DEVELOPMENT OF ENERGY BENCHMARKING OF MALAYSIAN GOVERNMENT HOSPITALS AND ANALYSIS OF ENERGY SAVINGS OPPORTUNITIES

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Abstract
There has been a growing interest in the Malaysian government on the issue of energy efficiency and the environment. This study presents the investigation and analysis of electrical energy performance characteristics of government hospital buildings in Malaysia. A generic questionnaire was developed to collect energy data of all government hospital buildings and a regression analysis was performed based on the feedback to predict the annual energy consumption of a Malaysian hospital building. Using the available surveyed data a generic hospital energy benchmark in Malaysia was developed and the surveyed data was also used to construct a typical base-case hospital building model using Energy Plus software. Using building simulation method with local weather data, areas of energy savings opportunities and its cost effectiveness are investigated. Simulation using selected cost effective energy savings measures suggests that the Annual Electrical Energy Use Index (EEUI) of the base-case hospital building model can be significantly reduced to as much as 28.85% with a simple payback of 3.7 years by applying energy saving measures such as improved glazing, lighting as well as optimization of ventilation and cooling system.

Key words: Hospital building; annual energy consumption; regression analysis; energy saving measures; Energy Plus modeling.

INTRODUCTION

The rapid economic growth in the past has resulted in the planning and construction of many new hospitals in Malaysia. Apart from this, many existing large referral hospitals have been or in the process of major physical upgrading and refurbishment to meet the current and stringent medical standards, and to provide new facilities and services for new and expanding medical services. With a hot and humid climatic condition, plus the high expectation and requirement of medical and clinical standards, most hospitals have become very energy intensive. The Malaysian Code of Practice on Energy Efficiency and Use of Renewable Energy For Non Residential Building (MS 1525:2007) aimed at promoting energy efficiency of buildings has been trying to encourage a general awareness in energy conscious design and operational practice (Standard Malaysia, 2007). Lately, there has been a growing interest in the Malaysian government on the issue of energy efficiency and the environment. Malaysia National Green Technology Policy was launched in 2009 under KeTTHA which promotes efficient use of energy that covers major area such as energy, building, transportation and water sector.

It is without question that a very significant increase in hospital operational costs is the result of the increase in energy usage. In the current healthcare environment, with hospitals as the main energy users, challengers in trying to reduce operating costs and improve patient care are becoming more important than ever. Investigation and analysis of energy performance characteristics of hospital buildings in Malaysia using appropriate assessment methodology and analytical tools is therefore important for the purpose of establishing areas of energy wastage and developing strategies in efficient energy usage. This is crucial in order to extract the maximum benefits out of a more efficient building system. While much information is already available insofar as technology and building engineering systems are concerned, there is lacking in the local performance information and benchmarking, and information on breakdown of energy consumption of hospital buildings. This information is critical for the understanding of Malaysian hospital's energy profile.

Energy usage in buildings has long become one of the priority areas in research in many countries. Many developing countries, in particular during the past years, have made various efforts in encouraging efficient use of energy in buildings, with attempts to regulate energy conservation program and energy efficient design in buildings. Studies are carried out with the aim of understanding local and global energy issues for the improvement of energy usage. Janda & Busch (1994) in their report indicated the importance of developing comprehensive building energy standards, codes and guidelines for the commercial building sector. Little consideration is been given to energy conscious design of buildings in the past (Goodsall, 1994). Many developed countries, however, have sustained developmental works in the area of energy efficient building technologies for quite a while. Various methods for energy and environmental performance evaluation have been developed due to people's concern on the environmental impacts of energy usage in building sector in the world (Cole, 1999).

Energy benchmarking is useful for hospitals to target energy savings opportunities. Developing energy benchmarking of hospital buildings is important in order to perform comparison of whole-building energy use relative to a set of similar buildings. Review of benchmarking practices of asset management in the health industries around the world confirmed that an information gap existed in the strategic management of hospitals in the context of measuring performance (Tucker & Then, 2001). In the UK, a guide of hospital benchmarks of consumption and energy costs where actual performance can be compared have been produced under the Best Practice Program (DETR, 1996), called the Energy Consumption Guide for Hospital Buildings (ECG-72). Two levels of performance (in GJ/100 m^3 heated volume) namely Good Practice and Typical Practice are used in the Guide with four different types of hospital categories. This guide introduces benchmarks and representative values for energy use in hospitals, providing performance indicators against which a hospital's actual energy and cost performance can be compared, in order to identify the potential for savings. An alternative guide on hospital performance benchmark is produced by Energy Efficiency Office in their publication "Energy Efficiency in Healthcare Buildings" (EEO, 1996), which uses a Normalized Performance Indicators(NPI) and are based on average annual energy consumptions from a wide hospital sample. This guide rates efficiency based on good, fair, and poor practice, also for four different types of hospital categories with slight variation in definition to the ECG-72 guide. The NPI values take into account the volume, Degree Days and occupancy for different types of hospital. Due to these accounts, this guide seems to be more detailed in obtaining its benchmarking values. Chartered Institution of Building Services Engineer (CIBSE) also produces a detailed guidance on benchmarks and energy efficiency measures (CIBSE, 2004). One particular Guide is the Energy Consumption Guide 19 (ECON 19), which considers the overall performance of the whole building, but targeted only for energy uses in office buildings (CIBSE, 2000). Later, the Energy Assessment and Reporting Methodology (EARM) was made available, with assessment methods and benchmarking values for office buildings, banks and agencies, hotels and mixed-use buildings (CIBSE, 1999).

The aim of this research was to collect and quantify actual electrical energy consumption of hospital buildings and to perform energy analysis on collected data using various regression techniques as well as establishing significant correlation of known energy parameters. A base case hospital building energy-use model, representative of the climatic condition and categories of hospital buildings was developed as well to demonstrate viable and cost effective energy improvement measures in existing hospital buildings.

