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Optimizing the energy saving potential of public hospital through a systematic approach for green building certification in Malaysia

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ABSTRACT

Hospital buildings are the main energy users among government facilities which require substantial energy reduction to save its annual operational costs. At the same time, the Ministry of Health Malaysia has set a policy for all hospitals to achieve green building certification, which in line with its global commitment to conserve the environment. Energy efficiency is an important component in every green building rating tool because of its high potential on point scoring. Thus, there is a need to find the most appropriate method to explore energy saving opportunities as much as possible. The overall aim of this article is to evaluate the potential for energy saving in public hospital using a systematic approach. Three methods are applied in this approach which involved energy audit, empirical evidence and simulation works. Energy audit predicts that the chiller system provides the highest energy saving amount of 1,535,175.40 kWh/year (45.54 %) with discounted payback period of 7.15 years. A chiller retrofit measure was implemented as pilot project and the predicted energy savings were validated by empirical evidence. The actual energy saving of 1,688,347.02 kWh/year (50.08 %) was obtained from the chiller system retrofit and slightly higher than what was predicted with discounted payback period of 6.29 years. Apart from active measures, many more energy saving potentials can still be explored through passive strategies. Simulation method is used to establish energy baseline as the basis for predicting energy saving potential for passive strategies that cannot not be measured through energy audit. The combination of these methods is essential to optimize the potential of energy saving through active and passive strategies that have so far has never been implemented in any public hospital in Malaysia.

1. Introduction

1.1. Background

Hospital buildings are the most complex facilities among other buildings because they have specific clinical requirements that must be complied to ensure the services provided to customers are met. Green building rating tools developed around the world are intended to guide architects, engineers, contractors, and building owners to conserve the environment through established methods and guidelines. Green building not only fulfils the function of a building in providing excellent service, but also ensures that it complies with all applicable local and international laws, regulations, and standards that support the operation of the hospital. In addition, the implementation of each green element in hospital buildings will help reduce operating costs through energy and water savings, as well as more efficient use of green technology.

The design and architecture of hospitals evolved from post-independence to the present. Among the factors that contribute to this change include new operational and clinical requirements, compliance with current standards, and climate change. In addition, the old and inefficient physical states of the building, equipment, and systems contributed to high electricity consumption and increased daily operational cost. Efficient electricity management has the potential to save on building, operating costs and preserve the environment globally [1]. Malaysia, as a developing country, needs to consider energy efficiency as a key policy in planning strategies toward sustainable development [2, 3]. Wise energy supply planning and strategies in every hospital building are important in ensuring that energy savings can be achieved, especially in the building sector, which is the highest energy consumer among other sectors [4]. It is very important for every hospital to implement a comprehensive energy management program so that the utility costs can be reduced and some of the savings are used for more

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essential things such as the replacement of medical assets and the day-to-day operation of the healthcare facility.

A study on energy consumption in hospitals shows that approximately 40 % of total electricity consumption are from centralized air conditioning systems [5]. The main source of energy used by buildings is electricity, which accounts for 75 % of total energy consumption. A study on the distribution of energy in hospitals conducted in 2014 found that the average annual electricity consumption was above 40,000.00 kWh with annual energy use intensity of 384 kWh/m2. This amount represents 63 % of the energy used by the air conditioning system, and 17 % of the energy is from lighting [6]. Another example of a study on energy consumption in Malaysian hospitals conducted in 2011 found that 36 % of energy consumption are from lighting, and 34 % of energy is used for the operation of medical equipment [7]. The deteriorating performance of the building, the environmental conditions that are no longer conducive to the need for environmental protection make green buildings an option for today's building owners to solve these problems. Geng et al. [8] also found that the building occupants had a higher satisfaction level inside green buildings compared with conventional buildings. In conclusion, public hospitals can also implement green practices in their buildings to solve the problem of high energy consumption while ensuring improved building performance with good environmental quality.

The key elements of green building that are often evaluated for rating and certification purposes include transportation, site management, water efficiency, energy efficiency, materials and resources, indoor environment quality, and innovation [9]. A brief description of each green building element is illustrated in Table 1 for the existing building certification in healthcare facility. The potential for achieving a green building rating for each of these elements can be recognized if the existing building is evaluated and audited [10]. The availability of this audit report will enable building owners to plan strategies and activities for implementing programs toward green and low-carbon buildings in a more cost-effective manner.

1.2. Green building rating tools

The rating tool for green building certification is used to evaluate the performance of buildings that have implemented all of the elements specified in each type of rating. Green buildings minimize the negative impact on the environment while optimizing their positive impact on the occupants. Chua and Oh [11] suggested that this action can be achieved through good design, construction, operation, and maintenance.

Table 1
Green building element description.

Elements	Description
Transportation	Planning of the use of environmentally friendly transportation, sharing of vehicles, and providing public transport and special parking facilities.
Sustainable Site Management	Conservation and preservation of existing sites to provide a good environment through well-planned landscaping, water management, and ecosystem conservation.
Water Efficiency	Efficient use of water through savings, recycling, rainwater catchments, and the use of technology.
Energy Efficiency	Optimizing energy use through the passive design of buildings, low- and medium-cost measures, and use of energy-efficient technology and renewable energy to improve overall building energy performance.
Material and Resources	The use of environmentally friendly materials and resources in the operation of buildings through the purchase of green products, recycling programs, and prioritizing local products.
Indoor Environmental Quality	Indoor air quality care, thermal comfort, lighting, and sound quality performance to achieve a quality indoor environment.
Innovation	New initiatives that innovate the implementation of every green element to meet the green building objectives.

Meanwhile, Chen et al. [12] found that occupant behavior interventions could be useful to achieve green building status through energy efficiency improvement, and the occupant behavior needs to be understood in a systematic framework [13]. Different green building rating tools are available around the world today, and they are designed to suit climate and local needs. However, the key elements of the green building in each rating tool are approximately the same. Sahamir and Zakaria [9] studied the commonly used green building rating tools in the world and Malaysia, namely, the Building Research Establishment's Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Green Star, and Green Building Index (GBI). BREEAM is the world's oldest rating tool from the United Kingdom (UK) and was developed in 1990 [14]. This rating tool is also an option for health facilities in the UK as a method of assessing environmental performance and green building certification. Meanwhile, LEED has been developed by the U.S. Green Building Council in 1998 and served as a platform for building owners to identify steps that could be taken to achieve green building status from design to operation and maintenance. As of December 2018, LEED has successfully drawn 96, 275 registered and certified projects that involved more than 160 countries [15]. Criteria related to health facilities are also included in the LEED rating tool under the existing building category to promote the health and environmental needs of the project [16]. It is very clear that green building rating tools have been widely used around the world which have managed to provide many benefits to building owners. The government needs to expand green practices in all public hospitals in Malaysia for long-term benefits in terms of energy and water savings, good environmental quality, and sustainable waste management.

Another widely used rating tool refers to the Green Star, which was established by the Green Building Council of Australia (GBCA) in 2003. The GBCA launched a green building rating tool dedicated to health facilities in 2009 to support the planning for sustainable high-performance buildings by emphasizing the health and productivity of building occupants, as well as cost savings [9]. The GBI is a widely used green building rating tool in Malaysia for building and township rating systems. The GBI was formed on the basis of existing rating tools, such as the Green Star and Green Mark in Singapore, which had a similar climate to Malaysia and was adapted to suit local needs [17]. Currently, GBI has developed a green building rating tool specifically for hospitals under the new construction and existing building categories. However, at present, only six private hospitals have been awarded green building certification under GBI [18] whereas one government public hospital has received such award under LEED certification. The number of green certified hospitals is very small compared with the total number of hospitals in Malaysia which require more attention from the government as a policy maker. The summary of green certified hospitals in Malaysia are shown in Table 2.

So far, hospital buildings in Malaysia have selected two green rating tools for their certification, namely, GBI and LEED. However, many more green rating tools developed for healthcare building categories are used in the world. Table 3 shows the comparison of commonly used green building rating tools around the world and in Malaysia for elemental and scorecard health facilities. According to the table, energy efficiency and indoor environmental quality (IEQ) elements, rank in the top three in all rating tools. As the largest energy user among government facilities, the improved energy consumption of the building will give advantage to the hospital management in achieving green building certification.

Thus, the overall aim of this article is to evaluate the potential for energy saving in public hospital using a systematic approach. Three methods are applied in this approach which involved detailed energy audit (DEA), empirical evidence through on-site measurement and building energy simulation works using the IES VE software. Apart from active measures, many more energy saving potentials can still be explored through passive strategies. Simulation method is used to establish energy baseline as the basis for predicting energy saving

Table 2
Green certified hospitals in Malaysia.

