Trends in Applied Sciences Research

ISSN 1819-3579

Academic
Journals Inc.

www.academicjournals.com

Trends in Applied Sciences Research 6 (11): 1256-1269, 2011
ISSN 1819-3579 / DOI: 10.3923/tasr.2011.1256.1269

A Study on the Impact of Operational Behavior on Cooling Energy in Highly-Glazed Academic Buildings in a Tropical Country

[1]Shaharin A. Sulaiman and [2]Ahmad Hadi 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

Corresponding Author: Shaharin A. Sulaiman, Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 31750 Tronoh, Perak, Malaysia Tel: 00605 3687013 Fax: 00605 3656461

ABSTRACT

Non-commercial buildings such as those in institutes of higher learning are unique that their occupancies vary throughout a day and year depending mainly on the students' activities. When operated with a large scale air conditioning system, the annual energy consumption of such buildings can be very high. In tropical countries, glazed buildings experience high energy cost due to the significant heat gain from the solar radiation. With uncertainties in the cost and availability of local and global energy nowadays, a study on the actual cooling load of a building system should be performed to reduce the energy consumption. The objective of this research was to study the effects of operational behavior to the cooling energy of highly glazed academic buildings. The study was conducted by computer simulation using EnergyPlus software on selected air-conditioned occupied areas. The potential savings in energy as a result of various proposed strategies in view of the gaps in the present operation are estimated based on computer simulation. In the aspect of operation, the effects of reducing the set point air temperature are also studied. It is found from the present study that there are significant potentials for savings in the cooling energy of the buildings.

Key words: Energy management, HVAC system, EnergyPlus, cooling energy

INTRODUCTION

The present increase in the world energy demand and depletion of fuel sources is partly contributed by energy consumption from the built environment. The energy consumption of buildings in developed countries comprises 20-40% of the total energy use in the EU and USA (Perez-Lombard *et al*., 2008). In Malaysia, it is reported by the Energy Information Administration (EIA, 2010) that the country is experiencing rapid increase in energy consumption in the last decade, mainly due to its high economic growth and increase in the standard living of household. The Energy Information Administration also reported that the country's consumption of natural gas, for example, has increased by 98% over the last decade. Not only energy is becoming more costly but the situation is worsened by the global warming resulted from the green house gas emission. Therefore, a more efficient energy usage such as through reduction in the wastage of cooling energy is required.

In tropical countries with hot and humid weather pattern like Malaysia, space cooling is required all year round in commercial buildings and some residential buildings. Air conditioners account for 42% of total electricity energy consumption for commercial buildings and 30% of residential buildings in Malaysia (Saidur *et al.*, 2009). These are relatively lower than, for instance, in Hong Kong where air-conditioners contribute to about 60% of the total electricity consumption for commercial buildings (Chan, 1994) during the cooling season from late March to early November. Energy cost is likely to increase in the future due to the anticipated decrease in the national oil wells' production rate in the next decade. Hence, reduction in the energy consumption for cooling of 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.

Although development of non-residential buildings in Malaysia has increased in the last two decades, the country is lack of legislation pertaining to building efficiency (Aun, 2004). In many situations, little attention has been given to the aspects of operation and maintenance of the building. On the other hand, the architectural designs of certain buildings seems to portray more on the aesthetics values but at the same time fail to consider the hot and humid climate of the country. Consequently, various studies were conducted with hopes to overcome problems related to thermal comfort and high cooling energy in these buildings (Sulaiman and Hassan, 2011; Bhaskoro and Gilani, 2011; Sharma *et al.*, 2011; Wang *et al.*, 2008).

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 12 h per day all year round in Malaysia. During the design stage, consideration for highly glazed buildings should be studied very carefully since they have a large impact on the energy efficiency as compared to 30 to 60% window to wall area alternatives (Poirazis *et al.*, 2008). A study on a typical office building in Singapore (Hien *et al.*, 2005) revealed that the use of double glazing is able to maintain lower internal surfaces temperature, thus reducing solar heat transfer to the internal spaces.

When a highly glazed building has already been constructed, little can be done on the design in order to conserve energy. Nevertheless, there are always opportunities for energy conservation in the operation and maintenance of the building's air-conditioning system. Improving operation and maintenance of energy systems may have a major impact on energy consumption and in many cases will exceed the potential energy savings from alternative energy and energy conservation technologies (Drost, 1992). Overcooling, for instance, was investigated by Lam (2000), who reported that there could be a 3% reduction in total building electricity use for every °C rise in the indoor design temperature. In an earlier study by Sekhar (1995) it was revealed that the space temperatures in air-conditioned office buildings in Singapore were around 23°C (relative humidity of 70-75%) which were not within the recommended ASHRAE comfort zone and thus increasing the space temperature would be able to reduce the cooling energy significantly. Building owners can also conserve energy by installing Automatic Fault Detection and Diagnosis (FDD) which was reported as a potentially practical method (Lee and Yik, 2010) to detect occurrence of faults in the equipment and measuring instruments of an air-conditioning system, although this may depend on the severity of the energy impacts of the faults.

