Energy and Buildings 67 (2013) 70–78

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Electricity cost saving comparison due to tariff change and ice thermal storage (ITS) usage based on a hybrid centrifugal-ITS system for buildings: A university district cooling perspective

Mohammad Omar Abdullah [a,*], Lim Pai Yii [a], Ervina Junaidi [a], Ghazali Tambi [a], Mohd Asrul Mustapha [b]

[a] Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[b] Asset and Management Division, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form 3 August 2013
Accepted 5 August 2013

Keywords:
Electricity charge
Cost saving
District cooling system
Tariff structure
Ice thermal storage

ABSTRACT

In this paper, the case study of a district cooling system of a university located in a South East Asia region (lat: 01°29′; long: 110°20′E) is presented. In general, the university has high peak ambient temperature of around 32–35 °C coupled with high humidity of about 85% during afternoon period. The total electricity charge for the Universiti Malaysia Sarawak Campus is very high amounting to more than $314,911 per month. In this paper, a few district cooling schemes are investigated to provide "what-if analysis" and in order to minimize the overall electricity charges. Few scenarios designed for the application of centrifugal with and without ice-thermal storage (ITS) systems on the buildings were investigated. It was found that, due to the local tariff status, marginally saving can be achieved in the range of 0.08–3.13% if a new tariff is adopted; and a total of further saving of 1.26–2.43% if ITS is operated. This marginally saving is mainly due to the local tariff conditions and lower local temperature range (ΔT) which are less favorable as compared with those reported in the literature elsewhere.

1. Introduction

The building industry involves two kinds of energy applications, i.e., building construction application, and post-constructions (occupants) application. The latter consumes much of the energy use due to the energy consumption over a period of much longer time [1]. For modern buildings, one of the notable energy usages is due primarily to the electrical-driven air conditioning systems, either for heating or cooling. For bigger system such as district cooling systems (DCS) application, higher capacity of the cooling systems are necessary due to the higher cooling or heating demand which necessarily incur enormous electrical energy costs. The advantages of DCS systems in huge building areas compared with individual air-conditioning unit systems are many, among others:

- *Economical advantages*: The DCS have overall lower total capital cost compared to the split cooling that require their own cooling equipment(s) [2,3].
- *Space conservation*: The space required for cooling equipment(s) can become vacant for other purposes for a district cooling systems [2,3].
- *Noise reduction*: The noise that produced by the cooling machines can be avoided in the consumer buildings [2].
- *Flexibility*: The DCS systems also flexible to employ a wide range of inter-related thermal storage technologies such as co-generation, tri-generation, and thermal energy storage (TES) [2,3]. The present paper is primarily concerning with the TES storage technique.

In respect of energy usage, it was reported that thermal energy storage (TES) not only dramatically reduces the use of peak-period high cost energy; it can also reduce the total energy usage by as much as 13% [4,5]. The United State Department of Energy reported that many ice storage applications can result in lower first cost and/or with higher system efficiency as compared to non-storage system [6]. This is because ice-storage allows downsizing of the conventional chiller system [3,7], the resulting cost savings may substantially or entirely cover the added incremental cost of the storage system [7]. MacCracken [8] pointed out that since thermal

* Corresponding author. Tel.: +60 82 583280; fax: +60 82 583409.
E-mail addresses: amomar@feng.unimas.my, amomar13@gmail.com (M.O. Abdullah).

0378-7788
http://dx.doi.org/10.1016/j.enbuild.2013.08.008

Nomenclature

C1	commercial 1
C2	commercial 2
C3	commercial 3
CAIS	Centre Academic and Information Services
CH	chiller
DCS	district cooling system
FCST	Faculty Resource Science and Technology
MEP	mechanical and electrical plant
MIS	main intake supply
N/A	not available
S1	Scenario 1
S2	Scenario 2
S3	Scenario 3
SESCO	Sarawak Electricity Supply Corporation
UNIMAS	Universiti Malaysia Sarawak
ΔT	ambient temperature difference

Measurement units

°C	degree Celsius
m^2	meter square
RM	Ringgit Malaysia
%	percent
RT	refrigerant ton
unit	kWh (kilowatt-hour)
$	US dollar (USD)

storage method operate at full load during the night time, the fuel cost for powering the ITS plant during the night (non-peak hours) will be reduced, as the cooling demand is shifted from peak hours to non-peak hours. The two main reasons for the saving are thus: (1) in the night, the base load plants are much more energy efficient than daytime plants; and (2) line losses are less during the night time because much less power is transmitted at night.