Hospital Name	Public/Private Hospital	Rating Tool/Country	Building Category	Green Rating	Year Received
KPJ Selangor Specialist Hospital	Private Hospital	GBI/Malaysia	Non-residential New Construction	Certified	2013
Gleneagles Hospital	Private Hospital	GBI/Malaysia	Non-residential New Construction	Gold	2015
Amanjaya Specialist Centre	Private Hospital	GBI/Malaysia	Non-residential New Construction	Silver	2018
Bandar Dato' Onn Specialist Centre	Private Hospital	GBI/Malaysia	Non-residential New Construction	Silver	2018
KPJ Damansara Specialist Hospital	Private Hospital	GBI/Malaysia	Non-residential New Construction	Certified	2019
UKM Specialist Children's Hospital	Private Hospital	GBI/Malaysia	Non-residential New Construction	Certified	2019
Sultanah Maliha, Langkawi Hospital	Public Hospital	LEED/United States	Operation and Maintenance: Existing Buildings v4	Gold	2020

Table 3
Commonly used green building rating tools for healthcare facility around the world and in Malaysia.

Rating Tool/ Country	Version/Year	Elements and Score	Certification Level	Top Three Elements
BREEAM/ United Kingdom	BREEAM Healthcare/2008	Management (12), Health and Wellbeing (15), Energy (19), Transportation (8), Water (6), Materials (12.5), Waste (7.5), Land Use and Ecology (10), Pollution (10), Innovation (10). Maximum points: 110	Unclassified: <30 Pass: ≥30 Good: ≥45 Very Good: ≥55 Excellent: ≥70 Outstanding: ≥85	1) Energy 2) Health and Wellbeing (IEQ is part of the element) 3) Materials
LEED/United States	LEED v4 for Operation and Maintenance: Existing Buildings/2016	Location and Transportation (15), Sustainable Sites (10), Water Efficiency (12), Energy and Atmosphere (38), Materials and Resources (8), Indoor Environmental Quality (17), Innovation (6), Regional Priority (4). Maximum points: 110	Certified: 40–49 Silver: 50–59 Gold: 60–79 Platinum: ≥ 80	1) Energy and Atmosphere 2) Indoor Environmental Quality 3) Location and Transportation
Green Star/ Australia	Green Star Healthcare v1/ 2009	Management (17), Indoor Environmental Quality (32), Energy (29), Transportation (12), Water (14), Materials (35), Land Use and Ecology (8), Emission (20), Innovation (5). Maximum points: 172	Best Practice (4 star): 45–59 Australian Excellence (5 star): 60–74 World Leadership (6 star): 75–100	1) Materials 2) Indoor Environmental Quality 3) Energy
Green Mark/ Singapore	BCA Green Mark for Healthcare Facilities (Version HC/1.0)/2014	Energy Efficiency (116), Water Efficiency (15), Environmental Protection (21), Indoor Environmental Quality (30), Sustainable Practices and Green Innovation (13). Maximum points: 195	Green Mark Certified: 50–74 Green Mark Gold: 75–84 Green Mark Gold^{Plus}: 85–89 Green Mark Platinum: ≥ 90	1) Energy Efficiency 2) Indoor Environmental Quality 3) Environmental Protection
GBI/Malaysia	Non-residential Existing Building (NREB): Hospital (Version 1.0)/2015	Energy Efficiency (38), Indoor Environmental Quality (21),Sustainable Site Planning and Management (10), Material and Resources (9), Water Efficiency (12), Innovation (10). Maximum points: 100	Certified: 50–65 Silver: 66–75 Gold: 76–85 Platinum: ≥ 86	1) Energy Efficiency 2) Indoor Environmental Quality 3) Water Efficiency

potential for passive strategies that cannot not be measured through energy audit. The combination of these methods is essential to optimize the potential of energy saving through active and passive strategies that have so far has never been implemented in any public hospital in Malaysia.

2. Methodology

2.1. Case study description

The study was conducted in Hospital Kepala Batas in Penang, which was located at latitude 5.51° N and longitude 100.43° E of Peninsular Malaysia. The hospital is part of the pilot project for the first Smart Energy City in Penang and in line with the state government's aspiration to make Penang a green technology and smart city [19]. This three-story building, which was categorized as minor specialist hospital, is owned and managed by the Ministry of Health (MOH) Malaysia. It has begun its operation since 2003. It has 108 beds that provide 10 basic specialties for resident services. In general, the MOH hospitals are classified into four categories, namely, are state hospital, major and minor specialist hospital, non-specialist hospital, and special medical institution, based on a number of basic resident specialist provided. However, it could also be classified based on the current needs decided by the ministry that involve several factors, such as demographics and population coverage, location of the hospital, accessibility of services to the public, and physical capacity of the hospital building [20]. The actual building dimension of Hospital Kepala Batas is shown in Fig. 1.

Hospital Kepala Batas has a building gross floor area (GFA) of 15,239 square meters, net useable area of 13,234 square meters, which represent 86.84 % of the total GFA and air-conditioned area (ACA) of 5787 square meters, which represent only 37.97% of the total GFA. Most of the areas were designed with natural ventilation and fitted with operable window. The details of the hospital building are summarized in Table 4.

Three floors in the building serve multi-purpose clinical services under several departments for the Kepala Bates community. The ground floor of the building consists of daycare unit, accident and emergency department (A&E), operating theater, imaging department, and pharmacy. The first floor was occupied with a maternity ward, delivery department, pediatric ward, medical record unit, and administration unit. The second floor comprises the male and female wards. The list of clinical service area in the Hospital Kepala Batas and air-conditioning and mechanical ventilation (ACMV) description are shown in Table 5.

Three methods, which involved detailed energy audit (DEA), empirical evidence approaches through on-site measurement and building energy simulation works using the IES VE software, were used

Fig. 1. Hospital Kepala Batas building.

Table 4
Building description summary.

General Information	Description
GFA (m^2)	15,239
ACA (m^2)	5787
Number of floors	3
Floor-to-ceiling height (m)	3.2
Type of window	Operable Window

Table 5
List of departments and ACMV description in Hospital Kepala Batas.

Floor Level	Clinical Services Area	ACMV Description
Ground	A&E	Partly air-conditioned/natural ventilation
	Daycare unit	Partly air-conditioned/natural ventilation
	Operating theater	Fully air-conditioned
	Imaging department	Partly air-conditioned/natural ventilation
	Pharmacy	Fully air-conditioned
First	Maternity ward	Partly air-conditioned/natural ventilation
	Delivery department	Fully air-conditioned
	Pediatric ward	Partly air-conditioned/natural ventilation
	Medical record unit	Partly air-conditioned/natural ventilation
	Administration unit	Partly air-conditioned/natural ventilation
Second	Male ward	Natural ventilation
	Female ward	Natural ventilation

in this study. The energy audit was first conducted on the existing inefficient installation to identify the potential for energy saving of active strategies for building performance improvement. Then the on-site post-retrofit measurement was performed as empirical evidence to validate the predicted energy saving from active measures. While simulation works were implemented to establish an energy baseline model as the basis for predicting the energy saving potential of passive strategies which could not be calculated through energy audit due to non-existence of the any existing measures. The established energy baseline will be used to simulate various possible passive measures to identify potential energy savings before the best passive strategies can be implemented. However, this study only covers until the establishment of the energy baseline while the saving potential will be predicted in future simulation works. The combination of these methods as a systematic approach as shown in Fig. 2 is essential to identify the potential energy savings as much as possible through active and passive strategies that have so far has never been implemented in any public hospital in Malaysia.

2.2. Detailed energy audit

Detailed energy audit (DEA) includes site assessment and data logging at the site to identify potential energy savings for active strategy implementation. A comprehensive energy audit study requires a thorough examination of all factors that influence energy. A systematic approach was used to ensure that all relevant factors were identified and assessed in terms of their impact on energy utilization. The data used in this study were based on documented evidence from existing digital power meter data reading installed as part of building management system, interview with operation and maintenance team, equipment manuals, assets list, specific audit reports, and field measurements and observations of building facilities. Details of the energy audit process are shown in Fig. 3. The DEA also refers to the registered references as follows:

- Part 1, Guidelines for Conducting Energy Audits in Commercial Buildings.
- Energy Efficiencies and Conservation Guidelines for Malaysian Industries. Part 1, Electrical Energy Use Equipment.
- Malaysian Standard, MS1525:2019, Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings.
- 2011 ASHRAE Handbook - HVAC Applications.