In this study, the effects of a few operational behaviors of centralized air-conditioning systems for glazed buildings in a university are studied by energy simulation using EnergyPlus software. A few gaps in the aspect of air-conditioning operation are identified and potential solutions are simulated using the software. One of the main gaps is the supply of cool air to rooms during the period of non-occupancy throughout the weekdays and weekends. The potential savings in energy as a result of various proposed strategies are estimated based on the computer simulation.

DESCRIPTION OF THE BUILDING

The buildings in the present study are located within an academic complex in a university campus. There are 16 buildings within the academic complex which are constructed next to each other, as illustrated in Fig. 1. 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 which have three floors only. The buildings aspect ratio is 3.1. The major functions of the buildings are 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 am and 7 pm from Mondays to Fridays. On Saturdays, a few areas are air-conditioned based on requests by the occupants; this is normally the case for selected laboratories and lecturers' offices.

The typical layout for the third floor of the buildings which is the most occupied floor, is shown in Fig. 2. Each of the floors comprises of two air-conditioned areas or wings which are identified as the AB side and the CD side, as depicted in Fig. 2. Each side comprises individual lecturers' offices which are air-conditioned. The area in between the two sides is not air-conditioned. An Air Handling Unit (AHU) which is located in a plant room to the right of the layout (not shown in the figure), serve each side or wing. For Levels G, 1 and 2, there are roof overhangs which act as external shadings. The main control of the air conditioning system is performed in the control room which is located in the administration complex not far away from the academic complex.

The cool air from each AHU is supplied through the Variable Air Volume (VAV) system. The installed VAV system can operate under two modes as defined by the manufacturer; i.e., pressure dependent and pressure independent. In the pressure dependent mode which is the default setting for the building, the VAV damper operation is set to correspond to a minimum (non-zero) flow rate that is specified by the manufacturer in order to assure the air motion required for the comfort of occupants. Nevertheless, the pressure dependent mode usually leads to over cooling since cool air is continuously supplied although at a small flow rate. As for the pressure independent mode, the

Fig. 1: Aerial view of the academic complex

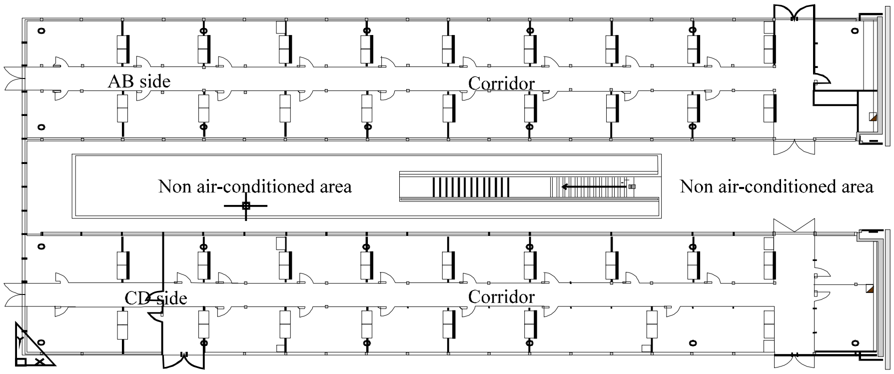

Fig. 2: Typical floor layout for level 3

Table 1: Typical envelop details of the academic building (Block 17)

Level	Dimension (m)	Wall area (m^2)	Wall construction (from outer layer)	Window area (m^2)	Window construction	Roof and floor construction
Ground	61.3×21.8×3.6	539	Tinted glass and MDF board	185.2	Single glass	Heavyweight concrete
			Corian ceramic and MDF board			
1	68.1×21.8×3.6	588	Tinted glass and MDF board	204.7	Single glass	Roof heavyweight concrete
			Corian Ceramic and MDF board			
2	AB		Tinted glass and MDF board		Single glass	Heavyweight concrete
	66.6×11.2×3.6	530		169		
	CD		Corian ceramic and MDF Board		Single glass	
	66.6×11.2×3.6	530				
3	AB					
	35.2×7.5×2.8	235	Singal glass	-	-	Rock wool insulation
	CD					
	35.2×7.5×2.8	235				Aluminum sheet

VAV damper operation corresponds to the local temperature set point. In addition, with the pressure independent mode, users may manually adjust the minimum damper opening according to their requirements, even to fully shut the damper. In contrast to pressure dependent mode, the pressure independent mode is capable of preventing overcooling although the consequent would be loss in air motion. Nevertheless, air motion is not required when the room is unoccupied.

