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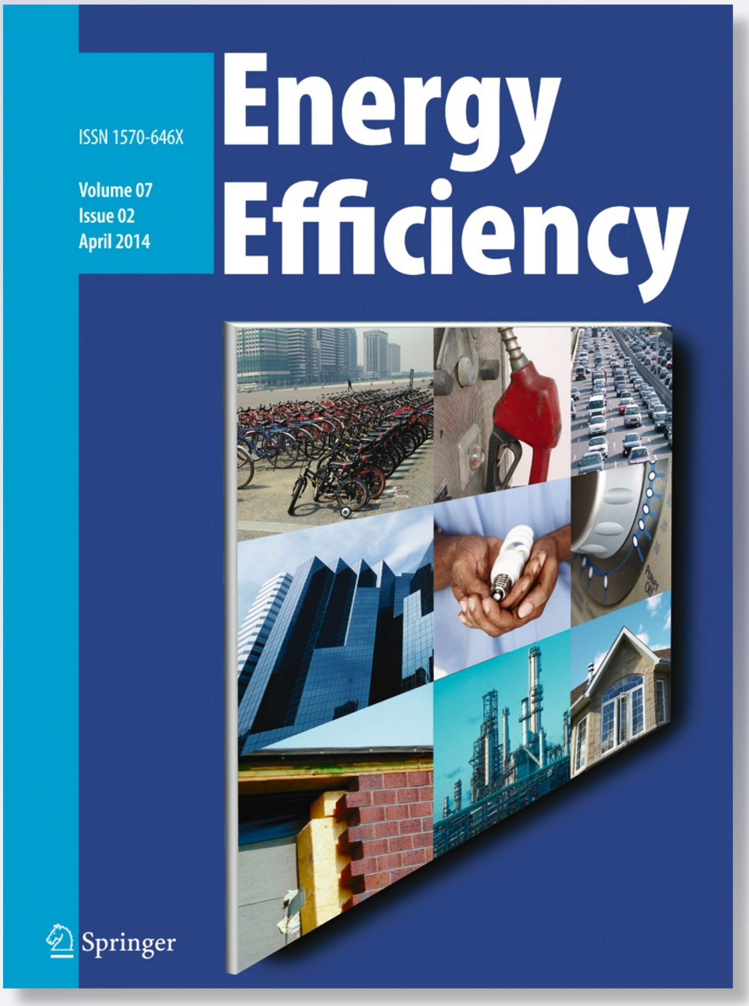

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ORIGINAL ARTICLE

Building energy index and end-use energy analysis in large-scale hospitals—case study in Malaysia

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Abstract Hospital energy consumption is relatively high, while saving energy and reducing cost comprise one of the most important challenges considered by the majority of building designers, engineers, and decision makers. An end-use energy analysis was conducted in a large-scale hospital in Malaysia to identify energy apportioning and energy end use in the areas of air conditioning, lifts, lighting, equipment, and others. The analysis was carried out by assessing the collected desktop and field data as well as some calculations. The Building Energy Index (BEI) was calculated to compare the consumption levels in the selected hospital, which is a typical hospital building, with other hospitals in Malaysia as well as low energy buildings and Malaysian standards. The main energy source in this case study was electricity with a supply of around 75 % of total energy consumption. The current average annual electricity consumed by this hospital was 44,637,966 kWh, out of which 63 % was used by air conditioning systems and 17 % by lighting. The BEI comparison revealed that the calculated BEI of 384-kWh/m^2/year is significantly higher than Malaysian rating systems and standards which recommend 200 kWh/m^2/year for hospitals, 135 kWh/m^2/year for commercial sectors, and is higher than previously observed hospitals with a BEI of less than 300 kWh/m^2/year.

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Keywords Building Energy Index (BEI) · End-use energy · Hospital · Electricity · Malaysia

Introduction

Energy consumption is among the larger challenges that architects and engineers are faced with in building design processes. Some studies reveal that in developed countries, energy usage in residential and commercial buildings has gradually grown by 20 % to 40 % in the last decade (Pérez-Lombard et al. 2008; Aste and Del Pero). In the commercial sector, the amount of energy consumed during the 5-year period from 2000 to 2005 increased more than 500 Peta Joules and it reached 3,127 PJ by 2010 (Chua and Oh 2010). Decision makers have been expressing mounting concerns and awareness regarding low energy buildings since 2000 (Lim et al. 2012). According to Saidur et al. in 2010, the commercial sector utilized roughly 32 % of the total energy consumed in Malaysia (Saidur et al. 2010).

Owing to increasing fuel prices, fossil fuel depletion and higher CO_2 emissions into the environment as well as global warming, the demand for designing and building energy-efficient projects has become more serious and may be considered a potential, cost-effective solution to mitigate the energy and environment issues (Teske et al. 2011; Bertoldi and Rezessy 2008). In addition, to keep up with the increase in global energy demand, low energy buildings are required to protect energy resources for future generations (Sebitosi 2008).