Considering that energy usage is influenced by the way a facility is operated and utilized, collecting data on occupancy rates (hours/day, days/week, weeks/month) and environmental control is necessary. Data on past energy consumption levels were gathered to establish an energy and cost baseline for saving calculation purpose. Equipment manuals and building layouts were investigated, and interviews with building occupants were conducted randomly to understand the building and equipment usage and functions. Sub-metering has been used as a part of data logging devices to establish building load profiles and major energy consuming end-user output. Several potential measures were developed on the basis of preliminary surveys and discussions with various building, operating staff members, such as nurses, head of units, and maintenance officers. The evaluation of the monitoring data also revealed the potential of energy conservation measures and provided crucial data for calculating conservation. The most feasible measures that would provide the shortest payback and highest savings potential were then selected. Overall, the main objectives of the DEA conducted in Hospital Kepala Batas were detailed as follows:

- To identify the energy supply information and status;

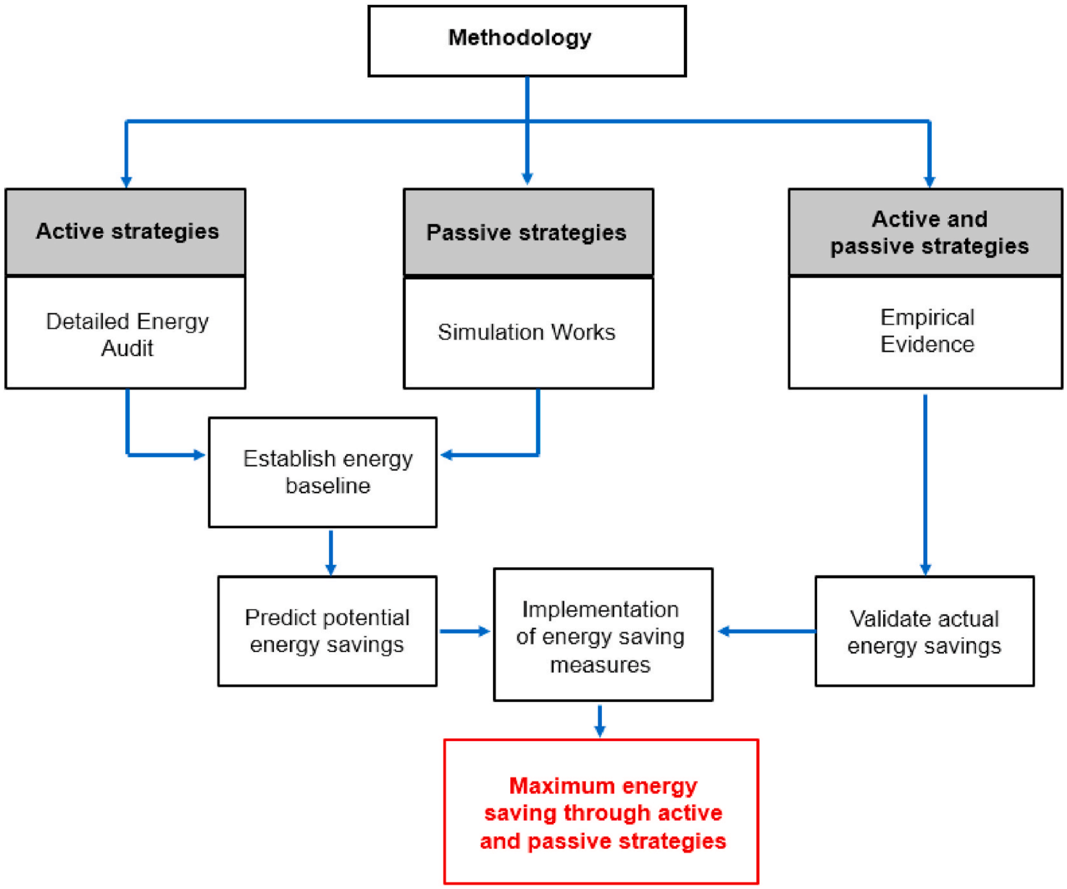


Fig. 2. Systematic approach for energy saving assessment and validation.

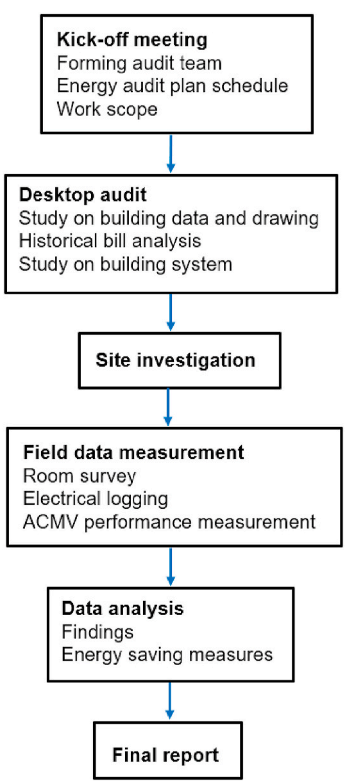


Fig. 3. Energy audit process.

- To identify present and historical energy usage pattern;
- To proposed energy conservation potential and measures (e.g., action plan and estimated time required to implement the measure recommended, amount of saving, and cost of implementation;
- To analyse the financial aspect of the proposed energy conservation measures.

2.3. *Implementation of energy saving measures*

The retrofit measure with the highest energy saving potential is identified and applied to the building. Then, the building performance will be re-assessed by comparing the actual results with the energy audit estimated values to provide an empirical evidence. The implementation of selected energy saving measures is using energy performance contracting (EPC) model that has been applied in most of the retrofit projects in MOH [21]. In this EPC model, the energy services company (ESCO) will invest their money to retrofit or replace the inefficient equipment in hospital to guarantee an energy saving. The government will get a new equipment which is more energy efficient and environmentally friendly while saving on daily operating cost. The repayment of investment to the ESCO is from the hospital's monthly utility bill saving.

2.4. *Post-retrofit measurement*

Energy avoidance by the installation of energy saving measures has been computed by subtracting reporting-period energy consumption from baseline energy consumption. Avoided energy use quantifies in the reporting period is relative to what energy use would have been without the energy saving measures. Avoided energy use, or savings are calculated as the difference between energy baseline and post-install energy conservation measures in kWh. While avoiding the energy cost is derived using the current energy tariff rate applied to the hospital.

2.5. Building energy simulation

An energy baseline model was developed using Integrated Environmental Solutions Virtual Environment (IES VE) as a benchmark to predict energy saving from potential conservation measures explored. The baseline model was established by collecting data and information, such as building geometry and orientation, gross floor area (GFA), air-conditioned area (ACA), and construction type with its thermo physical properties, through the DEA. The simulated annual energy consumption for the building that represents the energy baseline model was calibrated by comparing it with the actual electrical energy data obtained from the hospital's utility bills.

2.5.1. Building model

IES VE software was used to evaluate the energy performance of the hospital. ApacheSim was used as a tool for the dynamic thermal simulation of the hospital building because it was validated under ASHRAE standard 140. The construction type with its thermophysical properties (Table 6) was applied for the modelling of the building. Internal heat gain data were also added to the building model to calculate the energy consumption of the space when lighting, computers, and people exist. The values of the internal heat gain used in the simulation were based on the study conducted by Refs. [22,23]. Table 7 summarizes the internal heat gain values.

The weather data of Butterworth, which corresponded to the climatic region of Kepala Batas, were selected. The weather file design conditions were based on the climate design data 2009 ASHRAE handbook. The summary of weather data was briefly explained in Table 8.

The building geometry of Hospital Kepala Batas was constructed based on the available layout plan and followed the exact orientation to represent the current conditions of the building. For the purpose of the simulation, the thermal property values have been set to comply with Malaysian Standard minimum requirements [24]. The complete building model and sun's path of the building developed in IES VE are shown in Fig. 4 and Fig. 5, respectively.

3. Results and discussion

3.1. Energy saving potential

The main electrical loads were logged on the Main Switch Board during the energy audit, and load apportioning was developed through the data captured in energy monitoring system. From the sample data, the load apportioning for hospital by area and equipment are calculated as shown in Fig. 6 and Fig. 7, respectively. This approach will assist users to identify which area consume high electricity and need further improvement. From the chart, the plant room that consists of chiller, medical gas, and air compressor is the highest consumer, representing 62 % compared with other areas. The second highest user that represents 21 % of the total building consumption include wards and operation theater, which include highly critical and semi critical wards, respectively. The largest electricity consumption in hospital in terms of equipment is found from cooling system that consist chiller (49 %), AHU (8 %), and ACSU (7 %). Other major consumptions are drawn by power (27 %) that consists of plug load, biomedical equipment, computers, and other electrical appliances.