Table 1 summarizes the construction details of the building. 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 that require noise attenuation are constructed with double glass of which the overall U-value is 0.72 W m^{-2} K. External walls that are not glazed 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 glasses of the same heat transfer properties. The floor slab is 300 mm thick concrete. The ceiling finish is 13 mm gypsum board.

SIMULATION OF COOLING LOAD OF AN ACADEMIC BUILDING

The present study involved simulation of cooling energy in the buildings based on a few operational conditions or patterns using computer software.

Cooling loads calculations: 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 operates based on a heat balance method which allows for simultaneous calculation of radiant and convective heat transfer effect at both interior and exterior surfaces during each time step. The cooling load calculation method takes into account all the heat balances on outdoor and indoor surfaces and transient heat conduction through building construction (Eskin and Turkmen, 2008).

Outdoor and indoor design data: The design data was based on that for Kuala Lumpur (3°8' N, 101°42' E) in Malaysia which was available in the EnergyPlus database. The location of study, in Tronoh (4°25'N, 100°59' E) is situated less than 200 km to the north of Kuala Lumpur and has nearly the same ground elevation (62 meter average) and climatic conditions. Malaysia is a small tropical country with a warm and humid climate all year round. The outdoor design conditions correspond to dry bulb and wet bulb temperatures of 32.5°C and 26.9°C, respectively. The daily temperature range of Dry Bulb (DB) temperature is 8.2°C.

The indoor dry bulb temperature was set by the building operator to be 24°C with a relative humidity of 50% and these were within the range of values commonly practiced in Malaysia (Leong, 2009). The indoor air temperature was controlled by thermostats.

Existing modes of operation: The buildings within the academic complex are mainly used as lecture rooms, laboratories and lecturers offices. The official working hours is between 8.00 am and 5.00 pm and AHUs are operated approximately between 7.30 am and 5.30 pm. In some cases, the AHUs are turned off late at 7.30 pm, subject to requests by the occupants. The offices which are located on the highest floor, are generally fully occupied during the office hours. Nevertheless, a number of lecture rooms and laboratories are not always occupied for various reasons which are mainly related to the operation management of the buildings. In the present study, the pattern of rooms' occupation is observed.

Figure 3 shows a typical weekly occupancy pattern for Blocks 15 to 19. The dark and light bars represent the occupied and unoccupied h, respectively. Most of the lecture sessions in the lecture rooms are scheduled to be either continuous or intermittently. The longest gap between lectures is 5 h while the shortest gap is one h. The average occupancy of lecture rooms is 25 h per week per room, throughout the 14-week semester. Such patterns of occupancy are experienced due to the nature of the study programs. As for the laboratories, the occupancy patterns are not constant throughout the semester. On average, the laboratories are unoccupied for only 26 h per week. In addition, it is observed that some laboratories are occupied only for seven weeks out of the total of 14 weeks.

During the weekends, there are also requests for usage of air-conditioning system due to certain laboratory activities or requests by staff. An observation is made for three weeks on the trend of operation during the weekends and the results are presented in Table 2. It is shown that in some places, e.g., in Block 17 on Level 1, that the air-conditioning system is operated although the area is unoccupied. It is also observed that even if the request is made for one side of the floor, both AHU's (AB and CD sides) are turned on. From an interview conducted with the control room