LITERATURE REVIEW

Hospital Building Energy Assessment Survey (HBEAS)

One of the key tasks in identifying energy performance characteristic is the collection of all energy related data. An important part of study is the data gathering exercise through the development and use of survey/questionnaire form distributed to all government hospitals. The purpose of the hospital building energy assessment survey is to collect appropriate data for building design, construction, systems, occupancy, operation and maintenance and management in relation to measured energy usage and performance of the Malaysian hospital buildings. The emphasis will be on the annual energy consumption of hospital buildings in term of Annual Electrical Energy Use Index (EEUI), apportionment of major energy using systems and equipment, and analysis of other significant energy consumption drivers. The energy assessment survey involves all the 120 existing government hospitals. Only 24 hospitals out of the 120 responded to the final energy assessment survey. Based on actual metered consumption, both annual and monthly energy consumption was submitted by all respondents. Specific data are required by the survey for the calculations and estimates of energy end use or major energy consuming systems, such as lighting system, air-conditioning system and other plant and equipment. The questionnaire also involves the collection of multiple energy indicators. They were selected in light of using them to establish or develop a representative energy model through correlation and regression. There are:

a. Number of specialist services (SSNOS)
b. Gross area per bed GFA/bed (GFAB)
c. BOR %
d. Gross Floor Area (GFA) (m^2)
e. Treated floor area or A/Cond. Area (m^2) (TFA)
f. % or fraction of A/Cond. Area (%TFA)
g. No. of Bed (NOB)
h. Total No. of Asset (TNA)
i. Hospital Inventory (HVT)
j. Nos of chiller (CHLRNOS)
k. Nos of pumps all type (PUMPNOS)
l. Nos of fans all type (FANNOS)

Set Up Of Base-Case Hospital Building Energy Characteristics Using Building Energy Simulation Modeling

A typical medium size base case hospital building is modelled with the comprehensive Energy Plus simulation software to establish a base case model that is consistent with most common features and measurements of Malaysian hospital building of this category. Energy Plus simulation engine is used to simulate design and operating conditions to predict building cooling load, annual electrical energy use and total energy use intensity. The base case model is then used to determine improvements of annual energy consumption by varying or adding to it some important energy related parameters pertaining to building components, cooling system, lighting system and others. Construction of input information and creation of Energy Plus input file for the reference base-case building model is based on some crucial information gathered mainly from hospital energy assessment survey. That information included location and design climates of the building, building plan with typical construction information, building geometry and functional space zoning, building use information on lighting, equipment and occupancy density, building thermostatic control information of areas in building, typical ventilation and air-conditioning system specifications as well as scheduling of building operations.

Figure 1 shows a simplified four zone square shape layout of an average size reference hospital building with its main entrance facing north as well as its simplified building plan.

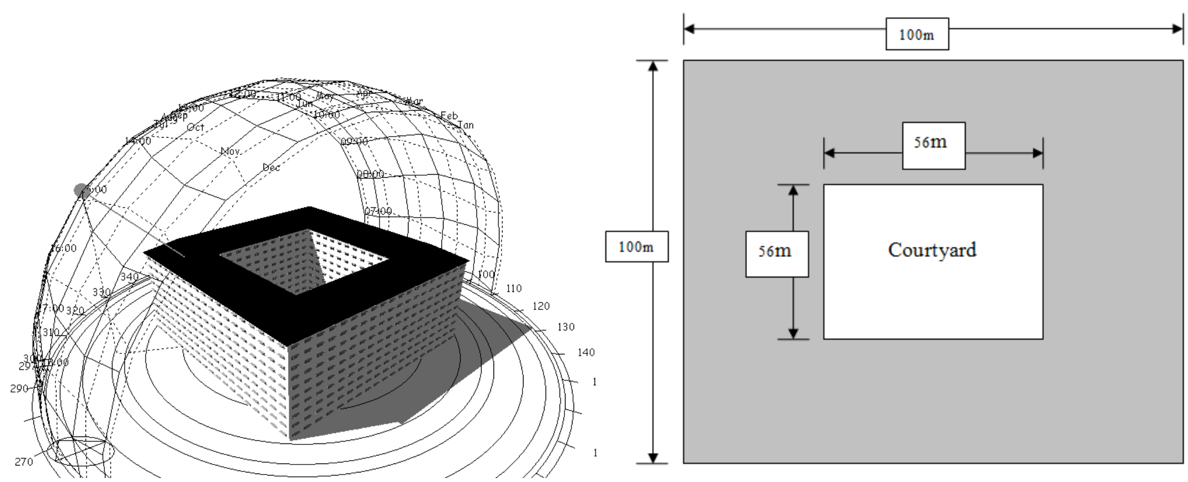


Figure 1: Base-case Hospital Building 3D view (Left) and plan of Base-case Hospital Building (Right)

The building has 10 occupied floors with a total gross floor area of 74,905 m^2, with about 65% of its gross floor area mechanically conditioned. Each floor is modelled as four external perimeter zones. The average floor-to-floor height is 4.0 m high with 1.0 m ceiling void for return air ducts and other engineering services. Each zone is defined as a region with collection of rooms group together to the same type of thermal control and having similar internal load profiles. Horizontal overhangs are fitted on all facades, typical of many low rise buildings in Malaysia to limit direct solar radiation and glare into building space. Typical to the existing hospital design, the ground floor consists of Operation Theatres, Intensive Care Units, Diagnostic and A&E Department (MRI and CT scanners, Angiography, Mammography, General Imaging, Linear Accelerator and Ultrasound), Laboratory and Pharmaceutical Department. First floor is the various Medical Specialist Clinics (consulting clinics, interview, examination, and treatment areas), and the rest of the floors are the mechanically and naturally ventilated patient wards. Design occupancy density for the zones varies between 0.08 and 0.125 person/m^2. All zones are mechanically cooled in first two floors and the rest are designed as partly naturally ventilated and partly mechanically cooled, common with Malaysian hospitals. For modelling purposes, the internal floors of the naturally ventilated floors are treated as adiabatic surfaces. Other intermediate floors are not modelled as adiabatic surfaces since they will have different internal load and operation requirement with slightly different occupancy density. The following Table 1 shows the base-case building construction elements, listed from outside to the inside of the zone.

Table 1: Hospital Building Construction Elements and Properties

No.	Type	Materials
1	Wall	Finish
		13 mm plaster
		115 mm Common brick
		13 mm plaster
		Finish
2	Window	6 mm Clear single pane glass with reflective blinds
3	Partition	Gypsum board or 19 mm plaster
		115 mm Common brick
		Gypsum board or 19 mm plaster
4	Roof	25mm clay tile with inside reflective coil
		Ceiling air space
		5 mm roof felt
5	Ceiling	Ceiling air space
		Acoustic tile 10 mm
6	Floor	150 mm cast concrete (200mm concrete slab for ground floor)
		50 mm sand cement render
		5 mm PVC flooring tile
7	Window shade	Medium reflective Venetian blinds

Occupants, lights, equipment, outside air infiltration and ventilation are described as internal gains for the zones. The hospital general indoor space temperature setting is typically designed to maintain a dry bulb temperature of range 22 ºC to 25 ºC with average relative humidity of 65% during occupancy hours. The intended cooling requirement was design to maximum outdoor dry bulb and wet bulb design conditions of 34.2 ºC and 31.2 ºC respectively.