Table 6
Thermophysical properties of construction type.

Construction Type	Properties
Roof	Concrete deck
External window	Uncoated single glazing with 6.0 mm thickness
Wall	Brickwall plaster on both sides

Table 7
Internal heat gain values [22,23].

Internal Heat Gain Sources	Values
Office equipment (e.g., desktop, laptop)	27.89 W/m^2
Fluorescent lamp	10.37 W/m^2
Occupancy density	24.84 m^2/person

Table 8
Summary of weather data.

Weather Data Information	Description
Location	Butterworth, Malaysia
Latitude	5.47° N
Longitude	100.39° E
Elevation	3.0 m
Time zone	8 h ahead of GMT
Data source	IWEC data
Reference file	KualaLumpurIWEC.fwt
ASHRAE climate zone	1A
ASHRAE description	Very hot-humid
Weather file design conditions	Climate design data 2009 ASHRAE handbook

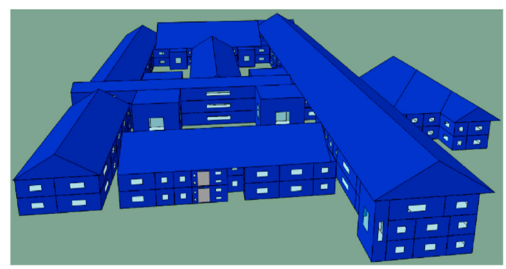


Fig. 4. Complete building model for simulation.

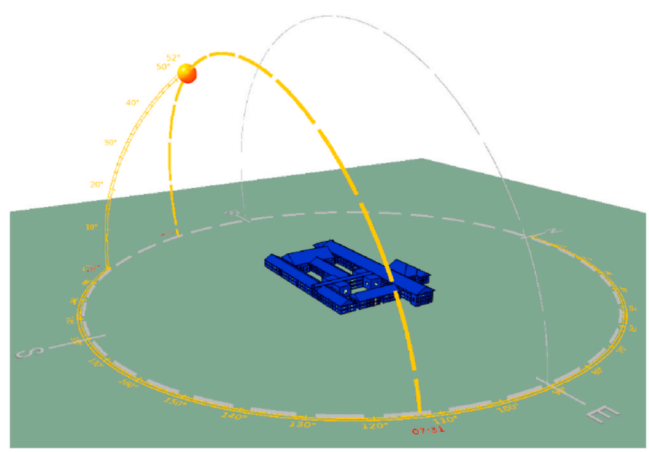


Fig. 5. Sun's path of the building.

The load apportioning analysis shown that the space cooling provided by the chiller system is the highest energy contributor among other systems or equipment. If the inefficient chiller is replaced, then it will result in a significant reduction of energy in the hospital building. Further investigation should be conducted to identify any potential saving, technically and economically. Apart from the chiller, lightings are another area to be concentrated for potential saving study because they are generally utilized in every area of the building. Compared with high-end biomedical equipment that consume high energy, lighting is easier to replace and provide more energy saving with the current new technology available in the market.

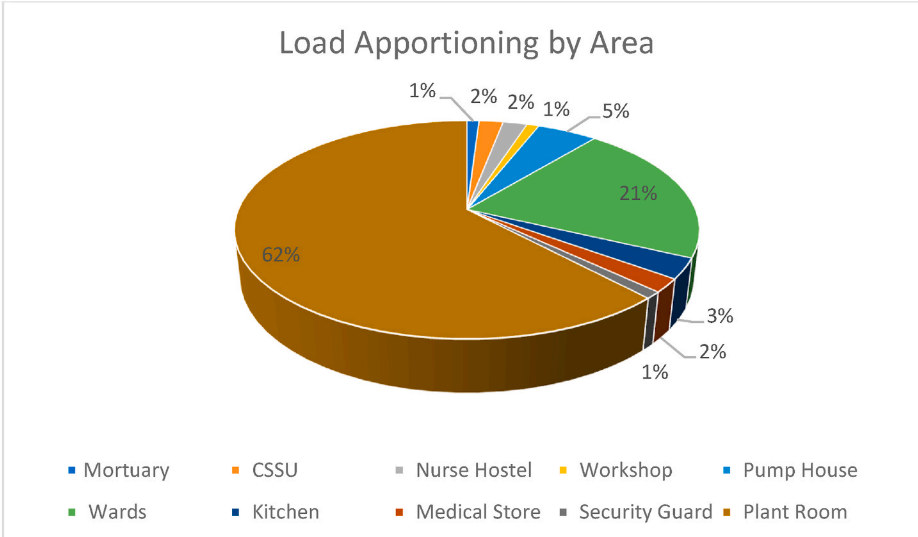


Fig. 6. Load apportioning by area.

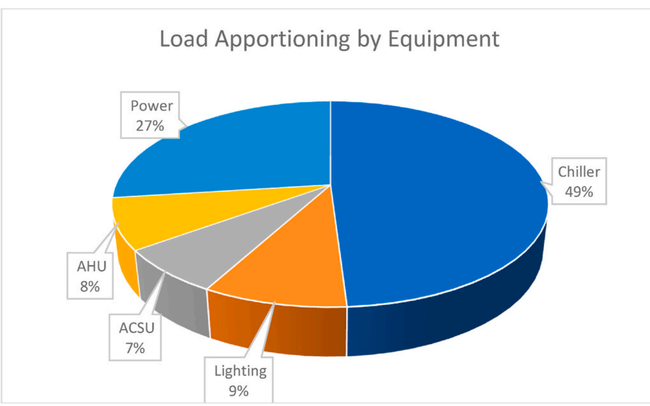


Fig. 7. Load apportioning by equipment.

3.1.1. *Potential energy saving from chiller system retrofit*

Hospital Kepala Batas uses a centralized chiller system and supplies to two types of cooling distribution system, namely, air handling unit (AHU) and fan coil unit (FCU). The chiller system is operating 24 h in a day, including weekends. The system consists of several numbers of equipment, such as chiller, cooling tower, AHU, and pumps, which combines to create one cooling network (Fig. 8). Replacement of existing chiller to the energy efficient chiller come with control logic accessories are proposed to ensure the overall chiller plant equipment will operate with lower energy consumption and as per building cooling load demands. The energy consumed by the chiller plant equipment shall concurrently ramp down once the building cooling load demands reduced. The multiple compressor type of chiller selection with variable speed drive (VSD) control of the compressor motor will reduce the energy consumption during the partial load demands. The existing condition of the chiller system is shown in Fig. 9.

The performance of chillers and plant was determined using two methods that commonly used globally, which are coefficient of performance (COP) and efficiency, which is in kW/ton rather than the seasonal energy efficiency ratio (SEER) which widely used in the United States. Chiller plant efficiency is defined as the total accumulated energy in kilowatt used by the chiller plant equipment (chillers, cooling towers and condenser water pumps) to produce one refrigerant tonnage of cooling. Refrigerant tonnage is a unit rate for cooling energy that is equivalent to the removal of heat at 12,000 Btu per hour. The lower the energy consumed for this activity, the higher the efficiency of the chiller plant. The formulas used to calculate the COP and efficiency are shown in Eqs. (1)–(3) below:

$$\mathrm{COP} = \frac{\text{Toatl Rejected Heat Load (kWr)}}{\text{Total Electrical Load (kWe)}} \tag{1}$$

$$\text{Efficiency} = \frac{\text{Energy Consumption (kW)}}{\text{Heat Removed (ton)}} \tag{2}$$

$$\mathrm{COP} = 12 \;/\; (\text{Efficiency}) \;/\; 3.412 \tag{3}$$

Electric power, flow and temperatures of chilled water were recorded continuously at every 5 min. The metering devices are placed permanently over the length of the entire reporting period to signal any variations in power use and cooling demand fluctuations. A baseline measurement was conducted using a portable electrical meter to measure the electricity input in kW, while portable ultrasonic flowmeter is used to measure flow rate. The measurement of supply and return temperatures were measured using thermocouples for calculating the cooling energy produced in refrigeration tons. The chiller plant in Hospital Kepala Batas consists of water-cooled chillers, cooling towers, condenser water and chilled water pumps. A measurement was performed on the electrical input to a chiller, cooling tower and condenser pumps. Based on the data obtained from the cooling load profile and chiller system power consumption, the average measured efficiency chillers were 1.31 kW/RT while the calculated average plant efficiency was 1.46 kW/RT as shown in Table 9. The summary of energy baseline analysis and efficiency rating result are shown in Table 10 and Table 11 respectively.