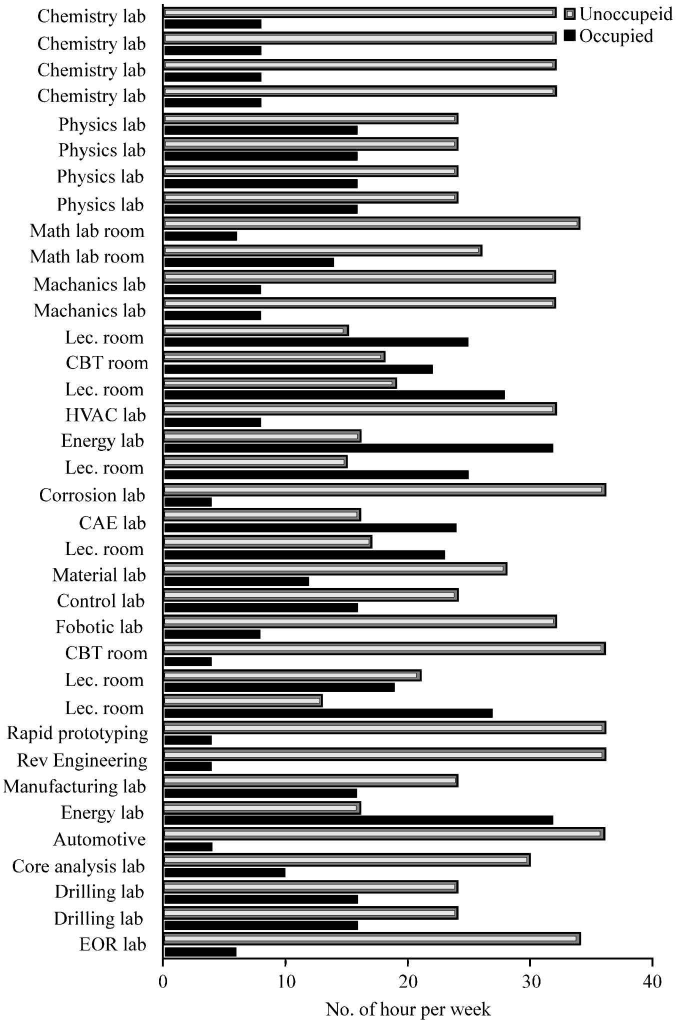

Fig. 3: Typical rooms' occupancy pattern for Blocks 15 to 19 during the semester

Table 2: Typical occupancy pattern during the weekends in various buildings for three consecutive weeks

			AHU operation							
			AHU AB		AHU CD		Occupancy			
Building	Day	Level	ON	OFF	ON	OFF	W1	W2	W3	Remarks
B1	Sat and Sun	2	0734	1700	0734	2359	No	No	No	-
B4	Sat and Sun	1	0738	2300	0738	2345	Yes	Yes	Yes	4 h, CD side only, PG Student
B15	Sat and Sun	2	0735	2330	0735	2330	No	No	Yes	24 h, PG Student, 3 months
	Sat and Sun	1	0739	2330	0739	2330	Yes	Yes	Yes	24 h, CD side only, 2 months
B16	Sat	1	0740	1900	0740	2330	Yes	Yes	Yes	Used every week until 6 pm
	Sat	G	0744	1900	0744	1900	Yes	Yes	Yes	Used every week until 6 pm
B17	Sat	1	0740	1900	0740	2330	No	No	No	-
	Sat	G	0744	1900	0744	1900	Yes	Yes	Yes	Request will be made for Saturday lab
B21	Sat	2	0737	2230	0737	2359	No	No	No	-
	Sat	1	0741	2230	0741	2230	Yes	Yes	Yes	Until 6 pm, used every week
	Sat	G	0745	1900	0745	1900	Yes	Yes	Yes	Until 6 pm

personnel, such occasions are said to occur due to insufficient information provided by the requesters; for instance the duration of the room usage is not clearly informed. It is realised in the present study that there is no proper mechanism to request for air-conditioning service after regular office hours.

The trends of occupancy during the weekdays and weekends clearly show that there is unnecessary wastage of energy. For an example, at Block 17 at Level 1 on the CD-side, the AHU operates from 7.40 am until 11.30 pm even though the area is observed as unoccupied. Furthermore, the observed trends only represent the situation when the undergraduate students are on campus. Larger wastage is anticipated during the semester breaks; i.e., a total of about 16 weeks per year. In the present work, EnergyPlus is used to estimate the savings in the cooling energy if supply of cool air to these rooms is temporarily cut off. In order to reduce the wastage a suitable control strategy is required.

Experimental scheduled isolation of cooled air supply: Scheduling of air-conditioning based on the daily and weekly occupancy schedule was proposed in previous researches; for example by Al-Rabghi and Akyurt (2004). In the present study, the potential saving resulted from scheduling of cool air supply is studied. By obtaining the occupancy plan in advance from the building administrator, the control operator may be able to schedule the supply of cool air and therefore, rooms which are unoccupied can be totally cut off from cool air supply by mean of VAV control. In this case the VAV is reconfigured from pressure dependent to pressure independent mode to enable 100% damper shut at the VAV box. The original configuration of the VAV control using the pressure dependent mode is observed to be unsuitable since it causes unoccupied rooms to be continuously supplied with cool air although at low flow rates.

With the pressure independent mode, the VAV box will maintain the minimum flow setting when the set point temperature is met. If the minimum flow is set to be at zero percent, after reaching the set point temperature, the cool air supply through the VAV box will be cut off. Therefore each and every unit of the VAV box can be controlled independently by varying its temperature set point. This is particularly beneficial during low occupancy periods such as in the weekends. If such change is applied to the whole academic complex, the issue of space overcooling which has been a problem to the occupants in the present, can be minimized.