Results from the study by the California Energy Commission [9] shows an even higher energy saving potential figures, for two typical major California utilities with energy usage reduction as much as 10% and can up to 30% has been reported [9,10].

Sebzali and Rubini [10] had conducted an investigation in a clinic building in Kuwait, which has hot climates with long summer condition. They found out, via computational modeling analysis, that the AC systems consume around 61% of the peak electrical duty and around 40% of the total electricity consumption. The saving is due to the advantage of hot climate and huge temperature difference between day and night time, considerably long summer and low energy costs in Kuwait.

A hybrid chilled water/ice thermal storage plant for the Lucile Erwin Middle School in Colorado, United State, has been reported to able to save more than $18,000 in energy costs annually. One of the contributing saving factors reported is due to the offer of low-interest financing from the local Florida power authority, and by completely eliminating chiller demand from the utility bill. The project uses a flexible ice thermal storage management system concept with a demand limit-controlled, chiller priority, and partial storage system. This ice storage system optimized energy efficiency by carefully avoiding electrical demand peaks caused by the system, where the chiller/storage match is designed for continuous chiller operation at about −6 °C chilled water supply temperature under normal conditions [11].

Morgan and Krarti [12] reported a TES application study on a school with total small floor area of 65,000 ft^2 (6038.7 m^2). They investigated the influences of using active and passive TES systems to shift the peak cooling loads to the nights to reduce building energy costs. The set point temperature during the occupied periods from 8:30 to 17:00 was at 24 °C and 32 °C during unoccupied periods. A 50 ton scroll compressor operates during the night (from 02:00 to 08:00) and charges three ice-tanks with a total capacity of 570 tons/h using the internal melt ice-on-coil system. They found that around 47% of the annual electricity cost could be saved by employing the TES systems. This huge cost saving is due to the incentive utility rate of $0.0164 kWh^{-1} as a flat consumption rate and a demand charge of $11.24 kW^{-1}.

It is to be noted that not all the literature came up with favorable TES applications. Habeebullah [13], for instance, had conducted an economic feasibility of using the huge ITS system in the Grant Mosque of Makkah, the results of which show that as the existing electricity rate is fixed at $0.07 kWh^{-1}, the ITS system does not have any gain neither for the partial nor for the full storage strategy. However, the author indicated that by employing the energy storage system via full load storage strategy combined with an incentive time structured rate, the electricity cost could be reduced.

In order to evaluate the energy performance and cost effectiveness potential, a feasible district cooling with ice-storage system was investigated by Chan et al. [14] for a hypothetical site in Hong Kong. In their works, a parametric study employing DOE-2 and TRNSYS simulation software was conducted to evaluate the system performance at different partial storage capacities, control strategies, and under three different tariff structures. Other than the basic design factors, the results from 27 cases studies showed the importance of the tariff structure, the capital cost and electricity costs. They found out that the district cooling plant with about 40% ice-storage capacity and chiller-priority control sequence can provide better energy performance. However, the saving in electricity cost is not attractive. The authors further suggested that in order to shorten the payback period, the power supply must come from the neighboring region that provides lower electrical charges and supporting tariff structure. This also implies that there is a potential of applying the integrated technology in the South China region but only when the investment becomes favorable and with supporting tariff structure.

From cited literature and experiences obtained elsewhere, favoring conditions of TES applications can vary from country to country, and in fact region to region, due to numerous factors. Generally, the usage of ice-thermal technology has been higher in regions where a significant day and night-time differential in both temperature, in the lower price of electricity exists, and with some utility companies provide cash incentives or rebates to developers that incorporate TES schemes.

The present study is an extension of previous work reported earlier in 2007 [15]. The previous work briefly investigated some parameters influencing the DCS performance, in particular cool air distribution, chiller capacity, and occupant behavior. This paper, however, is an extension of the previous work. The current study aims to seek on the overall district cooling saving possibilities due to the following two application aspects, viz. (1) the effects of tariff change and (2) the effect of ITS usage. For that purpose, few application scenarios are given for comparison. Due to the completeness and most recent data available, the authors have chosen a typical year, i.e. 2011 for the analysis.