Input data are obtained from earlier surveyed as-built data, available Malaysian Standard design guidelines (PWD, 1995), and from energy audit data by earlier researches relevant to this work (Chirarattananon & Taveekun, 2004). Quantity of fresh air intake for adequate indoor air quality is rated between 8 and 15 litre/sec/person depending on zone. Air changes per hour (ACH) or ventilation rate of building zones can then be estimated by dividing quantity of fresh air intake to room volume and multiplying by the occupancy. The determination of the amount of ventilation is quite complicated and is always subject to significant uncertainty in relation to space functionality and occupant comfort. Recent review on ventilation requirement for hospital building design in United States has been made by the American Institute of Architects and recommended new values based on scientific research, in consistence with new medical program requirements. One significant change relates to the increase in ventilation requirement for patient rooms, with increased air changes in HVAC design for the rooms (Ninomura & Bartley, 2001). Infiltration of outside air, generally caused by the frequent opening and closing of doors, from window and wall cracks, is rated at between 0.5 to 0.7 ACH in accordance with ASHRAE Standard 62 (ASHRAE Standard, 1989). Equipment peak gain varies between minimum of 5 W/m^2 in common and circulation areas and maximum of 45 W/m^2 in Operation Theatre and Intensive Care Units. Lighting consists of four T-12 cool-white Halophosphate low frequency 5 W/m^2-100 lux fluorescent lamps in standard parabolic reflective luminaries with magnetic core ballasts. Circulation areas and corridors use the compact fluorescent type. The actual zone lighting casual gain is calculated using the W/m^2-100 lux data of luminaries and the level of illuminance (lumens/m^2) specified for each zone. Table 2 summarized the main input parameters for the base-case building model required for simulation process in calculating design cooling load and estimating whole building annual energy consumption. The HVAC model assumes that all zones are served by the same system, but with different temperature set-point and cooling schedules based on its space use classification.

Table 2: Characteristics of Malaysian Reference Base-case Hospital Building

Parameters	Units	Values
Building Floor Type		Ground Flr: Treatment, Emergency, OT, ICU, Lab, Pharmacy and General area. 1st Flr: Specialist Clinics, circulations 2nd – 10th Flr: Patient Wards and others
Total Floor Area	m^2	75,000 (~65% with mechanical cooling)
Total Roof Area	m^2	7,870
Window to Wall Ratio		0.2-0.4
Shading coeff. of glass		0.95
U-value for windows	W/m^2-K	5.894
U-value for Wall	W/m^2-K	2.732
U-value for Roof	W/m^2-K	2.791
Lighting gain	W/m^2- lux	5
Equipment gain	W/m^2	5 - 40
Outside ventilation air	ltr/sec/person	8 - 15
Infiltration	ACH	0.5 – 0.7
Air Handlers		Constant Air Volume
Design Volume flow rate	m^3/s	1-4 based on space function
Rated Chillers COP		3.8
Indoor Temperature Set	ºC	22 - 25
Outdoor Design Temp.	ºC	34.2 Max, 22.2 Min of Dry Bulb Temp
Number of Occupants	Person/m^2	0.08 to 0.25
Working Hours and Days		Refer zones occupancy schedules
Shading devices		1 meter overhang on all facades & internal reflective blinds

Table 3 shows the breakdown of annual electrical energy consumption, total design cooling load requirement and annual energy intensity of the reference base-case hospital building model. The base-case hospital building model input and output files are checked to verify that there are no errors in running the program.

Table 3: Breakdown of Annual Energy Consumption for Base-case Building Model

Use type	Units	Simulation values	% of Total
Chiller system	kWh	7,321,991	39
Lighting	kWh	3,949,860	21
Equipment	kWh	4,114,463	22
Fan	kWh	1,735,641	9
Pump	kWh	1,389,008	7
Heat Rejection	kWh	433,877	2
Total annual electrical energy consumption	kWh	18,944,841	
Electrical Energy Use Index	kWh/m^2/yr	253	
Total Design Cooling Load Requirement	kWh	10986	

A calibration procedure is done by comparing, at the whole building level, the energy usage projected by the model to that of the measured utility data of the average of the medium size hospitals surveyed. Monthly simulated energy consumption and average monthly measured data for the medium size hospital are plotted against each other for every month in the data set, as shown in Figure 2. These measured average monthly consumptions are taken from the eleven surveyed hospitals categorized as state hospital by Ministry of Health Malaysia. To determine how well the model in predicting annual energy consumption, analysis of monthly error (ERRMonth) and coefficient of variation of the root-mean-squared monthly errors (CVRMSEMonth) is performed. Comparison of the measured average and simulated results produce an EERyr of 8.1% and CV-RMSEm of 9%, within the acceptable monthly and yearly calibration tolerance. Table 4 below specifies the acceptable tolerances for monthly and yearly values of ERR using monthly data calibration set by International Performance Measurement and Verification Protocol (Efficiency Valuation Organization, 2012).

Table 4: Acceptable tolerances for monthly and yearly ERR

Index	Tolerance
ERRM	± 15
EERyr	± 10
CVRMSE M	± 10

Estimated measured annual energy use index of the 11 surveyed state category hospital ranges with EEUI ranging from 72 kWh/m^2/yr to 275 kWh/m^2/yr, with average of 163 kWh/m^2/yr. The Base-case building, with 253 kWh/m^2/yr, is well within the range, in agreement and comparable to most of the surveyed hospitals of its size. The simulated model electrical energy apportionment, as in Table 3, can be seen as comparable to figures estimated by the Ministry of Energy for general commercial buildings in Malaysia (MECM, 1989), and also proved reliable compared to earlier surveyed data. Thus this base-case building model as a whole, has been calibrated to reflect the typical local construction and energy use features for a state category Malaysian hospital building for energy improvement retrofitting study.