Based on the audit results, the following improvement works are proposed for the main block chiller system:

- Retrofit two-unit chiller with higher efficiency chiller.
- Install measuring devices that include flow meters, temperature sensors, and digital power meters to the chiller system.
- Replace the chilled water pumps with the variable speed pumps.
- Install a control and monitoring system for the chiller system automation.

By implementing the proposed works, increasing the chiller system performance, efficiency from 1.46 kW/RT to 0.80 kW/RT is possible. This improvement will reduce the power consumption of the chiller system by up to 45.5 %, which reflect 38.9 % of the energy reduction

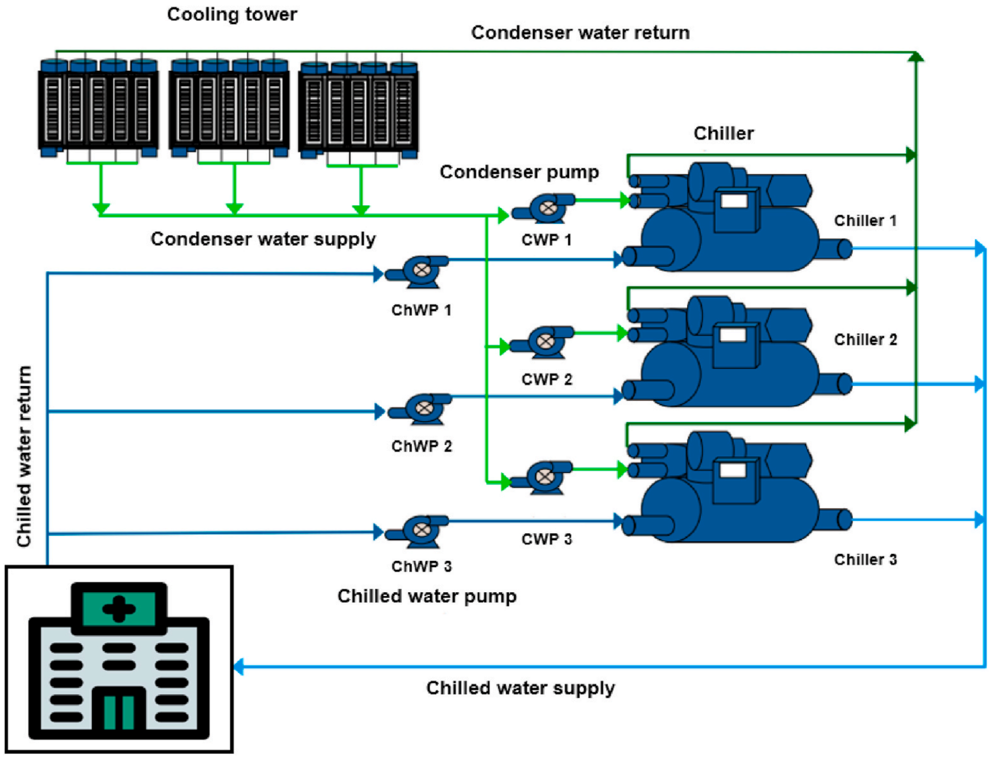


Fig. 8. Chiller system network in Hospital Kepala Batas.

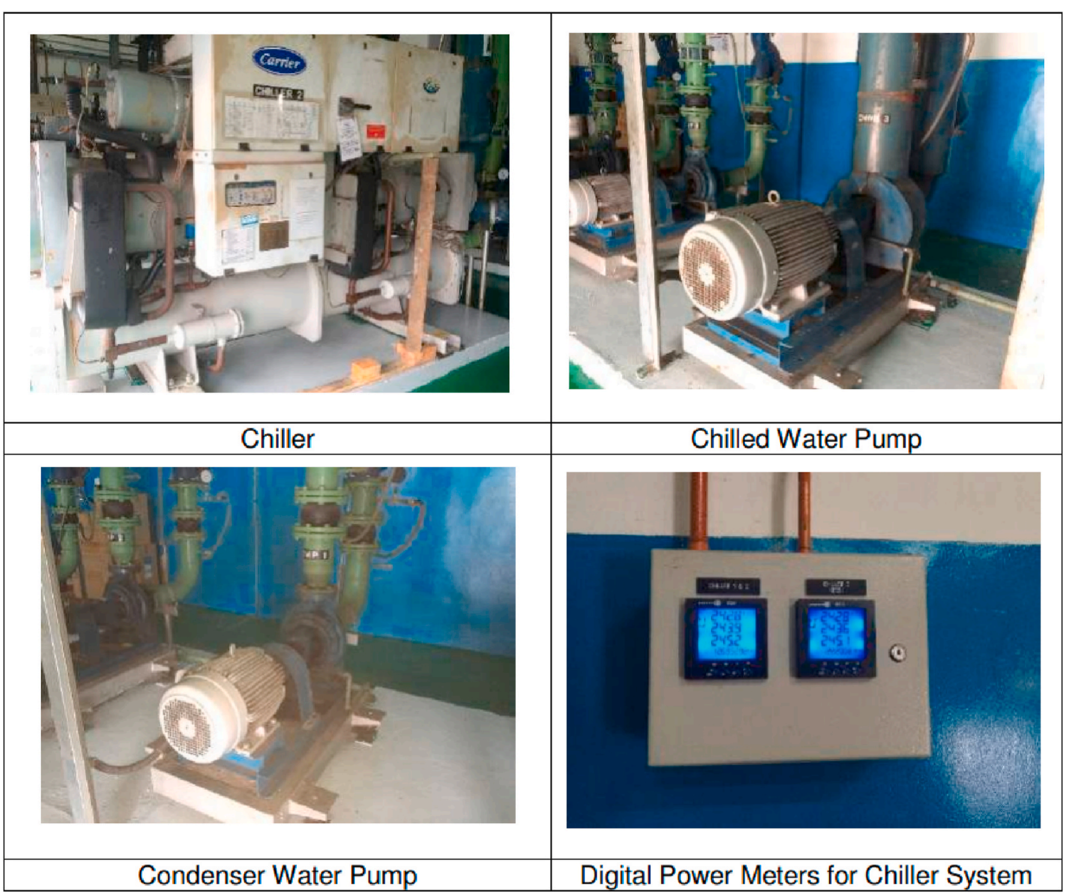


Fig. 9. Existing chiller system condition.

Table 9
Average efficiency of chiller and plant.

Description	Chiller Efficiency (kW/RT)	Plant Efficiency (kW/RT)
Chiller 1	1.06	1.21
Chiller 2	1.57	1.72
Chiller 3	1.29	1.46
Average	**1.31**	**1.46**

Table 10
Energy baseline analysis.

Description	Chiller system total power (kW)	Cooling load (ton)	Efficiency (kW/ton)
Mean	384.85	263.60	1.46
Standard error	0.45	0.31	0.0025
Median	378.51	259.25	1.40
Mode	337.29	368.94	1.32
Standard deviation	83.69	57.32	0.39
Sample variance	7004.55	3286.06	0.15
Kurtosis	-0.58	-0.58	2.76
Skewness	-0.03	-0.03	1.05
Range	870.01	595.90	4.87
Minimum	0.00	0.00	-0.71
Maximum	870.01	595.90	4.16
Sum	13443195.57	9207667	37072.78
Count	34931	34931	25392
95 % confidence level (absolute precision %)	0.88	0.60	0.0048
Lower system efficiency value	383.97	262.99	1.46
Higher system efficiency value	385.73	264.20	1.47
Tolerance level (relative precision %)	0.23	0.33	0.33

Table 11
Summary of efficiency rating result.

No.	Items	Results
1.	Operating design chiller capacity	555.00 RT
2.	Average power consumption per hour	384.85 kW
3.	Average chilled water supply temperature	43.40 degF
4.	Average chilled water return temperature	50.00 degF
5.	Average daily minimum cooling load demand	259.25 RT
6.	Average daily minimum cooling load demand period	04:00 to 07:00
7.	Average daily maximum cooling load demand	368.94 RT
8.	Average daily maximum cooling load demand period	13:00 to 18:00
9.	Average cooling output	263.60 RT
10.	Average plant efficiency	1.46 kW/RT

from total building energy consumption. That amount of energy reduction is equivalent to RM781, 404.28 per year with the current tariff of RM0.509. While the discounted payback period for this energy saving measures is 7.15 years, assuming a discounted rate of 9 %. From a previous study, approximately 1 million kg of carbon dioxide (CO2) is reduced each year, and more than 8000 MWh of energy can be saved when energy efficient chiller, such as hybrid or oil-free magnetic chiller, are used at 50 % load [7]. The predicted energy saving for chiller system retrofit measure in the hospital is as per calculated in Table 12.