2. The UNIMAS' district cooling system

Universiti Malaysia Sarawak (UNIMAS) is located in Kota Samarahan of Sarawak. By completion of new campus (or known as West Campus) in the year of 2005, the total build-up area of the new campus is approximately 223,619 m^2 and keep expanding from time to time (Fig. 1). With the location at equatorial climate which provide hot tropical weather basically on 365 days per year with average

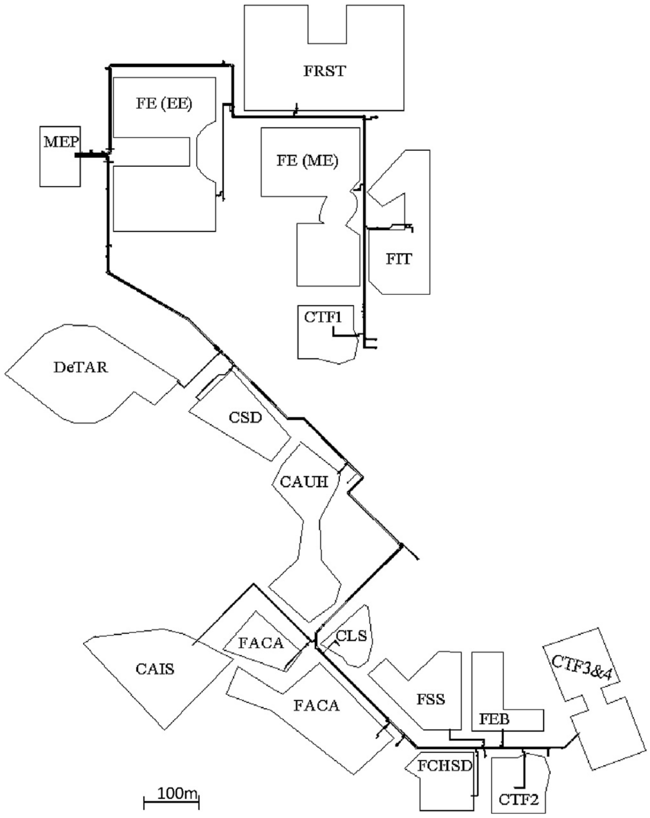

Fig. 1. District chilled water distribution pipeline for DCS in UNIMAS.

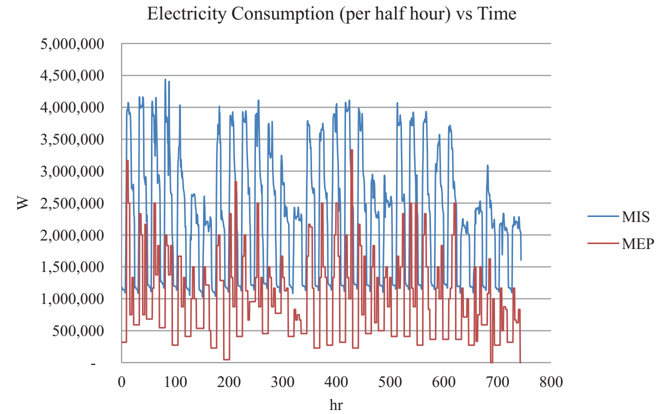

Fig. 2. Electricity consumption of the district cooling system for a typical month (August 2011). MIS, main intake supply; MEP, mechanical and electrical plant.