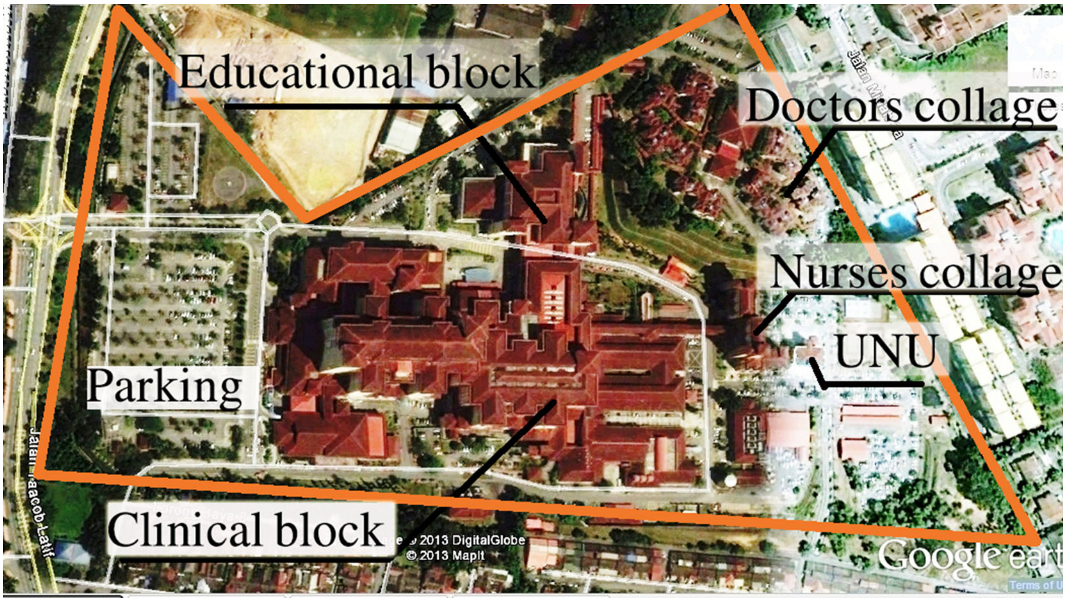

Fig. 1 Plan view of UKMMC

Efficient energy consumption must be considered one of the most important plans and policies in developed countries (Al-Mansour 2010; Mahlia et al. 2004; Guerra-Santin and Itard 2012). Energy supply planning for different buildings is a fruitful aspect of saving energy and protecting the environment due to the major shares the building sector has in energy consumption (Chung and Park 2010; Murakami et al. 2009).

Hospitals in particular are an immense consumer due to the around-the-clock operation. Hospitals utilize high energy levels through air conditioning systems, lighting, medical and office equipment, and so on. The high price for this energy has led hospital decision makers and management to make a goal of diminishing energy consumption. In hot-humid areas, air conditioning takes a significant energy toll when preparing good indoor air quality as well as thermal comfort, particularly in hospitals.

The main objectives in this study are as follows:

- to analyze the end-use energy in a large-scale hospital in Malaysia
- to calculate the Building Energy Index (BEI)
- to compare the BEI to other hospitals as well as green buildings, the Malaysian standard, and the green building rating system in Malaysia

Table 1 UKMMC blocks area

Area	Total area (m^2)
Clinical and teaching blocks	240,074
UNU (United Nations University)	1,300
KTDI Doctors college	9,400
Nurses college	9,000
Total building	259,774

Table 2 Clinical and educational blocks area

Area	Total area (m^2)	Area percentage
Clinical and teaching block	240,074	100 %
Total air-conditioned area1	178,632	74 %
Total occupied area 2	188,610	79 %
Total 24 h operation area	137,854	57 %

1 excludes lift core, staircase area, toilet, electrical, and mechanical service room. *2* excludes electrical and mechanical service rooms

Table 3 Wall materials at UKMMC

Wall type	Air-conditioned area external wall	Non air-conditioned area external wall	Internal walls
Materials	- Finishing paint	- Finishing paint	- Finishing paint
	- 2 cm cement	- 2 cm cement	- Cement
	- 10 cm brick wall	- 10 cm brick wall	- 10 cm brick
	- 30 cm cavity	- 2 cm cement	- Cement
	- 10 cm brick wall	- Internal paint	- Finishing paint
	- 2 cm cement		
	- Finishing paint		

Research methodology

Site description

Malaysia is a tropical country with a hot-humid climate lying between 1° and 7° North and 100° and 120° East (Azizpour et al. 2012). Yearly mean temperatures in Malaysia range between 26 °C and 27 °C, and high daytime temperatures can reach around 29–34 °C. The relative humidity throughout the year is 70 % to 90 % (Azizpour et al. 2011a; Moghimi et al. 2011). The case study selected University Kembangsaan Malaysia Medical Centre (UKMMC) for evaluation. The field study was established as an educational hospital in 1997 and is located in Cheras, Selangor. It comprises one 14-story clinic block, a 9-story educational block, and also 11, 4, and 3-story residential blocks including a college for nurses and doctors (KTDI). The United Nations University is a 5-story block behind the nurses' college (Azizpour et al. 2011b). The building's general plan view is illustrated in Fig. 1.