Table 12
Potential saving from chiller system retrofit.

Item	Estimated Amount
Annual Energy Consumption (kWh/year)	3,371,286.00
Annual Energy Cost (RM/year)	1,715,984.57
Annual Energy Saving (kWh/year)	1,535,175.40
Annual Energy Cost Saving (RM/year)	781,404.28
Energy and Cost Saving (%)	45.50 %
Investment (RM)	3,990,000.00
Discounted Payback Period	7.15

3.1.2. Potential energy saving from optimizing AHU operation

Affinity Law can be applied to calculate the energy reduction that can be gained by reducing the AHU fan speed. The speed can be reduced by installing the variable frequency drive (VSD) to the AHU fan motor. Table 13 shows the summary of the monthly saving calculation for every AHU in the plant room. The Affinity Law formula used to calculate the power reduction after reducing the speed is expressed as Eq. (4) below:

$$\frac{\text{Input Power}_2}{\text{Input Power}_1} = \left[\frac{\text{Air Flow}_2}{\text{Air Flow}_1}\right]^3 \tag{4}$$

Optimization of existing AHU can reduce a minimum 70,728 kWh/year from a total energy consumption of 261,012.00 kWh/year of the AHU's plant. That amount of energy reduction is equivalent to RM 36,000.55 per year. However, this energy measures may take a longer discounted payback period of 12.53 years because of a lower total energy saving reduction compared with its total investment. Table 14 shows the estimation of total energy saving in kWh if the AHU motor speed is reduced by 10 %.

3.1.3. Potential energy saving from lighting replacement

A total of 3993 fluorescent lamps and PLC downlights are installed in various locations inside the hospital building based on DEA conducted on-site. The type and quantity of lighting installed are shown in Table 15.

With current advanced technology, LED has been the most popular solution to reduce energy consumption because of its low initial outlay and significant savings. Previous studies found that new technologies, such as energy efficient lighting, can be used to improve saving and performance of existing building [25]. In Hospital Kepala Batas, the usage of 36 W and 18 W fluorescent lamp, is still widely used. Typically, fluorescent lamp is equipped with a bulb and ballast, which consume high power. LED lighting with power rated of 10 W can produce the same or higher Lux as compared with existing fluorescent lights. Comparison of used and proposed lighting characteristics in the hospital is shown in Table 16.

Replacement of existing lighting with LED will also reduce maximum demand. Standard T5 and T8 fluorescent tube has an average typical life span up until 25,000 h while LED tube can last up to 50,000 h [26]. Overall, LED lighting has more advantages in terms of lower operating and maintenance costs. The potential energy reduction by replacing existing fluorescent bulb with 10 W LED is shown in Table 17. The basis of potential saving calculation is as follows:

- Total wattage per bulb shall include additional 4 W ballast losses;

Table 13
Monthly saving calculation for AHU.

AHU	Measured Power (kW)	Potential Savings (kW)	Monthly Usage (kWh)	Monthly Saving (kWh)
AHU 3 Minor OT	3.62	0.98	956	259
PR 1–4 ICU	3.44	0.93	907	246
AHU 1 OT Room	5.29	1.43	1398	379
AHU PR 1-5	7.88	2.13	2080	564
AHU PR 1-2	0.59	0.16	156	42
AHU 2	11.49	3.11	3034	822
AHU Admin	9.33	2.53	2462	667
AHU PRU Dental	8.67	2.35	2289	620
AHU PR2 2	6.92	1.88	1828	495
AHU PR2 1	14.82	4.02	3914	1061
AHU CSSD 1	3.32	0.90	876	237
AHU CSSD 2	7.01	1.90	1851	502
Total	82.38	22.32	21,751	5894

Table 14
Potential saving from AHU optimization.

Item	Estimated Amount
Annual Energy Consumption (kWh/year)	261,012.00
Annual Energy Cost (RM/year)	132,855.11
Annual Energy Saving (kWh/year)	70,728.00
Annual Energy Cost Saving (RM/year)	36,000.55
Energy and Cost Saving (%)	27.10 %
Investment (RM)	264,000.00
Discounted Payback Period	12.53

Table 15
Type and quantity of lighting installed.

Department	Fluorescent		PLC Downlight
	36 W	18 W	13 W
Pharmacy	113	0	28
Dietetic	37	0	24
Workshop	4	0	0
Maintenance Office	40	0	0
Integration Store	94	0	0
Administration	88	2	94
CME Unit	96	0	116
Intensive Care Unit	90	2	12
Record Unit	64	0	10
Pathology	162	0	42
CSSD	180	0	0
Daycare	61	0	4
Hemodialysis	65	0	54
Telephonist	4	0	48
Operation Theater	311	3	56
Ward 2B	136	0	28
Ward 2A	116	0	70
Delivery	85	0	42
X-ray	24	0	66
Revenue Unit	27	4	6
Blood Bank	22	6	20
Physiotherapy	96	2	70
A&E Unit	161	15	84
TCM Unit	42	0	52
Works Unit	21	9	0
Specialist Clinic	83	75	264
Ward 3A	114	2	68
Ward 3B	91	0	44
Matron Office	4	0	16
Forensic	104	0	20
Total	2535	120	1338

Table 16
Comparison of lighting characteristics.

Description	Fluorescent (18 W & 36 W)	PLC Downlight (13 W)	LED Tube (10 W)
Light Output (Lumens)	1300–2700	400	950
Correlated Colour Temperature	4000–5000 K	3000 K	6500 K
Colour Rendering Index	65–80	65	≥80
Typical Lifespan	25,000 h	12,000 h	50,000 h

Table 17
Potential saving from lighting replacement.

Item	Estimated Amount
Annual Energy Consumption (kWh/year)	547,715.52
Annual Energy Cost (RM/year)	278,787.20
Annual Energy Saving (kWh/year)	375,217.92
Annual Energy Cost Saving (RM/year)	190,985.92
Energy and Cost Saving (%)	68.50 %
Investment (RM)	210,000.00
Discounted Payback Period	1.22

- Average tariff rate is RM0.509;
- Operating hour is 12 h/day, 30 days/month, and 12 months/year.

3.2. Post-implementation measurement

A chiller retrofitting measure was selected for implementation because of its ability to provide the highest energy savings to the hospital based on energy audit findings. Two new chillers with a capacity of 250 refrigeration ton (RT) each were installed at site as shown in Fig. 10 to obtain energy savings and improve the energy performance of the building. Thus, post-retrofit chiller system energy consumption and chiller loads were measured with a digital power meter (DPM) and British Thermal Unit meter (BTU Meter) as empirical evidence to validate the predicted energy saving potential obtained from the DEA. There are currently two DPMs installed to measure electrical power input chiller plant while BTU meter is installed to measure the chilled water thermal load of the chilled water plant. Measuring equipment's specification is shown in Table 18.

The measured parameters involved in the energy saving calculation are power drawn (kW), supply and return temperature (°C) and flow rate (l/s) of existing chiller (baseline) and new chiller (post-retrofit). Efficiency (kW/ton) and cooling load (ton) of the old and new chiller are computed from these measured data. The post-retrofit energy (kWh) is computed by multiplying the chiller efficiency (kW/ton) with cooling load (ton/hour) and subtracting the energy consumption of the chiller plant recorded by the digital power meter. While the energy savings is the difference between the baseline and post-retrofit energy. The cost savings calculation is derived using the current energy tariff rate applied to the hospital. In general, the energy savings calculation is computed as Eq. (5) below:

$$\text{Energy saving} = \text{Baseline energy use} - \text{Reporting period energy use} \pm \text{Routine adjustment} \pm \text{Non routine adjustment} \tag{5}$$

where.

Baseline energy use = Average power draw by existing chillers at every interval and respected cooling energy produced

$$\text{Reporting period energy use} = \text{Average power draw by new plant and (Post − retrofit) respected cooling power produced}$$

Overall, the chiller retrofitting project has shown substantial energy and cost savings. The actual energy saving of 1,688,347.02 kWh/year (50.08 %) was obtained from the chiller system retrofit and slightly higher than what was predicted. While the discounted payback period calculated for the pilot project is 6.29 years, which is shorter than calculated in the energy audit. The summary of measured energy savings results for 12 months and comparison of data between estimated DEA value and actual post-retrofit value are tabulated in Table 19 and Table 20 respectively.