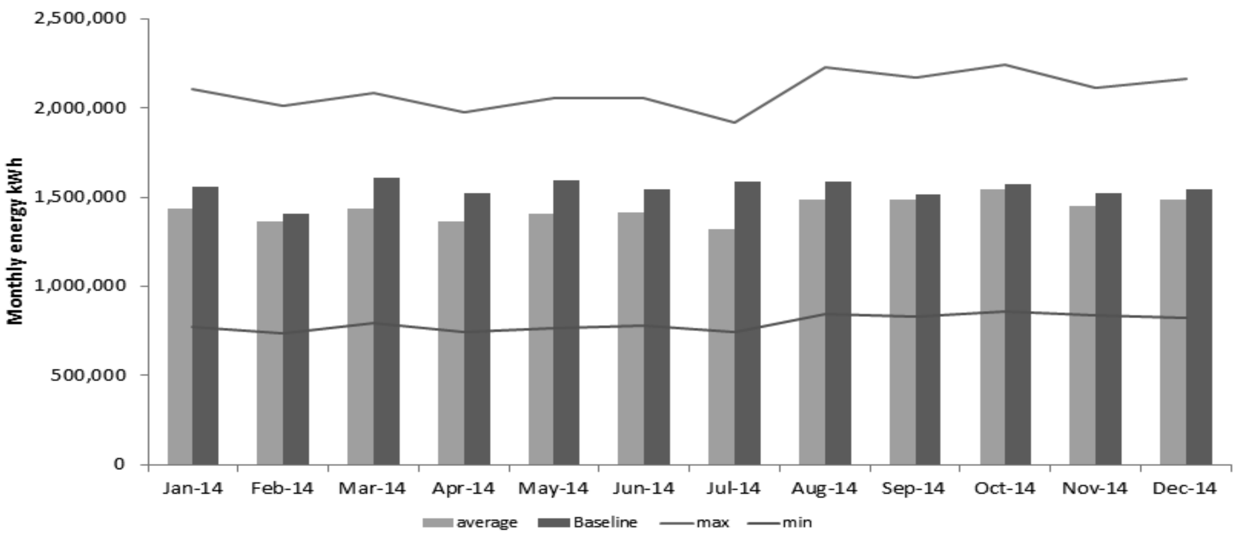


Figure 2: Comparing Base case Model to State Hospital Annual Energy

RESULT AND DISCUSSION

Malaysian Hospital Energy Trend

Figure 3 shows the monthly electrical consumption profiles of the 28 hospitals. The annual consumption ranged from 6 mil to 53 mil kWh/yr, with generally higher values for larger hospitals. The highest annual consumption was for a 2331-bed hospital and the lowest for a 516-bed hospital without a centralized cooling system. Although energy usage intensities varied significantly between hospitals, there was only a very small variation of monthly energy usage within each hospital. This can be attributed to the fact that activities in hospitals do not vary much throughout the year and that Malaysia experiences a very small monthly variation in ambient temperature. The 30 year Malaysian Average Monthly Temperature range is small, from 26 ºC to 28 ºC (MMS, 2005).

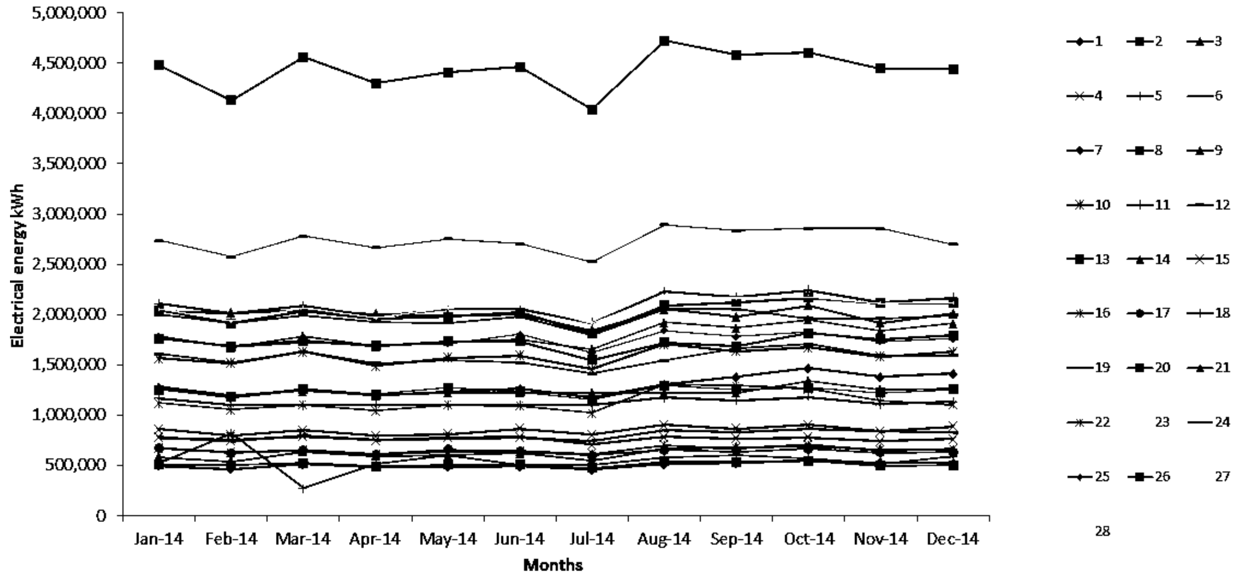


Figure 3: Monthly Consumption Trends of the 28 Malaysian Hospitals (legends shows hospital codes)

The measured averages for EEUI are shown in Table 5. In terms of GFA, an average EEUI of 172 kWh/m^2/yr were calculated from the collected energy consumption data for 28 hospitals whereas in term of mechanical cooling area (MCA) the calculated EEIU was 265 kWh/m^2/yr .Since space heating is totally not required in Malaysian hospitals and electricity is the only building related energy source, these calculated EEUI can be treated then as the total site energy consumption index of the sample hospitals.

Table 5 Measured Average Values of EEUI in kWh/m^2/yr for Malaysian Hospital and Comparison to Other Building Standard Values in Similar Climate

Average values of EEUI (kWh/m^2/yr)	Hospital	Typical office Building	Low Energy Office
based on GFA	172	269 (GFA)	135 (GFA)
based on MCA	265		

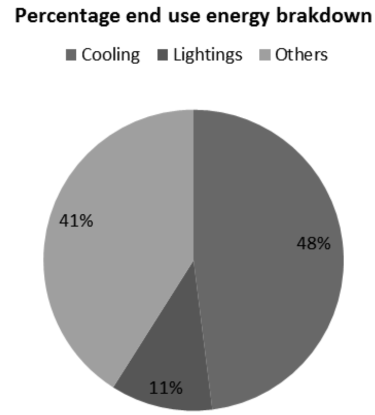
It is interesting to see that estimated average EEUI based on GFA of the 28 hospitals were observed to be significantly lower to available standard value for typical fully air-conditioning office building in Malaysia but almost near to the Low Energy Office value. In Malaysia, not until recently, this standard value of 269 kWh/m^2/yr (Kannan, 2001) is being suggested as a typical design base case for all commercial and governmental buildings. In contrast, measured average values of hospital EEUI from this study (shown in Table 5), suggest that typical average values for hospital building is much lower giving a more accurate reflection of the Malaysian hospital energy intensity. It is also important to note that on average, only about 69% of hospital building spaces are mechanically ventilated, much lower compared to other commercial buildings or even to new hospital design requirement. The results here should reflect a better level of expected energy efficiency standard to be achieved in new hospital design, and not to apply a generalized “typical” value of minimum energy intensity to all commercial buildings as suggested by the Malaysian standard. The result also suggests that a specific energy indicator for hospital, with lower EEUI, is necessary if we intend to design energy efficient hospitals in future.

Nevertheless, lower average EEUI values based on GFA registered by the hospitals does not actually mean that in Malaysia, hospitals are more efficient than commercial office buildings. It is important to note that most typical office buildings in Malaysia are fully treated with mechanical cooling and ventilation, whereas, hospital buildings are designed and operated with only selected area mechanically cooled. The HBEAS survey study shows majority of hospitals have large naturally ventilated general building spaces and also many patient wards use natural ventilation and oscillating fans for some cooling effect on occupants, thus explaining the lower average EEUI when its energy consumption is normalized to gross floor area.