The savings resulted by cutting off the supply of air to unoccupied rooms (pressure independent mode) is simulated using EnergyPlus. The scheduled isolation is experimented for Block 17 at Level 1. From the building administrator's schedule, the average daily room usage is found to be only 6 h. Only three rooms are occupied at all time while the rest are unoccupied. Therefore, in the present study, the EnergyPlus simulation is performed with the consideration that cool air is supplied to the affected rooms from the start of AHU operation at 7.42 am until 2.00 pm (approximately 6 h) and thereafter the cool air supply is totally cut off (isolated) except for rooms that are occupied. The savings in terms of the electrical power of the blower motor as a result of the scheduling is measured. The actual cooling energy is not measured since the appropriate measurement devices are not available.

RESULTS AND DISCUSSION

Effect of space overcooling: The set point temperature for the buildings in this study is 24°C which is within the indoor design temperature recommended by ASHRAE Standard 55 (McQuiston *et al*., 2004). However, it is usual that the operator in the control room receive requests from some of the occupants to reduce their room temperatures; mainly at the time when the sun is facing the external walls of their rooms. Although the required change in the temperature set point should be made by the control room operator for only one room, it is usual that the operator reduce the set point temperature for the whole floor, usually to 20°C. As a result, other occupants who are readily feeling comfortable start to feel colder and uncomfortable. Through interviews with a number of the occupants, it is discovered that most of them tend to keep quiet about the situation and thus the problem prolongs. This is also evident when a number of them start 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.

The effect of lowering the set point temperature in the academic buildings is simulated using EnergyPlus. Shown in Table 3 is the simulated annual cooling energy for a typical building (Block 23) as a result of using different set point temperatures; i.e., 20, 22 and 24°C. The differences in cooling energy are calculated relative to the energy required at a set point temperature of 24°C. It is shown 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. This shows that overcooling of a space in the highly glazed academic building involves huge amount of additional energy and thus should be avoided in the first place. Overcooling should also be avoided in order to provide a room temperature that is within the level of comfort of most occupants.

Cooling energy consumption during weekends: Operation of the air-conditioning system during the weekends cannot be avoided, as it is the decision of the building administrator but it is found in the study that there is a room for improvement of the energy consumption. Table 4 shows the annual cooling energy resulted from consumption during the weekends for various locations based on the occupancy observed throughout the study. The cooling energy is simulated using EnergyPlus. The weekend's total cooling energy for the whole academic complex is found to be 31,936 RTh per year. While the requests for air-conditioning service during the weekend are made by authorised staff, it is found that postgraduate students, who are not authorised to work in the building during the weekend, are also supplied with cool air from the air-conditioning services. There are also buildings that are air-conditioned but are found to be unoccupied despite frequent inspections. The unoccupied buildings and those occupied by postgraduate students

Table 3: Annual cooling energy for different set point temperatures in a typical building (Block 23)

Set point temperature	24°C	22°C	20°C
Annual cooling energy (RTh)	291,738	396,934	491,502
Increase in energy (%)		36%	68%

Table 4: Simulated annual cooling energy due to consumption during the weekends for various locations

Location	Authorized occupancy	Total cooling energy (Rth)
B1 Level 2	No	3,719
B4 Level 1	No	717
B15 Level 2	No	9,408
B15 Level 1	No	10,168
B16 Level G and 1	Yes	2,979
B17 Level G and 1	Yes	2,804
B21 Level G and 1	Yes	2,141
Total		31,936

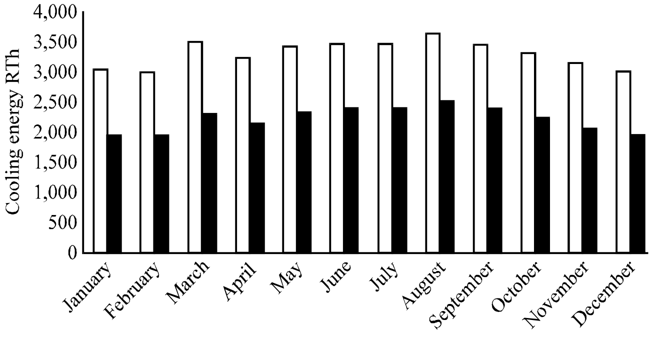

Fig. 4: Simulated annual cooling load for Block 17 Level 1 with isolation (black bars) and without isolation (white bars) of the unoccupied rooms

(without authorisation) contribute to cooling energy of 24,012 RTh per year which accounts for 75% of the weekend's total cooling energy. Such unnecessary waste of energy can be avoided in the future by imposing stricter rules for request of air-conditioning services during the weekends.