3.3. Simulation works

Passive strategies are able to provide additional energy saving to the hospital in addition to the implementation of active measures. The combination of passive and active strategies is very important to get the maximum energy savings possible for the building owner. The simulation works were performed to establish an energy baseline model as the basis for predicting the energy saving potential of passive strategies that cannot be measured through energy audit. The established energy baseline will be used to simulate various possible passive measures in future simulation workso identify the highest potential energy savings before the best passive strategies can be implemented. The data and information obtained during the audit has been used as an input to model the building for simulation purposes.

The energy simulation results showed that the annual energy

Fig. 10. New retrofit chiller system.

Table 18
Measuring equipment's specification.

Equipment	Zone	Brand	Accuracy	Measured Variable
Digital power meter	CH1, CH2, CH3, CHWP1, CHWP2, CHWP3, CWP1, CWP2, CWP3, CT1, CT2, CT3	DELAB/ PQM 1000S	±1.0 %	Electrical power
Flow meter	Chiller plant thermal load	MAG5100 (CLII)	±2.0 %	Flow
Temperature sensor	Outgoing and incoming chilled water header	KAMSTRUP	±2.0 %	Water temperature

Table 19
The summary of measured energy savings.

Month	Monthly Average Cooling Load (RT)	Chiller Energy Saving (kWh)	Cost Saving (RM)
1st month	300.42	144,600.87	73,601.84
2nd month	280.20	149,779.80	76,237.92
3rd month	272.42	155,222.15	79,008.07
4th month	286.21	155,690.57	79,246.50
5th month	284.64	147,374.07	75,013.40
6th month	315.40	126,843.13	64,563.15
7th month	299.33	133,968.30	68,189.86
8th month	292.65	140,742.88	71,638.13
9th month	296.00	134,431.82	68,425.80
10th month	276.97	135,344.66	68,890.43
11th month	287.52	122,662.79	62,435.36
12th month	273.70	141,685.95	72,118.15
Total	288.79	1,688,347.02	859,368.61

consumption of Hospital Kepala Batas for a building model floor area of 15,407 m2 is 4292.8 MWh per year. This value represents annual building energy intensity (BEI) of 278.6 kWh/m2. While air-conditioned energy consumption for an air-conditioned area of 5856 m2 is 2745.4 MWh per year which results an energy intensity of 468.8 kWh/m2. According to GBI, under the energy efficiency element, current BEI value

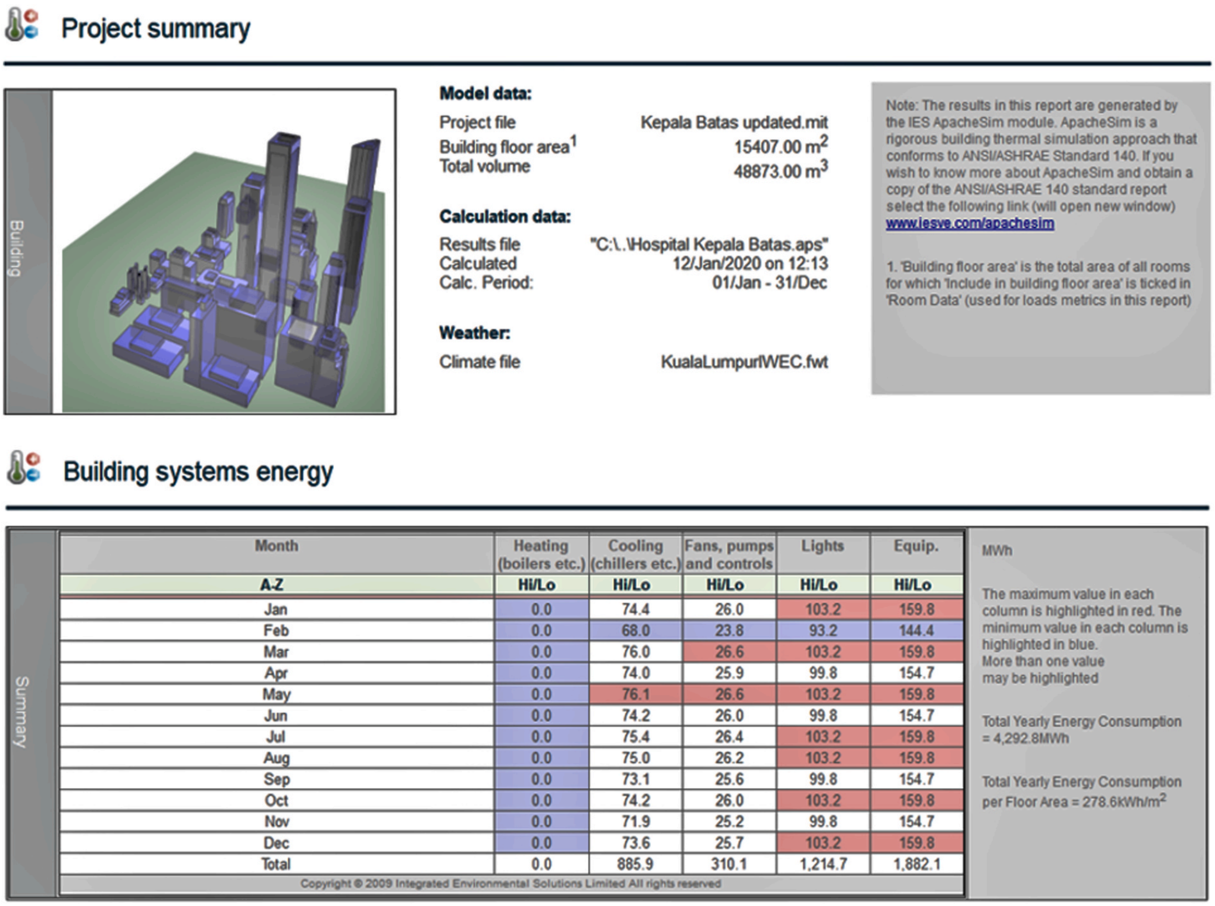
Table 20
Comparison between estimated and actual energy data.

Item	Energy Audit Estimated Data	Post-Retrofit Actual Data	Different
Baseline Energy Consumption (kWh/ year)	3,371,286.00	3,371,286.00	0.00
Baseline Energy Cost (RM/year)	1,715,984.57	1,715,984.57	0.00
Annual Energy Saving (kWh/year)	1,535,175.40	1,688,347.02	153,171.62
Annual Energy Cost Saving (RM/year)	781,404.28	859,368.61	77,964.33
Energy and Cost Saving (%)	45.54 %	50.08 %	4.54 %
Investment (RM)	3,990,000.00	3,990,000.00	0.00
Simple Payback Period	7.15	6.29	0.86

that falls between 270 kWh/m2 and 290 kWh/m2 for an existing hospital building category can only achieve 2 GBI points. Further reduction of BEI value will give a possible additional score of up to a maximum of 15 GBI points. The energy report generated from the completed simulation process and monthly electricity usage are shown in Fig. 11 and Fig. 12, respectively.

The annual energy consumption data are calibrated by comparing the simulation result with the actual hospital's monthly utility bill. As a result, the root mean square error (RMSE) between simulated energy consumption and actual energy consumption for both GFA and ACA is 2.1 % and 2.0 % respectively. The comparison of the RMSE of the data should not exceed 15 % tolerance for acceptable calibration process [27]. Thus, all simulated data can be used as a baseline to simulate energy saving potential of passive strategies before it can be implemented on-site. The comparison summary of simulated and actual data is briefly explained in Table 21.