Comparing energy usage index between countries is not as easy or as straightforward as it seems, due to mainly the differences in assumptions and normalization made in representing the values. Nevertheless, in contrast, the UK hospitals have typical benchmark values under its Energy Consumption Guide 72 for site total annual energy consumption of 495 kWh/m^2 of treated building area for large teaching hospitals to about 550 kWh/m^2 for smaller cottage and long stay hospitals (DETR, 1990;DETR, 1996). From the total, electricity energy consumption only accounts for about 18%, with the balance comes from fossil fuel consumption, mainly for space heating. Typical "electrical only" annual energy consumption in the UK hospital ranges from 121.9 kWh/m^2 for a large Teaching hospital to about 71.8 kWh/m^2 for the smaller Long-stay hospital. Not much information are known on hospital energy profile in other regions, but previous hospital buildings database (BTC, 2001) shows Korea (sample of 63 hospitals) and United States (sample of 196 hospitals) having average electrical only Energy Utilization Index (EEUI) of 165 kWh/m^2/yr and 212 kWh/m^2/yr respectively.

Nonetheless, comparison of annual electrical energy consumption according to hospital types and basing on gross floor area does not provide much meaningful evaluation on finding factors that could affect the characteristics of hospital energy use in general. It only provides some indication of energy usage but is not a determining factor in usage level. Other than trying to develop representative energy consumption index based on available data, it is also important here to develop a sense of the factors that might influence annual energy consumption so as, further detail analyses, when required, can be easily focused on these possible factors, signifying the potential causes of energy use variation.

Apportionment of energy observed in the charts of Figure 4 shows the significant contribution of space cooling system (chillers and environmental control system combined) in hospital building energy consumption. On average, the percentage of energy use under space cooling system is estimated to be about 48%. The charts also suggest that, other than the chillers, environmental control systems and lighting systems, large portion of site energy consumption comes from the 'other' various systems and equipment that exist in the hospitals. These are the medical equipment, boilers, hot water systems, computers, electric fans, pumps and many more items that contribute a large portion of hospital annual electrical energy consumption. All hospitals estimated average energy breakdown is 48% for cooling, 11% for lightings and 42% for others. Nevertheless, the chillers as a single energy consuming entity, contributes the most with an average of 23% to 28% of total consumption. Energy dedicated for space cooling are estimated, on average, to be around 48% of total consumption, but on average, only about 69% of hospital's building areas are treated with air-conditioning. This is in contrast to estimated figures of energy use for a typical commercial building in Malaysia, where the cooling system alone, which treated about 90-95% of gross building area, accounts for about 60% of total building energy consumption (MECM, 1989).



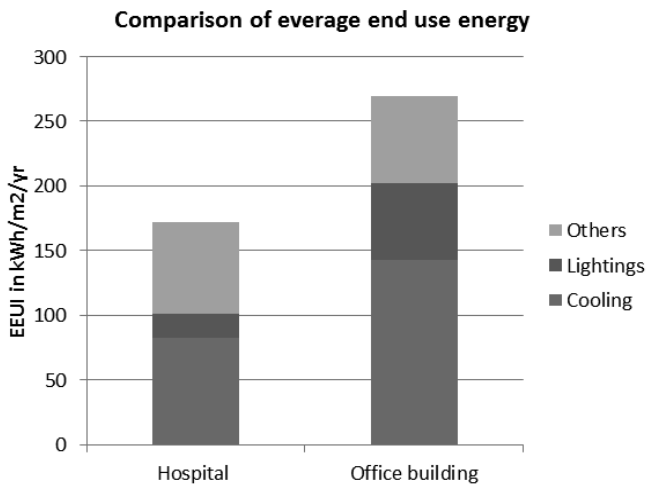


Figure 4: Comparison of Energy Breakdown for hospital and office category (MECM, 1989)

The result suggest to the fact that hospitals in Malaysia have large gross floor area, but on average, only about 69% of its building area is treated with some kind of air-conditioning, making its total EEUI (when normalized to gross floor area), much smaller.

In developing new energy benchmarks for hospital buildings, it is important to identify measurable parameters of a hospital in a way that performance targets can be established. Energy benchmarking derived from data collection of buildings and its engineering services should satisfy a few main criteria such as it must be achievable by a significant proportion of the hospitals and apply to all hospitals, the performance indicator on which the benchmark is based should be easy to calculate from readily available information and simple to understand and also benchmarks should be dynamic in that as hospital energy efficiency requirement improved, continuous review and adjustment can be made to raise the required performance level.

With the available statistics, we can develop a representative distributional benchmark for each hospital categories. For each category, comparison of energy intensity can be made between hospitals, and also, with other standard EEUI of other building categories in Malaysia, such as hotels and office buildings. This distributional benchmarking is very useful since it can pinpoint the hospitals that can be categorized as energy inefficient based on an average value or a set of minima or maxima EEUI for efficient hospital operation. It does not, however, show what and where the actual inefficiency is, but the idea is to provide information in helping to focus our efforts, in identifying where the problem areas are. It is also important to remember that this type of distributional benchmarking using energy use intensity terms (kWh/m^2/yr) is only based on site energy terms. In other words, the analysis does not involve source or primary energy terms (energy at site plus generation, transmission and distribution), which, in the real sense, can be more accurate since it involves the whole energy cycle. But site energy is more useful than source energy when comparing other buildings of similar function and of similar fuel mix, such as hospital buildings.

Depending on type and the actual measured level of EEUI, individual hospital can compare their performance to the developed representative benchmarking or target consumption as shown in Table 6. Benchmark was developed to have set values for Typical and Good Practice, based on their EEUI calculated mean values and their lower percentiles respectively. Nevertheless, the developed benchmarking indicators are based only on the 28 hospitals. Significant improvement in terms of representation can be made further by including as many hospitals in the data analysis. The idea is to provide a simple but practical framework to help individual hospital understand their energy usage and identify the possibility of energy saving measures.

Table 6 Representative Benchmarks in kWh/m^2/yr for Malaysian Hospitals Developed from Survey Data

	Hospital (Values in kWh/m^2/yr)	
	Typical	Good Practice
Chillers	45	26
Environment Control system	37	13
Lighting system	19	11
Others	71	44
Overall Hospital Electrical Energy Benchmarks	172	94

To adopt the developed representative benchmark, we consider an actual 990-bed large referral hospital, with gross floor area of 65221 m^2 and about 72 percent of its floor area treated with air-conditioning. The breakdown of its estimated energy consumption and comparison to representative values of Typical and Good Practice (G.P) target of Table 6 is shown in Table 7 below. From its energy bills of 14,674,725 kWh, this hospital registered an annual EEUI of 225 kWh/m^2, which is quite high when compared to both Typical and Good Practice target in the representative benchmark.