This building was constructed with most windows facing directly North and South. The clinical and teaching blocks are connected at the basement and second floor. The 2nd to the 7th floors of the clinical block are utilized as wards, except the third floor which is an unoccupied service floor; clinics are located on the ground floor and first floor. Most office spaces are located at levels 8 and 12, while most laboratories are at the basement, ground, and first floors. The generator room, main meter room, and chiller and boiler rooms are situated at the ground floor. The main entrance is on the West side of the building. There are five main building

Table 4 Methods of evaluating annual, monthly and daily energy consumption in UKMMC

Methods	Desktop data collection					Field data collection				Calculation		
	Architectural drawing maps	Electrical drawing maps	Mechanical drawing maps	Historical data on energy bills	Technical documents	Building energy related data survey	Reading the main electricity meter	Reading the electricity submeters	Energy end use measurements	Equation 1	Equation 2	Equation 3
Annual energy consumption				•								
Monthly energy consumption				•								
Daily energy consumption							•					

Table 5 Methods used to evaluate different electricity consumption sources

Methods		Desktop data collection					Field data collection				Calculation		
		Architectural drawing maps	Electrical drawing maps	Mechanical drawing maps	Historical data on energy bills	Technical documents	Building energy related data survey	Reading the main electricity meter	Reading the electricity submeters	Energy end use measurements	Equation 1	Equation 2	Equation 3
Air conditioning system	Central system (Chillers, pumps)	●	●	●					●				
	Mini chillers			●		●				●			
	AHU			●		●					●		
	FCU			●		●					●		
	Split Unit			●		●					●		
	Ceiling fans		●			●	●				●		
	Exhaust fans			●		●					●		
Lifts		●								●			
Lighting		●	●				●					●	
Equipment and other		●			●								●

AHU air handling unit, *FCU* fan coil unit

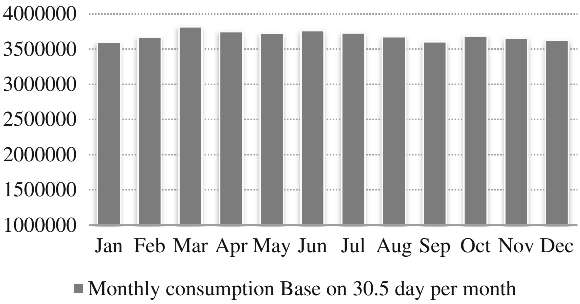

Fig. 2 Monthly electricity consumption based on 30.5 days per month

cores, of which four are in the clinical building and one is in the teaching block. Each core includes lifts, staircases, and electrical and mechanical service rooms. Moreover, there are emergency staircases at the corridor ends in the Western and Eastern building sections.

The gross area of the hospital is 259,774 m^2, of which 70 % is air-conditioned. This study focused on the clinical and teaching blocks.

Details of the floor areas are provided in Tables 1 and 2 below:

The external wall materials in the air-conditioned and non-air-conditioned areas are not exactly the same. Table 3 illustrates the external wall materials from outside to inside as well as the internal wall materials. The window frames are made of aluminum and the glazing is normally 6 mm thick. The majority of door frames are made of metal and the doors are wooden. All the windows in the air-conditioned areas are supposed to be closed; however, a few windows remain open, especially in the lobby or some corridors during measurement times. Also, the windows have no shading devices. The building runs on a scale schedule, whereby the office and clinic working hours are from 8:00 am to 5:30 pm and wards operate 24 h over three shifts: 7 am to 3 pm, 3 pm to 11 pm, and 11 pm to 7 am.

Table 6 Type sizing of UKMMC lighting

Per capita lighting (W/m^2)		Working hours (h)	Time usage factor (%)	Working days (days)
0	3	24	100	365
3.5	5	12	80	244
6	6.3		20	
7	7.3		10	
9	10			
11.3				

Table 7 Annual electricity consumption of UKMMC blocks

Zone	EC (kWh)
KTDI	1,161,087
UNU	260,000
Nurses college	1,347,600
Clinical and educational block	41,379,113
Total UKMMC	44,147,800

EC electricity consumption

Energy monitoring methods

The data used to monitor the energy were based on the three main steps of gathering building energy-related data as follows:

Desktop data collection

The aim of collecting desktop data is to minimize the amount of field energy related data collected by using all available facility data, as well as to decrease the cost and time of gathering data. The desktop data utilized in this study includes:

1. Architectural drawing maps
2. Historical data on energy bills
3. Electrical drawing maps
4. Mechanical drawing maps
5. Technical documents

Field data collection

The purpose of collecting field data is to complete missing information, verify the accuracy of desktop data and understand building functions and operation. The field study technique applied comprises:

1. Building energy related data survey
2. Reading the main electricity meter
3. Reading the electricity submeters
4. Energy end-use measurements

Calculation

Calculations were done to estimate energy consumption by using some data according to desktop and field data based on certain equations. The three equations employed in this study are:

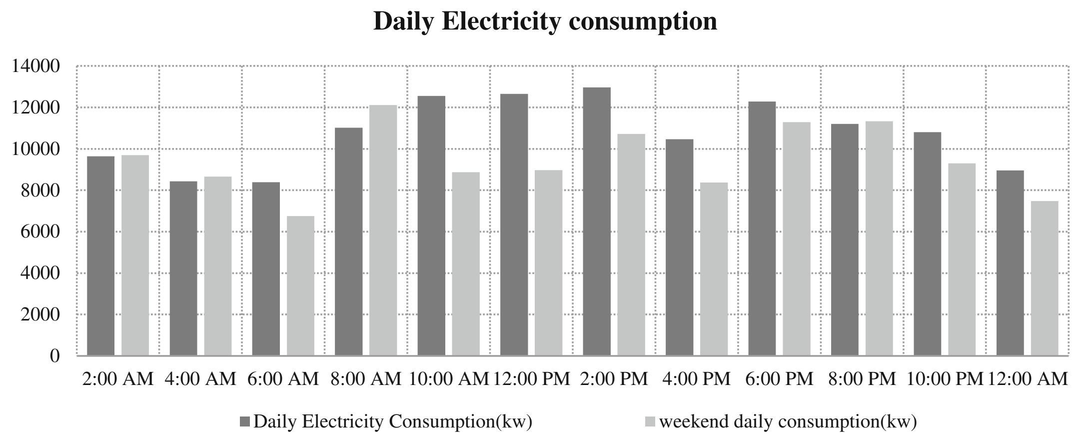

Fig. 3 Daily electricity consumption in UKMMC

1. Annual electricity consumption of motors used in air conditioning systems

   Equation 1: Annual motor electricity consumption

   $$AECm = P \times TU \times LD \times TUF \times Nd$$

   where AECm is annual motor electricity consumption in kWh, P is power in kW, TU is time usage in a day, LD is loading factor in %, TUF is time usage factor in %, and Nd is the number of usage days in a year.
2. Annual lighting electricity consumed by each lighting zone

   Equation 2: Annual lighting electricity consumption

   $$AECl = LT \times A \times TU \times TUF \times Nd \Big/ 1000$$

   where AECl is annual lighting electricity consumed in kWh, LT is lighting type in W/m^2, A is the area of each lighting zone, TU is time usage in a day, TUF is time usage factor in %, and Nd is the number of usage days in a year.
3. Annual equipment electricity consumed by medical and office equipment, and general plugs

   Equation 3: Annual equipment electricity consumption

   $$AECe = TAEC - (AECa + AECl + AECli)$$

   where AECe is annual equipment electricity consumption in kWh, TAEC is total annual electricity consumption in kWh based on electricity bills, AECa is annual air conditioning electricity consumption in kWh, AECl is annual lighting electricity consumption in kWh, and AECli is annual air lift electricity consumption in kWh.

Table 8 UKMMC daily electricity consumption in a year

	Daily consumption (kWh)	Percentage (%)	No. of days in a year
Working day	129,363	100	244
Weekends/ holidays	113,544	88	121

Energy consumption

Electricity is the main source of energy in this hospital and is supplied by TNB (Tenaga Nasional Berhad). According to TNB, hospitals fall under Tariff C2 which charges customers a flat rate of RM0.288($ US 0.092) per kWh at peak times, RM0.177($US 0.056) during off-peak times, and maximum demand rate (MD) of RM35.60 ($ US 11.39) per kW (TNB:Tenega National Berhad 2012). UKMMC is supplied with four utility meters at HV (high voltage). The incoming power supply is 11 kv. It steps

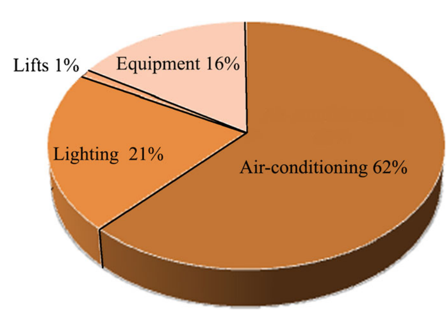

Fig. 4 UKMMC energy electricity apportioning

Table 9 Electricity consumption of different sections in UKMMC

Sections	Consumption (kW)			Percentage of total (%)	
Air conditioning	Main central system (Chillers, pumps, mini chillers)	19,323,977	25,663,203	46.7	62.0
	AHU	3,361,624		8.1	
	FCU	621,842		1.5	
	Split Unit	1,172,791		2.8	
	Ceiling Fan	30,660		0.1	
	Exhaust Fans	1,152,309		2.8	
Lifts	552,664			1.3	
Lighting	8,513,900			20.6	
Equipment and others	6,649,345			16.1	
Total	41,379,113			100	

AHU air handling unit, *FCU* fan coil unit

down through 11 kv/433 volt transformers to the main switchboard (MSB) at 9 substations. The electricity energy is distributed throughout the building from the various substations. In each section, normal and essential electricity is divided into two sectors: lighting-power electricity and mechanical electricity. Since hospitals operate 24/7 and due to the importance of some equipment, they must be supplied with electricity all the time. The backup electricity at UKMMC hospital is supplied by a generator that uses diesel oil in small part.