Scheduled isolation of cool air supply: Figure 4 shows the annual cooling load estimated by EnergyPlus simulation, with and without scheduling of cool air supply for Block 17 Level 1, as represented by the dark and light bars, respectively. For simplicity, the simulation is made with the assumption that the weekly schedule is the same throughout a year. It is shown that the scheduling is capable in reducing 33% of the annual cooling energy which is equivalent to an annual saving of about 13,089 RTh. Such a significant reduction is obtained due to the fact that out of the 16 air-conditioned rooms on Level 1, only three rooms require full-time cool air supply during lectures and laboratory activities, while the other rooms are supplied with cool air for only 6 h a day. The energy saving is anticipated to be higher if further reduction in the cooling energy during the semester break is accounted for.

In addition to saving in the cooling energy, there is also saving in term of electrical power to run the AHU's blower motor. When the motorized dampers of the VAV's are partially or fully shut, it causes an increase in air pressure in the main duct. As the pressure transducer detects the built-up pressure, the system will respond to counter the pressure increase in the main duct. The control system will send a signal to the Variable Speed Drive (VSD) control of the blower motor to reduce the pressure in the main duct by reducing the motor speed which consequently reduces the electrical power consumption.

Figure 5 and 6 show the variations in the motor loads of the AHU blowers with and without isolation of cool air supply to the unoccupied rooms for AB and CD sides, respectively, at Level 1 of Building 17. The results are presented for three consecutive weeks. As shown in the Fig. 5 and 6, the AHU's were turned off from midnight until 5.12 am, after which the AHU blowers were turned on for about 45 min to purge the indoor air. The blowers were turned on again at 7.42 am when the occupants started to arrive at the buildings. The results for the original setting; i.e., without isolation of the cool air supply to the unoccupied rooms, are represented by the thick line. The ones with scheduled isolation are represented by the continuous thin lines (for Week 1) and dashed lines

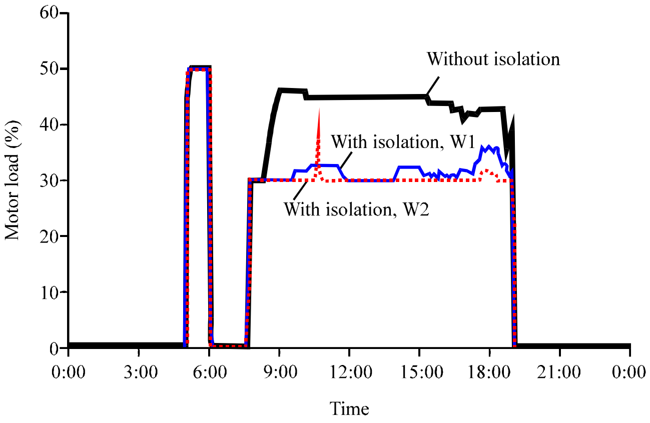

Fig. 5: Variation of the AHU motor load (in percentage) with time for Level 1 of Block 17 (AB-Side) with and without isolation of cool air supply to the unoccupied rooms

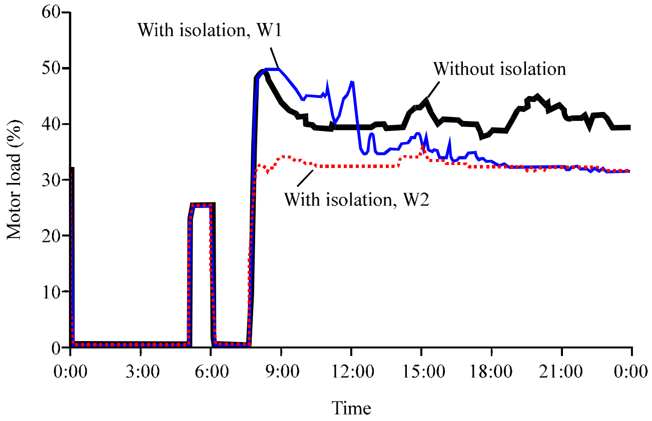

Fig. 6: Variation of the AHU motor load (in percentage) with time for Level 1 of Block 17 (CD-Side) with and without isolation of cool air supply to the unoccupied rooms

(for Week 2). The motor load for the AB-side is shown to reduce by about 15% during the operation hours, as a result of the isolation of cool air supply.

The trend was not so clear for the CD-side, as shown in Fig. 6. During the first week of the isolation, the motor load was observed to be higher for the first five hours probably due to increase in load resulted by increase in the number of occupants. Nevertheless in the second week, a consistent saving of about 17% was observed throughout the operation period of the CD-side AHU. The blower in the CD-side AHU was shut off at midnight as opposed to 7.00 pm for the AB-side AHU (due to request by the occupants).