Table 7 Comparison of the 990-bed Hospital Actual Annual Consumption to Set Target (Hospital representative benchmark of Table 6)

	Estimated EEUI	% difference in use density	
	(kWh/m^2)	Typical	G.P.
Chillers	50	11%	92%
Environment control sys.	37	0%	185%
Lightings	15	- 21%	36%
Others	123	73%	180%
Total EEUI	225	31%	139%
Annual Total (kWh)	14,674,725.00 (actual)	31%	139%

From Table 7, estimated energy performance by the hospital chillers is about 11% higher than the typical benchmark value. Therefore, the cooling systems in general, should be further investigated in detail since we know there is much opportunity for savings. From this information alone, we can imply that there is no serious strategy by hospital building designers to make energy efficiency as a core element in cooling system design. Energy performance for Lightings is estimated to be good but energy for 'Others' are exceptionally high, and further effort should also be taken in analysing this area. This knowledge on utilization performance can imply to several possible factors that requires further investigation by the hospital for savings opportunities.

Annual Energy Consumption (AEC) Prediction

EXCEL regression analysis package was chosen as the easiest and appropriate method in the model building process. The chosen model was intended to represent all hospitals or at least, the hospitals represented in the final sample and aims to explain as much of the variability of energy consumption. Once the model is developed, it is evaluated using the least-square approach to find the best fit to the data. The model usefulness and fitness is tested using the square of the correlation coefficient, R^2, telling what percentage of the variability in annual energy consumption explained by the model variables. The standard deviation of the error, E or residual of the regression model is used to draw an important statistical inference about the model performance, in a way that enables us to judge whether the model is an appropriate energy estimation tool. It is also assumed that all the regression assumptions in model development are satisfied statistically. These assumptions are mentioned in much detail in most statistical technique books and publications.

Multiple indicators from survey data, which are assumed to be ones that have major influences, were selected for the study of their sensitivity to annual energy consumption (AEC). 28 hospitals were selected for the correlation analysis. Table 8 shows EXCEL output of the pair-wise correlations. Analysis of correlation of selected variables for determining pair-wise correlations helps in the selection of variables for the model. The selection property is that, variables with coefficient of determinations R^2 of more than 0.20 (a cut-off figure) are selected. As mentioned before, R^2 is use to relate how well the independent variables in predicting variations in the hospital building annual energy consumption. Variables with lower correlation coefficient are eliminated, leaving only the highly significant ones to be selected for model production.

Table 8: Values of Pair-wise Correlation Coefficient of Determination (R^2) (only 1st EXCEL sheet column value is shown here)

		Average Energy Consumption (kWh/year)
1	Average Energy Consumption (kWh/year)	1
2	Num of specialist services (SSNOS)	0.47
3	Gross area per bed GFA/bed (GFAB)	0.28
4	Bed occupancy rate % (BOR)	0.23
5	Gross Floor Area (m²) (GFA)	0.69
6	A/Cond. Area (m²) (TFA)	0.59
7	% A/Cond. Area (%TFA)	0.24
8	No. of Bed (NOB)	0.74
9	Total No. of Asset (TNA)	0.79
10	Hospital Inventory (HVT)	0.07
11	Nos of chiller (CHLRNOS)	0.04
12	Nos of pumps all type (PUMPNOS)	0.73
13	Nos of fans all type(FANNOS)	0.69

If we want to predict the annual energy consumption (AEC) in kWh/yr by the selected independent variables, then the output shows highest correlation of 0.79 to total number of assets (TNA). Second highest is to the numbers of beds (NOB) with 0.74 followed by number of pumps (PUMPNOS) with 0.73, number of fans (FANNOS) with 0.69, hospital gross floor area (GFA) with 0.69 as well as treated area or air conditioned area (TFA) of 0.59. If we must use a single explanatory variable to predict AEC, the values suggest that TNA is the best candidate. This provide a linear regression model of AEC = 1153(TNA) +2,244,679. If we can use more explanatory variables for AEC, then SSNOS, NOB, GFA and TFA should be used with TNA. Nevertheless, percentage of treated floor area or air conditioned area (%TFA), gross floor area per bed (GFAB) and bed occupancy rate (BOR) may also explain the variation in energy consumption. Hospital inventory (HVT) and number of chiller (CHLRNOS) may provide some explanation but their significance to AEC are quite weak in statistical terms due to low coefficient of determinations. Furthermore, from the regression results, there exist problems with multi-collinearity in some model parameters. Multi-collinearity causes large uncertainty bounds in regression coefficient resulting in uncertainty of developed model.

Using EXCEL data analysis regression function, all indicators mentioned earlier were included as the X input in the regression command whereas the annual energy consumption kWh/year is selected as the Y input. The regression output that is of interest is the calculated coefficient and the P factor for each indicator. The regression command will be repeated again to exclude any indicator that has a P factor exceeding 0.05. It is found initially that 3 indicators (GFAB, NOB and FANNOS) could explain the variation in AEC with R^2 of 0.88. This means the regression model with 3 coefficients could explain 88% of the variation in AEC. However when considering the indicator FANNOS in this model, it is quite difficult for anyone to determine the number of ventilation fans in any building unless some cost and time is spent to conduct a survey. To allow for easy prediction of AEC, alternative indicator is chosen such as TNA together with GFAB and NOB where information such as these is easily acquired without much effort in any hospital premises under Ministry Of Health Malaysia. The suggested final model could explain 85% of the AEC with 90% confidence interval in its prediction. The regression model proposed from this analysis is as follows.

$$y = -7343383.26 + 43080.80*GFAB + 11415.15*NOB + 657.52*TNA \qquad \text{(Eq. 1)}$$

Prediction of AEC with GFAB, NOB and TNA produced a similar prediction precision compare to the earlier choice of GFAB, NOB and FANNOS as shown in Table 9.

Table 9: Precision comparison of alternative indicators

Nom of Coefficients	8	3	3
Standard deviation	9,000,489.20	8,857,256.62	8,957,799.13
Standard Error	1,700,932.58	1,673,864.16	1,692,864.91
Absolute precision (90% confidence interval)	2,891,585.38	2,845,569.08	2,877,870.35
Relative Precision	0.17	0.17	0.17
List of predictors selected			
Gross area per bed GFA/bed (GFAB)	✓	✓	✓
Gross Floor Area (GFA) (m^2)	✓		
Treated floor area or A/Cond. Area (m^2) (TFA)	✓		
% or fraction of A/Cond. Area (%TFA)	✓		
No. of Bed (NOB)	✓	✓	✓
Total No. of Asset (TNA)	✓		✓
Nos of pumps all type (PUMPNOS)	✓		
Nos of fans all type (FANNOS)	✓	✓	

Figure 5 shows a comparison of metered annual hospital energy use and the predicted value. The regression model suggested could explain 85% of the annual energy consumption. It is recognized from this study, that there is difficulty in obtaining reliable data on Malaysian hospital energy use. The questionnaire sent to all hospitals (120 totals) only provides a feedback response of 28 hospitals. Data provided are summarized statistically to obtain correlation of selected parameters to measured energy consumptions in the process of developing a regression model representative of hospital building energy use in Malaysia. More demanding analysis should be performed, by taking larger samples, with inclusion of other non-parametric variables that could be included to statistically explain the variability of energy consumption in a hospital building.