From the simulation result, the peak demand of electrical usage throughout the year, which represent 514.8 kW, is predicted on March 2, 2020. The total energy consumption and maximum demand in hospital can be reduced by applying energy conservation measures, such as the optimization of cooling system, lighting replacement, reduction of heat transfer through thermal insulation, and prevent unwanted solar heat gain through shading and glazing improvement [28]. The list of energy saving potential for active measures could be obtained through energy audit while predicting energy saving for passive strategies is calculated through simulation. Measuring or observing the potential of passive strategies during the energy audit is difficult because of out-of-control factors, such as weather tabulation, climate condition, and building materials. Thus, simulation is the best way to propose energy saving measures through passive design strategies. The



Project summary

Building

Model data:

Project file	Kepala Batas updated.mit
Building floor area[1]	15407.00 m^2
Total volume	48873.00 m^3

Calculation data:

Results file	"C:\..\Hospital Kepala Batas.aps"
Calculated	12/Jan/2020 on 12:13
Calc. Period:	01/Jan - 31/Dec

Weather:

Climate file	KualaLumpurIWEC.fwt

Note: The results in this report are generated by the IES ApacheSim module. ApacheSim is a rigorous building thermal simulation approach that conforms to ANSI/ASHRAE Standard 140. If you wish to know more about ApacheSim and obtain a copy of the ANSI/ASHRAE 140 standard report select the following link (will open new window) www.iesve.com/apachesim

1. 'Building floor area' is the total area of all rooms for which 'Include in building floor area' is ticked in 'Room Data' (used for loads metrics in this report)

Building systems energy

Summary

Month	Heating (boilers etc.)	Cooling (chillers etc.)	Fans, pumps and controls	Lights	Equip.
A-Z	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo
Jan	0.0	74.4	26.0	103.2	159.8
Feb	0.0	68.0	23.8	93.2	144.4
Mar	0.0	76.0	26.6	103.2	159.8
Apr	0.0	74.0	25.9	99.8	154.7
May	0.0	76.1	26.6	103.2	159.8
Jun	0.0	74.2	26.0	99.8	154.7
Jul	0.0	75.4	26.4	103.2	159.8
Aug	0.0	75.0	26.2	103.2	159.8
Sep	0.0	73.1	25.6	99.8	154.7
Oct	0.0	74.2	26.0	103.2	159.8
Nov	0.0	71.9	25.2	99.8	154.7
Dec	0.0	73.6	25.7	103.2	159.8
Total	0.0	885.9	310.1	1,214.7	1,882.1

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MWh

The maximum value in each column is highlighted in red. The minimum value in each column is highlighted in blue. More than one value may be highlighted

Total Yearly Energy Consumption = 4,292.8MWh

Total Yearly Energy Consumption per Floor Area = 278.6kWh/m^2

Fig. 11. Energy report generated from simulation process.

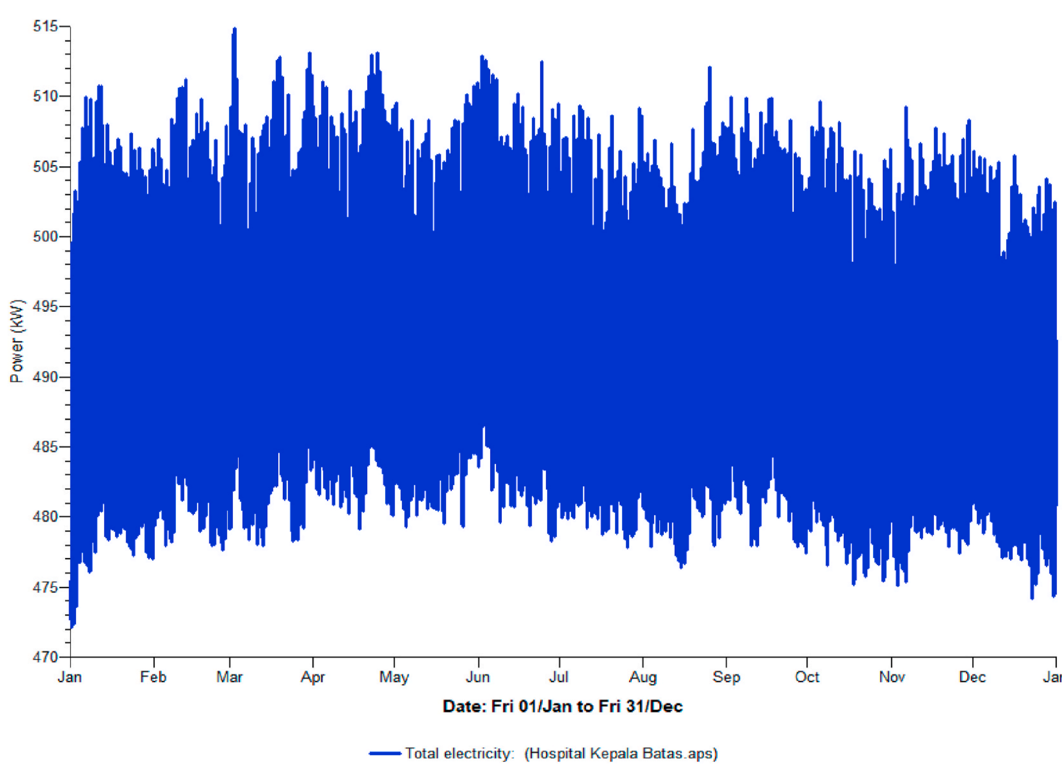

Fig. 12. Monthly simulated electricity usage.

Table 21
Comparison summary of simulation and actual data.

	Simulated	Actual	Tolerance
Total GFA (m^2)	15,407	15,239	1.1 %
ACA (m^2)	5856	5787	1.2 %
Building energy consumption (MWh/year)	4292.8	4203.5	2.1 %
Air-conditioned energy consumption (MWh/year)	2745.4	2690.2	2.0 %
Building energy intensity (kWh/m^2)	278.6	275.8	1.0 %
Air-conditioned energy intensity (kWh/m^2)	468.8	464.9	0.8 %

calculation of energy reduction is based on energy baseline developed from the simulation process discussed above.

4. Conclusion

In this study, a systematic model is used to evaluate the potential for energy saving in a public hospital. Three methods are applied in this model which involved detailed energy audit (DEA), empirical evidence approaches through on-site measurement and building energy simulation works using the IES VE software. The energy audit was first conducted to identify the energy saving potential for active measures to improve building performance. The DEA predicts that the chiller system retrofitting provides the highest amount of energy savings for Hospital Kepala Batas but with a longer discounted payback period. Meanwhile, the replacement of existing fluorescent bulbs offers the shortest discounted payback period but with a smaller amount of energy savings.

A chiller retrofitting measures were selected to be implemented as a pilot project because of its ability to provide the highest energy savings amount to the hospital based on energy audit findings. Two new chillers were installed on site and data was collected as empirical evidence to validate the energy saving predicted from DEA. Overall, the chiller retrofitting project has shown substantial energy and cost savings. The actual energy saving from the chiller system retrofit was found to be slightly higher than what had been predicted. While the discounted payback period calculated for the pilot project is shorter than that calculated in the energy audit.

However, many more energy saving potentials can still be explored in the hospital building. Passive design strategies study is not covered in the energy audit because calculating the potential saving without existing installation on site is difficult. It should be evaluated through simulation process with energy saving potential can be seen when the simulation results show a reduction in the amount of energy consumption from the developed energy baseline. The passive strategies are not only offering an additional energy reduction and cost saving to the hospital building [29–31] but also provides a lower investment of implementation and most cost-effective initiative [32], especially in hot and humid climate. The tolerance value of energy consumption between the simulated result and on-site measurement in this study was found to be acceptable and can be used as a baseline to calculate the potential energy savings for future simulation works. The energy baseline for annual consumption and BEI are developed through building simulation as a benchmark for the calculation of energy saving potential. The established baseline will be used to simulate various possible passive strategies to identify potential energy savings before the best measures can be implemented.

As a conclusion, both passive and active strategies need to be considered for implementation in Hospital Kepala Batas to optimize any potential saving identified through energy audit and simulation works. An on-site post-retrofit measurement is also conducted as empirical evidence to validate the predicted energy saving from the active measures. The combination of these methods as a systematic approach is essential to identify the potential energy savings as much as possible through active and passive strategies that have so far has never been implemented in any public hospital in Malaysia. Considering that hospital buildings are the main energy users among government facilities, the need for energy reduction is essential to save annual operational costs and environmental conservation. In addition, most of the hospital areas were designed with natural ventilation. Thus, improving thermal comfort in current climate change conditions while maintaining existing energy consumption is needed, especially in hospital building [33]. Indirectly, these passive [34,35] and active approaches will help building owners to optimize energy saving, increase the level of comfort in the building, and provide a better environment for building occupants, as well as assists the hospital toward achieving green building status which also in compliance with the MOH policy. Besides, energy efficiency is an important component in every green building rating tool compared with other green elements because of its high potential on point scoring.

Authorship statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the *Hong Kong Journal of Occupational Therapy*.

Authorship contributions

Please indicate the specific contributions made by each author (list the authors' initials followed by their surnames, e.g., Y.L. Cheung). The name of each author must appear at least once in each of the three categories below.

Category 1

Conception and design of study: N.M.A. Rahman.
acquisition of data: N.M.A. Rahman.
analysis and/or interpretation of data: N.M.A. Rahman.

Category 2

Drafting the manuscript: N.M.A. Rahman.
revising the manuscript critically for important intellectual content: C.H. Lim, A. Fazlizan.

Category 3

Approval of the version of the manuscript to be published (the names of all authors must be listed).
N.M.A. Rahman,C.H. Lim, A. Fazlizan.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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