Natural gas (LPG) is the second energy source used to heat water in this hospital for kitchen use, sterilization, laundry and others. PETRONAS is the company supporting all natural gas demand of UKMMC.

To achieve the first objective of this study, three levels, namely annual, monthly, and daily energy consumption, were calculated based on the previously mentioned energy monitoring methods. Table 4 illustrates the method utilized for each level.

To calculate the annual and monthly electricity and LPG usage, the historical energy bills for the entire UKMMC from January 2009 to December 2011 were collected. Four, high-voltage incoming sources from TNB enter the building through the high voltage room. To measure daily consumption, the data from 4 m were read every half an hour during the day from 8 am to 10 pm, and hourly during the night from 10 pm to 8 am. Measurements were taken on both working days and weekends including two working days and 2 days at the weekend on 29–30 December 2011 and 7–8 January 2012, respectively. The daily consumption over the holidays is considered the same as for weekends.

Energy electricity apportioning

To find the energy apportioning in this hospital, all sources of electricity consumption are divided into four main groups: (a) air conditioning, (b) lifts, (c) lighting, and (d) equipment and others. Table 5 shows the methods applied to each group.

To measure the electricity consumed by any specific part such as air-conditioning systems or lifts, a power logger was used. This equipment can log and record electricity consumption data over a particular period of time. The power logger model employed for this project was 1735-Fluke.

Air conditioning

To find UKMMC's end use of the air-conditioning systems, the central system (9 main chillers and pumps), 9 mini chillers, 141 AHU units (Air Handling Unit), 833 FCU units (Fan Coil Unit), 308 split units, ceiling fans, and exhaust fans were evaluated. The 9 main chillers have particular submeters which must be read in order to calculate electricity consumption. The 9 mini chillers were logged with a power logger for 14 days continuously from

Table 10 Total annual energy usage in UKMMC

Energy source	Energy consumption (kWh)	Percentage (%)
Electricity	41,379,113	72
LPG	15,926,293	28
Total	57,305,406	100

Table 11 Comparison between energy consumption of three hospitals

			UKMMC	Hospital A	Hospital B
Energy consumption	KWh	Annual Electricity Consumption (kWh)	41,780,454	14,704,367	25,000,000
		Annual Fuel Consumption (kWh)	15926293	9,200,000	10,600,000
		Annual Energy Consumption (kWh)	57,705,036	23,904,367	35,600,000
	Percentage (%)	Electricity consumption %	72	62	70
		Fuel consumption %	28	38	30
Area	Area m^2	Occupied air-conditioned area (m^2)	150196	80,597	90,000
	Area %	Air-conditioned area over occupied area (%)	80	71	75
BEI	KWH/m^2/year	BEI: total energy over occupied air-conditioned area	384	217	297
Electrical energy apportioning	Percentage (%)	Air-conditioning	62	63	65
		Lighting	20.6	22	18
		Equipment, lifts and others	17.4	15	17

8th February to 21th February 2012, including 10 working days and 4 weekends. Owing to the tropical climate, the cooling demand throughout the year is nearly always the same with little fluctuation. Moreover, according to Fig. 2, February is a medium cooling demand month and may be a proper representative of the whole year. Electricity consumption of other air-conditioning system parts including split units, AHUs, and fan coils, was calculated using Eq. 1during both working days and weekends.

Lifts

UKMMC has 33 lifts of which 29 are located in 5 main hospital cores and the 4 remaining are particularly for operation rooms in the clinical block and the library in the educational block. Energy consumption of each group of lifts in each of the five cores was measured by a power logger separately. In total, 16 days were logged for the lift rooms, with 13 days of measurement during working days and 3 days at weekends on 11–31 January 2012. The measurement details are tabulated in Appendix Table 14.

Lighting

To calculate annual electricity used by lighting, all the zones were classified according to different lighting types. Table 6 shows the various types of lighting based on per capita lighting, working hours, time usage factor,

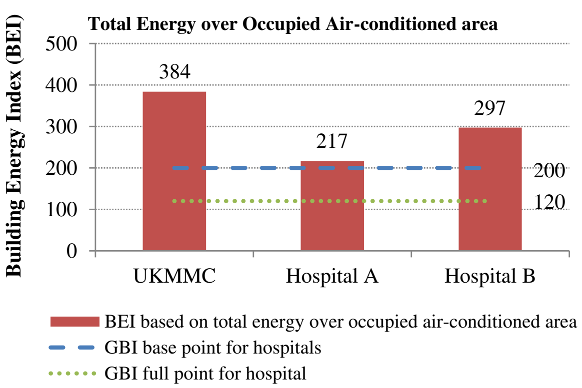

Fig. 5 BEI comparison between UKMMC and 2 other hospitals and GBI recommendation limit