Table 5 shows the total daily electrical energy consumptions for the AHU blower motors presented in Fig. 5 and 6. Comparisons are made with the results of Week 1 (i.e., without isolation)in order to assess the energy savings. It is shown in Table 5 that the electricity consumption for the CD-side AHU is about 2.5 times higher than that of the AB-side AHU. This is due to the greater occupancy in the building and also because the CD-side receives more sun radiation throughout each day due to the building's orientation relative to the sun's position. In addition, the CD-side AHU operates on longer hours due to the use of a computer lab

Table 5: Block 17 level 1 AHU fan electricity consumptions

	AHU (Side)		AHU (Side)		AHU (Side)	
	Week 1		Week 2		Week 3	
Factor	AB	CD	AB	CD	AB	CD
Total kWh (Electricity)	321.2	826.9	239.6	749.2	241.8	708.1
% Energy saving			25.4	9.4	24.7	14.4

until midnight. From the comparison, it is shown in Table 5 that the isolation of cool air supply results in an average of 25% electrical energy saving of AHU motor for the AB-side and an average of 12% for the CD-side. The difference is resulted by variation in the cooling load of the rooms in the AB and CD sides.

It is clearly demonstrated that the combination of scheduled isolation of cool air supply and reconfiguration of the VAV system to pressure independent mode would result in savings in the cooling load energy and the electrical energy of the blower motor. By reconfiguring the VAV system to the pressure independent mode, the VAV dampers opening is now fully responsive to the room temperature disregard of the need for a minimum air flow, as explained earlier. A greater saving is expected if the buildings' operations during the semester break are taken into account since the occupancy period of these areas is further reduced. The trend of improvement is expected for other floors and buildings as they have similar trends of occupancy.

Effect of outdoor air infiltration: Outdoor air infiltration caused by cracks or by opened doors or windows is one of the contributors of space cooling load through increase in both sensible and latent heat gain. During the design of an air-conditioning system, the engineers will normally incorporate infiltration load based on the level of air tightness of the building. Nevertheless, additional infiltration load may be imposed during the system operation if doors are purposely left open. Through inspections in the buildings of study, it was found that doors are usually left open, by placing objects that prevent them from shutting, for a long period of time to enable students and visitors to move in and out of areas within the buildings. These doors were usually locked for security reasons and therefore students and visitors would be required to call the staff in the area to open the door for them. In the present study, a simulation of cooling energy was performed for Block 23 with the assumption that each floor has one door that was purposely left open during the day time (8 am-5 pm). The infiltration rate was set in the simulation as one cubic foot per minute per square foot of the door area (Pita, 2001).

It was estimated from the simulation that the annual cooling energy for Block 23 would increase from 685,160 kWh to 1,026,043 kWh (higher by 50%) as a result of infiltration load from the door openings. Figure 7 shows the result of the simulation in term of monthly cooling energy over the period of 12 months. The dark color bars represent the results for air-tight building and the light color bars represent those with the specified infiltration rate. It is probable that the occupants would be able to accept the thermal condition caused by infiltration, as implied in one report (Kwong *et al.*, 2009). However, with the significant increase in the cooling energy in the present study, it is vital for the building operator to strictly ensure that doors are not left open for a long time to minimize infiltration load.

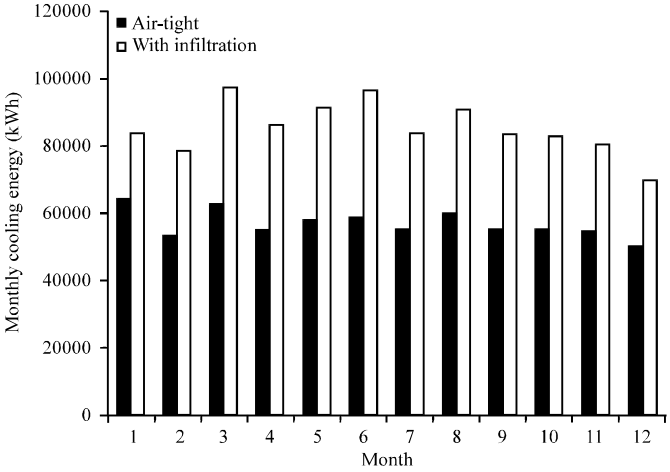

Fig. 7: Variation of monthly cooling energy for Block 23 with an infiltration rate of 1.0 cfm ft^{-2} of door area

CONCLUSIONS

Simulation of the cooling energy as a result of the operational behavior for highly glazed academic buildings was performed using EnergyPlus. From the study, the followings conclusions can be drawn:

- Space overcooling by reduction of the set point temperature of the thermostat in the glazed academic building would result in significant increase in the cooling energy by up to 70% and this would consequently increase the operational cost. In addition, overcooling was observed to cause discomfort among a large number of occupants
- Occupancy of buildings during the weekends was observed to contribute unnecessary wastage in the cooling energy if cool air is supplied to the unoccupied areas or buildings due to failure to check for the details in the requests made by occupants. From the present study, the wastage accounted for 75% of the weekend's total cooling energy and could be avoided by introduction of proper mechanism for request of air-conditioning services outside office hours
- The scheduled isolation of cool air supply and reconfiguration of the VAV system to pressure independent mode would result in significant savings in the cooling load energy by about 35%. Such strategy may also reduce the electrical energy of the blower motor by up to 25% through response of the variable speed drive of the AHU blower motor
- Outdoor air infiltration through opened doors could lead to a significant increase in the cooling energy of the buildings of study (by about 50%). The building operator with the cooperation of the occupants should ensure that doors are not constantly left open during regular buildings' operation periods

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Universiti Teknologi PETRONAS in the present study. The assistance of M Fatimie Irzaq in providing the related design information is highly appreciated.

REFERENCES

Al-Rabghi, O.M. and M.M. Akyurt, 2004. A survey of energy efficient strategies for effective air conditioning. Energy Convers. Manage., 45: 1643-1654.

Aun, C.S., 2004. Energy efficiency-designing low energy buildings using energy 10. 7th CPD Seminar, Pertubuhan Arkitek Malaysia.

Bhaskoro, P.T. and S.I.U.H. Gilani, 2011. Transient cooling load characteristic of an academic building using TRNSYS. J. Applied Sci., 11: 1777-1783.

Chan, A.L.S., 1994. Development of guidelines for Energy-efficient operation of fully Air-conditioned buildings in Hong Kong. Mphil. Thesis, City Polytechnic of Hong Kong.

Drost, M.K., 1992. Impact of operation and maintenance on the performance of energy systems. Human Factors Society (HFS) Annual Meeting. Atlanta, GA, United States. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6829355

Dupont, 2010. DuPont™ Corian®. DuPont science and technology. http://www2.dupont.com/Science/en_US/

EIA, 2010. Official energy statistics from the U.S. Government. Energy Information Administration. http://www.eia.doe.gov.

EnergyPlus, 2010. EnergyPlus energy simulation software. http://apps1.eere.energy.gov/buildings/energyplus/

Eskin, N. and H. Turkmen, 2008. Analysis of annual heating and cooling energy requirement for office buildings in different climates in Turkey. Energy Build., 40: 763-773.

Hien, W.N., W. Liping, A.N. Chandra, A.R. Pandey and W. Xiaolin, 2005. Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy Build., 37: 563-572.

Kwong, Q.J., S.H. Tang and N.M. Adam, 2009. Thermal comfort evaluation of the enclosed transitional space in tropical buildings: Subjective response and computational fluid dynamics simulation. J. Applied Sci., 9: 3480-3490.

Lam, J.C., 2000. Energy analysis of commercial buildings in subtropical climates. Build. Environ., 35: 19-26.

Lee, S.H. and F.W.H. Yik, 2010. A study on the energy penalty of various air-side system faults in buildings. Energy Build., 42: 2-10.

Leong, C.T., 2009. MS 1525: 2007 ACMV system energy management system. PAM CPD 2009 Seminar on Green Building Index Malaysia. Malaysia.

McQuiston, F.C., J.D. Parker and J.D. Spitler, 2004. Heating, Ventilating and Air Conditioning: Analysis and Design. 6th Edn., John Wiley and Sons, New York.

Perez-Lombard, L., J. Ortiz and C. Pout, 2008. A review on buildings energy consumption information. Energy Buildings, 40: 394-398.

Pita, E.G., 2001. Air Conditioning Principles and Systems: An Energy Approach. Prentice Hall, Upper Saddle River, New Jersey.

Poirazis, H., A. Blomsterberg and M. Wall, 2008. Energy simulations for glazed office buildings in Sweden. Energy Build., 40: 1161-1170.

Saidur, R., M. Hasanuzzaman, M.M. Hasan and H.H. Masjuki, 2009. Overall thermal transfer value of residential buildings in Malaysia. J. Applied Sci., 9: 2130-2136.

Sekhar, S.C., 1995. Higher space temperatures and better thermal comfort-a tropical analysis. Energy Build., 23: 63-70.

Sharma, V.K., D. Marano, C.N. Anyanwu, G.I. Okonkwo, C.N. Ibeto and I.S. Eze, 2011. Solar cooling: A potential option for energy saving and abatement of greenhouse gas emissions in Africa. Singapore J. Sci. Res., 1: 1-12.

Sulaiman, S.A. and A.H. Hassan, 2011. Analysis of annual cooling energy requirements for glazed academic buildings. J. Applied Sci., 11: 2024-2029.

Wang, F.J., Y.R. Zheng, C.M. Lai and C.M. Chiang, 2008. Evaluation of thermal comfort and contamination control for a cleanroom. J. Applied Sci., 8: 1684-1691.