration load from door or window openings can result in a significant increase in the cooling energy. Therefore, the building operator must ensure that doors are not left open for a long time to minimize infiltration load.

CONCLUSIONS

Simulation of the annual cooling energy for highly glazed academic buildings was performed using Energy Plus. From the study, the followings can be concluded:

- The installed AHU's were found to be overdesigned by at least 20%. It was found to be high in Building 1, which was 47%. Although overdesign is practiced by design engineers, the normal range is within 10-15%. With the equipment not operating close to its maximum capacity would lower the plant efficiency. Although at the present stage, this cannot be corrected, plans should be made in the future, such as allocation for greater occupancy in order to optimize the system
- The building orientation with respect to the sun was one of the important factors that results in the variation of annual cooling energy in each building. Due to the large area of glazed walls, the effect of heat gain through solar radiation was significant for the buildings
- Application of blinds or shadings for the glazed academic buildings could yield high savings in the annual cooling energy due to their high reflectivity and low transmittance properties against the solar incident energy.
- Overcooling of a space by reducing the set point temperature of the thermostat in the academic building would involve significant increase in the cooling energy and operational cost. In some situations, overcooling was found to cause discomfort among a large number of occupants. A balance between comfort and cost should be made by setting the most suitable set point temperature
- Infiltration of outdoor air through opened doors or windows could lead to a significant increase in the cooling energy. Hence, the building operator should ensure that doors are not constantly left open during regular buildings' operation periods

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