temperature of 25–35°C during daytime, air conditioning system was installed in almost all of the building spaces to provide comfortable environment for both students and staffs [15]. The main cooling system which is selected to install in this new campus is district cooling system (DCS) due to the extremely huge built-up area and the potential to expand in future depend on demand. Most of the buildings are operating with the air-conditioning system that essentially sharing the cooling from the same resources from mechanical and electrical plant (MEP) with the piping buried underground for distribution. There are a total of 15 facilities (as end of 2011) in the compound which were using the same resources for cooling purpose. The total cooling capacities supplied by base chillers from MEP reached up to approximately 8000 refrigerant tan (RT).[1] Up until December 2011 in the MEP, there are a total of eight centrifugal chillers with total 8500 RT, two brine chillers with total 900 RT, and also 10 cooling towers of total 14,000 RT were used for provide heat rejection. Brines chillers are connected with ice thermal storage; while centrifugal chillers supply cooling directly to buildings by chilled water. The heat rejection is accomplished by using cooling towers with makeup water tank as to replace the evaporated water in cooling towers. For effectiveness of heat transfer, heat exchangers and pumps also use in MEP to assist in transporting the cooling to buildings. However, the brine chillers and the ITS are just for backup and not in operating so far, as well as heat exchanges which used to assist brine chillers in distributing. This is mainly due to the fact that the current tariff does not have the different charging rate provision for on peak and off peak. The electricity charge of UNIMAS's new campus is very expensive, reached more than $314,911 or more per month (data from Ref. [15]), thus in the present work, some feasible study are seek to investigate the effects on the use of different tariff in reducing overall electricity cost; and to estimate the how much saving if a hybrid centrifugal-thermal storage system is used instead. Fig. 1 shows the UNIMAS campus layout plan illustrating the district cooling water pipeline from the Mechanical Electrical Plant (MEP) throughout the university's campus. The total electricity consumption of the District Cooling System for a typical month (August 2011) is given in Fig. 2. The MEP only consumed about 34% while the rest of the consumption goes to the main intake supply (MIS).

There are eight centrifugal chillers with total of 8500 RT (CH1-400 RT, CH2-1300 RT, CH3-1300 RT, CH4-1300RT, CH5-800 RT, CH6-800 RT, CH7-1300 RT, and CH8-1300 RT), the centrifugal chiller function as supply direct cooling to consumer buildings (facility). There are also two brine chillers in the MEP which used to charging the ITS (7000 RTh) with total of 900 RT (450 RT each). While for the heat rejection system, ten units of cooling towers with total of 14,000 RT (1400 RT each) applied in central plant. Between, to replace the evaporated water inside the cooling towers, there are one expansion tank and two make up tank used. Apart from that, there are also three heat exchangers with a total of 1800 RT (two units with 450 RT each and another one with 900 RT) available at the MEP which support the brine chiller and the ITS as the loop used is different with that of the direct cooling supply by centrifugal chiller, hence the heat exchanger is become an essential. Nevertheless, there is also some quantity of heat exchangers inside each consumer buildings which function as receive cooling from the central plant. The capacity of the heat exchangers for each building is different depending on the cooling load received. The cooling is supply via the pipe buried underground which connected from the central plant to each buildings. The ITS facility comprises of a brine chiller system, an ice thermal storage (Fig. 3), a cooling tower system and a heat exchanger system. It generates chilled water required to meet the cooling load demand for various air-handling units distributed in the buildings. Besides, the brine chillers are also used to generate ice for the thermal storage plant. It is divided into the following 5 sections, i.e. (1) brine chiller system, (2) base chiller system, (3) cooling tower system, (4) thermal storage system consists of one ITS and associated motorized valves, and (5) heat exchanger system. The chilled water system (central air conditioning system) is networked to have multiple cooling coils distributed throughout the large distributed buildings with the refrigeration chiller placed at one base central location.

[1] Anyhow, it is to be noted that there are few other standalone buildings having their individual cooling systems, for instance the Centre of Information Study (CAIS) building, the requirement of which is to operate 24 hours per day due to which it is not economical for the MEP to supply cooling just for the CAIS building alone at midnight. Apart from that, some buildings which are located too far from the based, like Faculty Recourse Science and Technology (FRST) external laboratory building also having their individual cooling equipments.

Fig. 3. The ice thermal storage (capacity rated at 7000 RTh).

In the previous work as reported in [15], many parameters influencing the DCS had been briefly covered which includes cool air distribution, chiller capacity, and occupant behavior. This paper, however, is an extension of the previous works which is a detail study of the changing of tariff effect as well as the ITS application to the overall saving possibilities. Few application scenarios are also investigated. For that purpose and due to the completeness and most recent data available, the authors have chosen a typical year, i.e. 2011 for the analysis.

3. UNIMAS electricity charge for year 2011

The main target of the present analysis was UNIMAS' new campus, the electricity's main intake for UNIMAS' new campus is known as main intake supply (MIS) which supply majority of the electricity required. Monthly electrical consumption, monthly maximum demand, and electrical charge are described in the following subsections.