In the model building process, relevance of other related factors, such as building construction, climate, occupancy pattern and infiltration, were not taken into consideration, but might be crucial in explaining annual energy consumption. In other words, alternative causal explanation is not considered but might be significant in this study. Therefore, improved survey questionnaire and data collection technique should provide better and comprehensive information for better regression-based modelling, but this can be very time consuming and expensive to be further continued here.

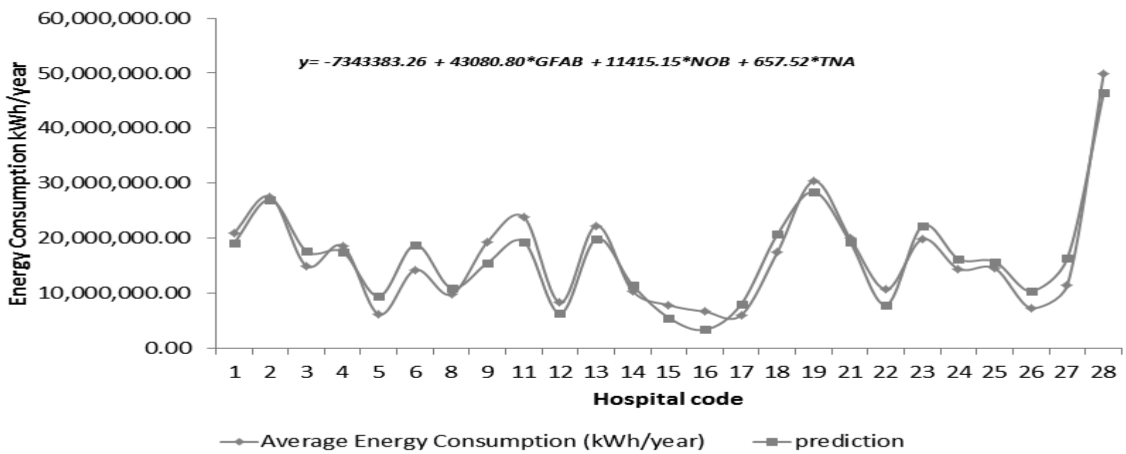


Figure 5: Prediction of annual energy consumption of Malaysian hospital with 90% confidence interval

Strategies in Retrofits Energy Efficiency and Conservation Measures

Based on the base case model set up described earlier, a general energy efficiency and energy saving strategy is proposed here that is the lighting system with more efficient lightings for reduced power density, ventilation and air-conditioning system efficiency for reduced running cost, improving glazing construction material for reduced solar heat gain, and also better ventilation control of outside air for the hospital building.

To determine how energy saving measures (ESM) affects the energy consumption characteristics of the base-case hospital building, input parameters relating to building construction, ventilation and air conditioning, and lighting in the base-case simulation input file are changed with some conservative values. The proposed input parameter changes were selected with the consideration that they must be practical enough in real situation to represent accurately the savings potential this building would provide based on the analysed results. To this, a simple cost effective analysis on proposed savings measures must be made. Earlier studies have shown that some measures, often advocated in temperate climates, were found to be of little significant in a hot and humid climate like Malaysia. For instance, in examining mechanisms for implementing energy conservation programs in Thailand, analysis using DOE-2 simulation program shows that roof insulation retrofit on low rise government buildings offers attractive energy consumption improvement, but the use of double glazing is not so in terms of cost effectiveness (Chirarattananon & Taveekun, 2004). Parker & Fairey (1997) use simulation analysis to select list of energy conservation options and shows that higher than code-mandated levels of wall materials, glazing components and roof insulation were shown to provide little savings, but nevertheless been specified in most high performance buildings.

Table 10 below considers and provides a conservative and realistic type of input changes as a basis for possible energy improvement measure to be compared with the base-case hospital building model total energy use characteristics. Simulation result were analysed from the perspective of energy reduction potential, reduction in cooling load capacity due to reduced heat gains and improved system efficiency, and cost effectiveness of the proposed measures. Table 11 provide comparison of the selected Energy Conservation Measures (ECM) technical and economic potentials.

Table 10: Simulation Input Changes for Potential Reduction in Energy Consumption

Item	Base-case Parameters	Base-case Indicators	Feasible Energy Saving Measures
1	Glazing: 3 mm Clear single pane glass with reflective blinds	U-value = 5.894 W/m^2-K. Shading coefficient = 0.86	Improvement of glazing with higher performance spectrally selective glazing. Lower shading coefficient and lower U-value for reducing solar and conductive gains.
2	Lightings: T-12 cool-white Halophosphate low frequency control	Light Power Density = 20 W/m^2 , 5 W/m^2-100 lux	High efficiency lighting system: Various T-8 Triphosphor fluorescent lamps with high frequency electronic ballasts and T-5 type for reduced power density and heat output

3	HVAC: Constant Air Volume (Design as Unitary Multi-volume CAV in simulation for simplification)	Chiller COP = 3.8 (Efficiency rating 0.91 kW/TR)	Various systems such as the VAV with reheat and Fan Coil. Variable speed fans for AHU for reduced fan energy and efficient ventilation. High efficiency chiller with improved part load characteristics
	Incorporating energy recovery to ventilation system and improving humidity ratio		Lowering the fresh outside air intake temperature and moisture content for better humidity control with suitable heat recovery system

The table summarizes changes to annual energy use breakdown, annual energy use intensity, retrofits cost effectiveness in simple payback periods (the ratio of the incremental cost of retrofit measure and the annual energy cost savings) after each variation of the selected retrofitting is added to the reference base-case model. This is based on a simple energy tariff of RM 0.208 per kWh of electricity and using the Malaysian Public Works Department component cost data for minor works (PWD, 2012).