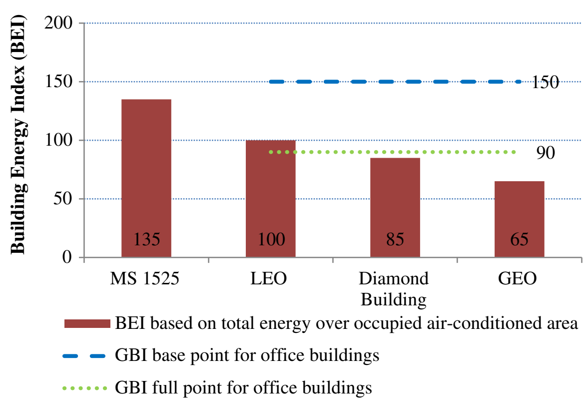

Fig. 6 BEI comparison between Malaysian standard, green buildings, and GBI recommendation limit

Table 12 Indoor air condition of UKMMC comparison to Malaysian Standard (MS1525)

	Dry temperature (°C)	Air velocity (m/s)	Relative humidity (%)
Average of objective measurement	25.84	0.135	54.92
Recommended standard MS1525	24–26	0.15–0.50	50–70

and working days over a year. According to these 4 factors, UKMMC is separated into 28 sections of lighting by 2 ft, 4 ft, and efficient lamps based on electrical plans and observation. Equation 2 was applied to calculate the electricity consumption in this section. The list of different lighting zones is given in Appendix Table 15.

Equipment

To calculate the electricity consumed by equipment including medical and office equipment in addition to general power, Eq. 3 was calculated.

Building Energy Index (BEI)

Building Energy Index (BEI) is the ratio of a building's total energy usage (kWh) per year to the building area (m^2; GBI:Green Building 2010).To understand the energy usage level of UKMMC, the BEI of this hospital was calculated and compared to the BEI of other hospitals in the same climate and some low energy buildings in Malaysia.

Green Building Index (GBI)

The GBI was launched in April 2009 by the Malaysian Institute of Architects and the association of Consulting Engineers Malaysia together with the building industry to enable green grading and the certification of Malaysian buildings. GBI is a rating system that provides a comprehensive building assessment framework in terms of energy efficiency, indoor environment quality, sustainable site planning and management, materials and resources, water efficiency, and innovation. According to GBI, for green grading of existing non-residential buildings 15 points are allocated to energy efficiency. A building defined as an efficient building based on its BEI. The base BEI for an office building to obtain points is 150, while for hospitals, it is 200 kWh/m^2/year. To get full energy efficiency points, office buildings and hospitals should have a BEI of 90 and 120 kWh/m^2/year, respectively. In this study, the BEI of UKMMC is compared to the GBI recommended limit (GBI: Green Building Index 2010).

Results and observations

Electricity consumption

Annual electricity consumption

According to the historical monthly electricity bills over 3 years from January 2009 to December 2011, the average annual electricity consumption of UKMMC was 44,147,800 kWh. Since this study focused on the clinical and educational blocks, these two blocks' annual energy usage was calculated and 41,379,113 kWh was obtained. Table 7 illustrates the annual electricity consumption of all blocks in the hospital. The summary of the monthly energy bills for the whole PPUKM from January 2009 to December can be seen in Appendix Table 16

Monthly electricity consumption

To accurately compare monthly electricity consumption, it was calculated based on 30.5 days. According to Fig. 2, the monthly electricity usage is almost the same throughout the year. Nevertheless, March has the highest electricity consumption and January has the lowest, due to the minimal difference in seasonal cooling demand.

Daily electricity consumption

To evaluate daily electricity consumption, it was measured and calculated every two hours for weekdays and weekends separately. Figure 3 shows that the largest amount of energy consumed is from 8 am to 2 pm in both weekdays and weekends due to the clinical and medical imaging sections like MRI and radiology which function more during this period of time. Therefore, maximum demand should refer to this period. In other words, if energy can be saved in each section during this period, the maximum demand would decrease as along with the bills. In addition, some strategy of shifting the energy consumption from peak time to off-peak time could help reduce the maximum demand. During the night from 2 am to 6 am, electricity consumption decreases by two

Table 13 Energy efficiency strategies recommended by MS 1525 for Malaysia

No.	Energy efficiency strategies	
1	Architectural and passive design strategy	Day lighting, thermal insulation, renewable energy, facade design, air leakage
2	Lighting	Lighting controls, high efficient lighting equipment
3	Electric power and distribution	Alternative current (A.C.) electric motors, cabling, transformers, inverters, sub metering
4	Air-conditioning and mechanical ventilation (ACMV) system	Load calculations, system and equipment sizing, separate air distribution systems, controls, piping insulation, air handling duct system insulation, duct construction, ACMV systems
5	Energy management control system	Energy management system (EMS), control of equipment, monitoring of equipment, integration of equipment subsystems, training for users

thirds compared to peak hours, while consumption is the lowest during both working days and weekends.