3.1. Monthly electricity consumption

Fig. 4 shows the monthly electricity consumption of UNIMAS for year 2011 which was essentially increasing over the months. The increment was reasonable due to the increasing of built-up area throughout year 2011. But there were exception for June–August 2011 due to semester break period where most of the occupants, in particular the undergraduates are out of the campus for holiday.

3.2. Monthly maximum demand

Table 1 show that monthly maximum demand only occurred during Monday to Thursday. In detail, maximum demand only occurred during office hour period. Hence, it can be deduced that maximum demand was impossible to occur on weekend and public holiday due to decrease of occupants and overall usage. The

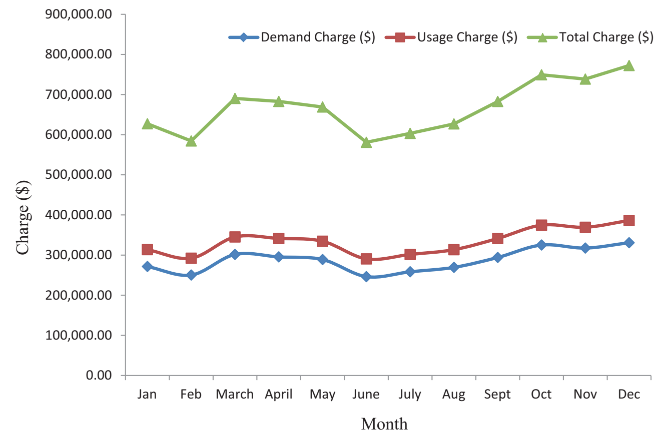

Fig. 4. Distribution of usage charge, demand change and total charge for year 2011.

maximum demand was increased when getting toward the end of year 2011, thus the increased of total electricity charge.

3.3. Methodology and data analysis

The huge data is collected for the project and enable further analysis. The data includes: (1) monthly electrical charge for UNIMAS's new campus (MIS); (2) monthly electrical consumption of central plant (MEP); (3) electricity consumption of UNIMAS's new campus for year 2011 and schedule of tariff both of which is available from local electrical service provider.

Electricity charge of MIS can be divided into usage charge and demand charge to find the opportunity to decrease the electricity charge. Since huge number of data is involved, Microsoft Excel is used to compile and analyze the data sets. Standard deviations with confidence interval of 95% (Error bars with 5% errors) were used to represent the distribution of the data.

In the present study, ice storage tank only chosen to be operating during off-peak hour. This is because, from the literature, many deduced that ice thermal storage not really economical in regard to energy saving, but cost earning primarily from the tariff structure benefit of on-peak and off-peak hour. In this study, it is assumed that with a total daily charging period of 6 h (off peak is from 00:00 to 06:00 h), the ice tank only able to discharge for about 5.5 h, due to the fact that many literature predicted losses of around 10% for thermal storage.

4. Results and discussion

Computation of electrical charge and effect of ITS usage on the hybrid operating system is discussed in Section 4.1 and 4.2, respectively.

4.1. Computation of electricity charge

4.1.1. Applying different tariff structure

In year 2011 an average of 39.54% electricity was contributed by MEP central plant alone. As for the overall air-conditioning system, the electricity consumed by the system will be more than 39.54% out of total consumption, since MEP only generate the main cooling equipments. While the other components like split units, individual cooling equipments, air handling unit, fan coil unit, etc. was not included in the 39.54% figure.

There are three tariffs available for UNIMAS as listed in Table 2. UNIMAS is applying tariff C2 currently (including year 2011) [16]. In order to take advantage from converting from tariff C2 to tariff C3, the increment of maximum demand charge should overcome

Table 1
Occurrence of maximum demand for year 2011.

	Date	Day	Time	Maximum electricity consumed per half hour (kW)
January	04-01-2011	Tuesday	0930–1000	4233.976
February	23-02-2011	Wednesday	1430–1500	4222.604
March	16-03-2011	Wednesday	1100–1130	4387.816
April	28-04-2011	Thursday	1530–1600	4627.604
May	10-05-2011	Tuesday	1600–1630	4590.928
June	27-06-2011	Monday	1600–1630	4452.476
July	26-07-2011	Tuesday	0930–1000	4356.732
August	04-08-2011	Thursday	0900–0930	4441.456
September	15-09-2011	Thursday	1430–1500	4765.392
October	04-10-2011	Tuesday	0830–0900	4989.480
November	16-11-2011	Wednesday	1530–1600	5217.680
December	01-12-2011	Thursday	0900–0930	5574.548
			Average	4655.06

Table 2
Tariff structure available for UNIMAS.