Table 11: Cost Effectiveness Analysis from the Selected Energy Conservation Measures (ECM)

Parameter	Annual energy (kWh/m^2)	Annual savings (kWh/m^2)	Percent savings (%)	Energy cost savings* (RM/m^2)	Change in building cost** (RM/m^2)	Simple payback (Years)
Basecase typical hospital building	253					
With Glazing of:						
Single Green 3mm	252.4	0.61	0.24%	0.13	2	15.8
Single Green 6mm	252.2	0.81	0.32%	0.17	2.5	14.8
Single LoE(e2=.2) Clear 3mm	252.4	0.63	0.25%	0.13	3.5	26.6
Double 6mm/13mm air/6mm	252.2	0.83	0.33%	0.17	3.8	21.9
Double LoE Tint Spec Sel. 6mm/6mm air/6mm	250.5	2.53	1.00%	0.53	4	7.6
With Lightings of:						
T8 halophosphate low freq control	243.1	9.87	3.90%	2.05	3.1	1.5
T8 halophosphate high freq control	234.0	18.98	7.50%	3.95	3.68	0.9
Fluorescent T5	227.7	25.30	10.00%	5.26	5	1.0
With HVAC of:						
Improved chiller COP (ICCOP)	222.0	31.00	12.25%	6.45	26	4.0
ICCOP with VAV terminal reheat system	204.0	49.00	19.37%	10.19	44	4.3
ICCOP with Fan Coil system	202.0	51.00	20.16%	10.61	47	4.4
Base-case with Cost Effective ECM (ECMs in shaded)	180.0	73.00	28.85%	15.18	56	3.7

Further analysis of results shows that for every retrofit component, the most cost effective retrofits are with the double LoE tint spectrally selective glazing, T5 lightings, improved chiller COP and the application of FCU air conditioning system. Energy Plus input files containing the selected cost effective improvement measures were run. The installed lighting power was reduced from 52.7 W/m^2 to 35.8 W/m^2, FCU system is used for the cooling system, glazing SHGC improved from 0.861 to 0.291 with the double loE tint glazing. Table 12 provides comparison of the base-case hospital building energy intensity to the one with the selective overall improvement.

Table 12: Breakdown of Annual Energy Consumption of Selected Cost Effective ECM in Comparison to base-case Building

Parameters	Units	Base Case	All ECM
Chillers	kWh	9,144,876.93	6,414,456.87
Lighting & equipment	kWh	8,064,322.72	6,800,367.48

Fans	kWh	1,735,641.39	242,688.83
Total End Uses	kWh	18,944,841.04	13,457,513.18
EEUI	kWh/m^2	253	180
EEUI reduction	(%)		28.85

Simulation result produced a 661 kW reduction of design cooling load requirement from 10,986 kW to 10,325 kW. There is a 28.85 % reduction in energy intensity from the selected ECM retrofits, providing an energy cost savings of RM 15.18 per m^2 of building area. Figure 6 shows an incremental comparison between the best individually selected energy conservation measures and the one with all measures put together. This is to illustrate technically, the level of significance of each measure in reducing energy consumption of the base-case building. Individually, improving the HVAC system yields the greatest annual energy savings followed by lightings retrofit. Improvement on HVAC system and lighting system provides the best strategy to reduce maximum cooling, thus smaller cooling system capacity. Nevertheless, savings through the combination of all cost effective measures is the best and more realistic than simply adding savings from individual measures. With all the energy conservation measures considered, annual electrical energy use index for the base-case hospital building was reduced by 28.85 % from 253 kWh/m^2 to 180 kWh/m^2, and its designed cooling capacity reduced by 6 % from 10986 kW to 10,325 kW.

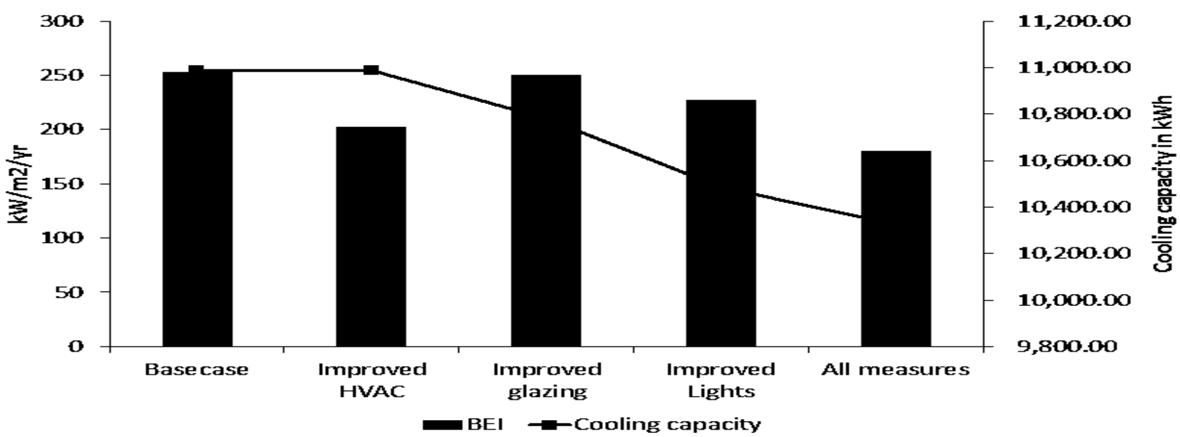


Figure 6: Comparisons of EEUI and Cooling Capacity Reduction from Selected ECM

CONCLUSION AND RECOMMENDATIONS

Investigation and analysis of electrical energy use characteristics of 28 Malaysian public hospitals has been performed, based on information gathered from a pilot energy survey questionnaire. The study highlighted the diversity of electrical energy consumption across hospitals which also allowed the formulation of a benchmark EEUI for a typical Malaysian hospital. The findings suggest that there are wide variations in energy usage patterns across hospitals of different sizes in Malaysia. Simple correlation analysis was performed on a number of predictors that could explain the variables for annual energy consumption. The suggested regression model equation used to predict the annual energy consumption could explain 85% of the energy consumption with 90% confidence interval in its prediction. Surveyed data was used to develop a base-case model of the Malaysian hospital, and using computer simulation method to study the impact of possible energy conservation measures. Through some conservative measures, the annual EEUI of a typical Malaysian hospital building can be significantly reduced. The simulation also shows that retrofitting with efficient HVAC system, improved glazing and efficient lighting system provided the best energy saving measures compared to others. Finally, this study will give hospital engineering support services, health care professionals and other governmental and organizational institutions in Malaysia a reference energy metric data, which currently does not exist, to evaluate the energy performance of various hospital buildings for the purpose of establishing acceptable energy performance, comparing individual performance to benchmarks, and determining cost effective energy savings retrofits.

Recommendations For Further Work

It is recognized from this study, that there is difficulty in obtaining reliable data on Malaysian hospital energy use. The HBEAS survey questionnaire sent to all hospitals (120 totals) only provides a feedback response of 28 hospitals. The regression-based energy use model might be further improved if more quality data could be obtained from further surveys. An appropriate study on energy management programme for the Malaysian hospital buildings should be initiated before implementing any energy saving measures, enabling correct and cost effective decisions in the long run. A demonstration project of using appropriate energy efficient technologies and energy conservation methods in hospital building retrofits should provide an excellent picture on the magnitude of real savings in energy usage. Further investigation using a life cycle approach in hospital building energy assessment should be beneficial. Other measures such as day-lighting perimeter zone controls, occupancy and dimming lighting controls can be accurately simulated to show realistic electrical energy saving measures.

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