As clarified in Fig. 3, the difference between electricity consumption during the day time and night time is not as much as expected. Two reasons justify this fact. First of all, 90 % of total gross area in UKMMC is occupied and 57 % operates around-the-clock, meaning that 63.3 % of the occupied area functions at night. Secondly, UKMMC uses ice storage for air conditioning, which works during the night to make and store ice to be used for the daytime cooling load. Thus, the difference in consumption between the night and day time is almost 30 %, much less than for other buildings.

There are a number of sections in UKMMC that operate during weekends and holidays including laboratories, wards, and emergency and on-call offices. As Table 8 shows, the electricity consumed during weekends and holidays is around 88 % of the working days. Therefore, the energy efficiency strategy may yield much better results than other buildings in addition to a shorter payback period. In the Malaysian calendar, there are 244 working days and 121 off days.

Electricity energy apportioning

UKMMC end-use electricity usage was calculated according to historical bills, power loggers, and submitters. Figure 4 shows UKMMC energy electricity apportioning depicts the percentage of 4 main electricity consumer sections in the hospital including air conditioning, equipment, lighting, and lifts. Moreover, Table 6 displays the annual consumption of each section in kW. The pie chart and Table 9 clarify that air conditioning is the highest in terms of energy usage in this case study by around 63 % of total energy consumption, while chillers constitute the largest portion of air conditioning with 44 %.The UKMMC energy apportioning is almost identical to 2 other hospitals in Malaysia which were studied by Saidur et al. in 2010 (Saidur et al. 2010).

LPG consumption

The second energy source in UKMMC is liquid petroleum gas (LPG) which is supplied by PETRONAS. By reviewing 3 years worth of historical bills, it is evident that the average annual consumption was approximately 16 million kWh. Moreover, similar to electricity usage, there was no significant difference between the months over a year since LPG in this hospital was consumed for water heating used in kitchen, sterilization and laundry. The summary of the annual LPG usage can be seen in Appendix Table 17. Table 10 demonstrates the amount and percentage of two energy recourses including electricity and LPG in UKMMC.

BEI calculation

BEI comparison with other hospitals and GBI

To determine the energy usage level of UKMMC, a comparison between three hospitals in Malaysia was performed. Table 11 illustrates the data summary for the three hospitals (Saidur et al. 2010; Kassim and Bathish 2001). It is clear in Fig. 5 that the BEI of UKMMC is higher than that of two other hospitals in terms of total energy. However, because these hospitals are not fully comparable, it can be said that UKMMC requires some changes towards reducing the BEI. A comparison between the recommended

GBI and the hospitals' BEI indicates that the BEI of all hospitals is higher than the base GBI point.

BEI comparison with Malaysian standard and green buildings in Malaysia

In Malaysia, there are two references which provide the proper level of BEI according to various building classifications, including the Malaysian Standard (MS1525: Malaysian Standard 2007) and the Green Building Index (GBI: Green Building Index 2010). To compare green and efficient buildings, in light of the lack of green hospitals in Malaysia, three main low energy office buildings that properly utilize several energy efficiency strategies were selected, namely the Low Energy Office (LEO), the Diamond building, and Green Energy Office (GEO; Chua and Oh 2010). However there are differences in operation hours and required equipment between hospitals and offices, the data obtained from these green offices can show how much energy efficiency strategies can be effective in Malaysian buildings located in tropical climate. In addition, the comparison illustrates the UKMMC have opportunities to become more efficient building. Figure 6 shows the comparison between Malaysian standard and three Malaysian green buildings. the BEI of all three green building offices in Malaysia is less than 100 kWh/m^2/year while the GBI base point and full point for office buildings are 150 and 90 kWh/m^2/year, respectively. This finding emphasizes the need for UKMMC to retrofit and apply new energy efficiency strategies.

Energy efficiency strategies to reduce the BEI

The average of indoor air factors (air temperature, air velocity, relative humidity) measured in various time and location was calculated. Table 12 illustrated the indoor air factors average value and recommendation limit by Malaysian standard. According Table 12, the dry bulb temperature and relative humidity(RH%) are within the recommended range declared by MS1525. the air velocity is also close to recommendation limit.

To make the UKMMC meet the Standards in terms of BEI and energy consumption, there are some strategies recommended by MS 1525 to apply to the building (MS1525: Malaysian Standard 2007).

Table 13 listed the strategies categorized in 5 main parts including architectural and passive design strategies, lighting, electric power, air conditioning and energy management control system.

Conclusions

Due to the importance of energy efficiency, this study—carried out in one of the large-scale hospitals in Malaysia (UKMMC)—aimed to determine end-use energy, calculate the BEI, and also make a comparison with other buildings and standards (Appendix Tables 14 to 17).

- Energy apportioning in this case study was almost the same as in the other two hospitals in Malaysia, while air conditioning carries the largest load of energy consumption at around 63–65 %, lighting at roughly 18–22 %, and other equipment at approximately 15–17 %.
- The calculated BEI according to total energy over the occupied air conditioning area was 384 kWh/m^2/year.
- It was also shown that the BEI according to total energy over the air-conditioning area was 2 times higher than GBI recommendation limit for hospitals. Furthermore, it was 1.5–2 times higher than two other Malaysian hospitals. This finding highlights the need for UKMMC to apply some low energy strategies.