	Rate per unit
Tariff C1 – commercial	
For the first 100 units per month	RM0.40 ($0.124)
For the next 4900 unit per month	RM0.34 ($0.101)
For each additional unit per month	RM0.30 ($0.093)
Tariff C2 – commercial demand	
For each kilowatt of maximum demand per month	RM16.00 ($4.96)
For each unit	RM0.25 ($0.078)
Tariff C3 – commercial peak/off-peak demand	
For each kW of maximum demand per month during peak period	RM20.00 ($6.200)
For each unit during the peak period	RM0.25 ($0.078)
For each unit during the off-peak period	RM0.144 ($0.045)

Note: 1 RM = $0.31 (exchange rate as per 15 July 2013). $ refer to US dollars.

Table 3
Savings regard to tariffs for year 2011.

	Cost saving
Tariff C1 → tariff C2	$136,632
Tariff C2 → tariff C3	$49,272

by earning from off peak period. By referring to electricity bill when applying tariff C2, the usage for off peak period is somewhat ambiguity. Hence, the detail data obtained from the electricity provider, SESCO is essential.

Appendix A shows an example of calculation on a specific month which is August 2011 for different type of tariff structures. Appendix B shows the calculated total charge for three different tariffs as well as the reality charge for tariff C2 which obtained from the Sarawak Electricity Supply Corporation (SESCO). Table 3 show that total saving of $50,052.37 (RM 158,941.32) can be obtained for year 2011 by applying tariff C3 rather than tariff C2. The accuracy of the calculation was considered high due to the calculated and the actual total electricity charge for year 2011 with tariff C2 were very close as $1.92 (RM6.11) whole year. Besides, Table 3 shows that there was more saving from tariff C1 to tariff C2 compare to tariff C2 to C3. This means that UNIMAS had made a smart choice by switch from tariff C1 to tariff C2 many years ago.

Table 4
Percentage of usage and demand charge for year 2011.

Tariff	Percentage of usage charge (%)	Percentage of demand charge (%)
C1	100	N/A
C2	86.14	13.86
C3	82.46	17.54

Table 4 shows that applying tariff C3 will lead to decrement in percentage of usage charge, but increment in percentage of maximum demand charge. Hence, if applying tariff C3, it is importance to put more effort in order to decrease the maximum demand due to the high charge for maximum demand compare to tariff C2.

4.1.2. Equation and regression of saving

Appendix B and Table 3 show that there is saving from changing tariff C1 to tariff C2 as well as from tariff C2 to tariff C3.

In the subsequent sections, some equations are developed to calculate both of the savings based on the obtained information and related analysis. Regression equations were use to relate between the savings and the influencing factors.

4.1.2.1. Tariff C1 to tariff C2. Eq. (1) is developed to represent the saving per month by switching from tariff C1 to tariff C2

$$\text{Saving,}\quad S_{C1-C2} = \$0.0155\,\text{kWh}^{-1} \times U - \$4.96\,\text{kWh}^{-1} \times D + \$63.86 \tag{1}$$

where S_{C1-C2} = saving from switch tariff C1 to tariff C2 ($), U = total usage (kWh), D = maximum demand (kWh) (double the largest number of kilowatt supplied during any consecutive 30 min).

The following equations were required for the purpose of developing the graphs in Figs. 5 and 6:

$$\text{Percentage of maximum demand} = \frac{D}{U} \times 100\% \tag{2}$$

$$\text{Percentage of saving} = \frac{S_{C1-C2}}{T_{C1}} \times 100\% \tag{3}$$

where S_{C1-C2} = saving from switch tariff C1 to tariff C2 ($), U = total usage (kWh),