Future work

Further studies regarding various passive and active energy efficiency strategies and renewable energy are recommended to predict the percentage of energy saved through each strategy. Moreover, the new BEI for this case study can be calculated in addition to the net saving cost and payback period of different strategies.

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Appendix A

Table 14 Lift data measurement of UKMMC

Cores	A	B	C	D	E	Others
Total daily consumption by power logger	225.0	211.6	249.5	174.3	219.3	
Number of lifts logged	3	4	5	4	5	4
Lifts NO	4_5_6	7-8-10-11	13-14-15-20-21	22-23-24-25	26-27-28-29-30	16-17-18-19
Daily working day consumption of each lift (kW)	75.0	52.9	49.9	43.6	43.9	21.8
Daily weekend consumption of each lift (kW)	60.7	43.0	40.4	35.3	30.7	17.6
Annual consumption of each lift (kW)	25,650	18,116	17,069	14,901	14,415	7,451
Lifts NO that estimated at the same consumption	1-2-3-4-5-6	7-8-9-10-11-12	13-14-15-20-21	22-23-24-25	26-27-28-29-30-31-32-33	16-17-18-19
Total number of lift at the same consumption	6	6	5	4	8	4
Total consumption at each core (kW)	153,897.9	108,696.1	85,344.8	59,605.4	115,317.5	29,802.7
Total consumption of lifts (kW)	552,664					

Table 15 lighting zones in UKMMC

No.	Zone	Area (m^2)	Operating hour	Usage factor (%)	EC (W/m^2)	Annual EC (kWh)	Annual working day
1	Ward 1 (normal)	44,561.5	24	80	7.3	2,279,695	365
2	Ward 2 (ICU-CCU)	2,031.1	24	80	7.3	103,908	365
3	Clinic	13,352	12	100	9	351,852	244
4	Laboratory 1 (Normal)	16,486.2	24	80	6	693,212	365
5	Laboratory 2 (Radiology–Dialyses)	2,929	24	80	6	123,159	365
6	Lobby 1 (24 h)	1,797.2	24	100	5	78,717	365
7	Lobby 2 (12 h)	355.7	12	100	5	5,207	244
8	Void	3,444.2	24	0	0	0	365
9	Office 1 (Normal)	40,019.9	12	100	9	1,054,604	244
10	Office 2 (1 day a week)	3,584.4	12	20	9	18,891	244
11	Office 3 (library)	2,133.1	24	80	9	89,938	244
12	Office 4 (24 h)	766.5	24	100	9	60,431	365
13	Lecture hall	1,843.4	12	80	10	43,180	244
14	Corridor 1 (24 h)	24,010.3	24	100	5	1,051,651	365
15	Corridor 2 (12 h)	4,425.3	12	100	7	90,701	244
16	Stair case	9,021	24	100	3.5	276,584	365
17	Parking	14,024	24	100	3	368,551	365
18	Store 1 (normal)	2,692.4	24	10	3	7,076	365

Table 15 (continued)

No.	Zone	Area (m^2)	Operating hour	Usage factor (%)	EC (W/m^2)	Annual EC (kWh)	Annual working day
19	Store 2 (Air con 24 h)	1,447	24	10	5	6,338	365
20	Core	12,678.4	24	100	5	555,314	365
21	Service 1 (Kitchen–laundry)	3,461.3	24	80	5	121,284	365
22	Service 2 (Mechanical)	16,851.5	24	10	3	44,286	365
23	Service 3 (Electrical–air con)	422.9	24	100	5	18,523	365
24	Roof	43,903.8	0	0	0	0	365
25	Entrance–terrace	4,444	24	80	5	155,718	365
26	Praying room	836.1	24	80	6.3	36,914	365
27	Emergency	3,859.2	24	80	7.3	197,430	365
28	Surgery	8,596.2	24	80	11.3	680,737	365
	Total					8,513,900	

EC electricity consumption

Table 16 Annual electricity consumption over 3 years 2009–2011

Month	Monthly consumption (kW)	Number of days	Total consumption per day (kW)
January	3,655,070	31	117,906
February	3,368,302	28	120,297
March	3,878,100	31	125,100
April	3,684,240	30	122,808
May	3,780,181	31	121,941
June	3,698,370	30	123,279
July	3,787,807	31	122,187
August	3,734,425	31	120,465
September	3,543,360	30	118,112
October	3,743,756	31	120,766
November	3,591,420	30	119,714
December	3,682,769	31	118,799
Annual consumption(KW)	44,147,800		

Table 17 Annual LPG consumption over 3 years 2009–2011

Year	Total consumption per year (KG)	Total consumption per year (kWh)
Annual LPG consumption 2009	1,217,743	16,439,536
Annual LPG consumption 2010	1,179,599	15,924,582
Annual LPG consumption 2011	1,141,834	15,414,761
Average annual LPG consumption	1,179,725	15,926,293

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