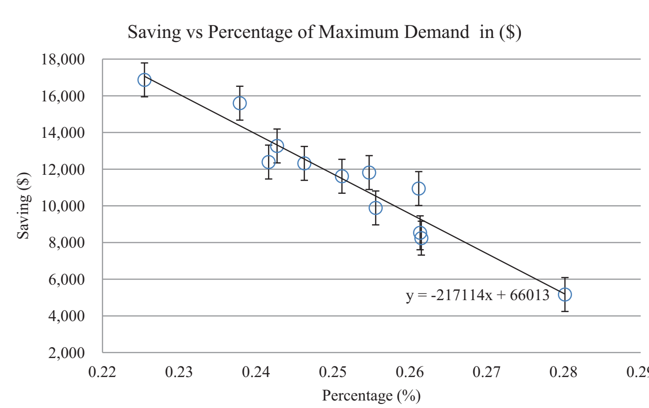

Fig. 5. Variation of saving (C1–C2) with percentage of maximum demand.

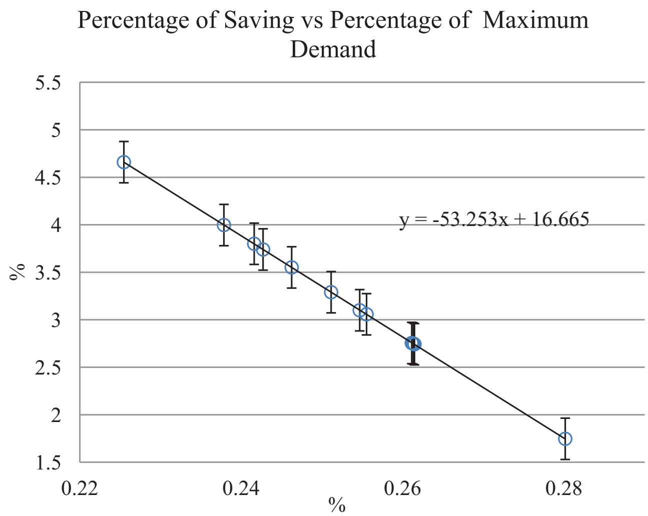

Fig. 6. Variation of saving's percentage (C1–C2) with percentage of maximum demand.

D = maximum demand (kWh) (double the largest number of kilowatt supplied during any consecutive 30 min), T_{C1} = electricity charge with tariff C1 in $.

The equation line in Fig. 6 shows the maximum saving of 16.66% when maximum demand percentage was zero, but the scenario was impossible to occur. From the line, the condition of lost occurred by switching tariff C1 to tariff C2 can be estimated. The condition was the intersection point between the line and x-axis, which is 0.31% of maximum demand. This means it is not worth to switch from tariff C1 to tariff C2 when the maximum demand's percentage was more than 0.31%. Based on the error bars at the 95% confidence interval, no significant differences were observed between the data points for both Figs. 5 and 6.

4.1.2.2. Tariff C2 to tariff C3. Eq. (4) is developed to represent the saving per month from tariff C2 to tariff C3.

$$\text{Saving,}\quad S_{C2-C3} = \$0.0329\,\text{kWh}^{-1} \times \varnothing - \$1.24\,\text{kWh}^{-1} \times D \qquad (4)$$

where S_{C2-C3} = saving from switch tariff C2 to tariff C3 in \$. $Ø$ = Off peak usage in kWh. D = Maximum demand in kWh (double the largest number of kilowatt supplied during any consecutive 30 min).

The following equations were required for the purpose of sketching the graphs in Figs. 7 and 8:

$$\text{Percentage of maximum demand} = \frac{D}{U} \times 100\% \qquad (5)$$

$$\text{Percentage of saving} = \frac{S_{C2-C3}}{T_{C2}} \times 100\% \qquad (6)$$

$$\frac{\text{Off peak usage}}{\text{Maximum demand}} = \frac{\varnothing}{D} \qquad (7)$$

where S_{C2-C3} = saving from switch tariff C2 to tariff C3 in \$.

U = Total usage in kWh.

D = Maximum demand in kWh (double the largest number of kilowatt supplied during any consecutive 30 min).

T_{C2} = Electricity charge with tariff C2.

$Ø$ = Off peak usage in kWh.

Graph in Fig. 7 shows the intersection occurred when percentage of maximum demand charge was 3.29%. The intersection indicate the moment starting of negative value in saving (loss) occur, hence can be estimated that it was not worth to switch from tariff C2 to tariff C3 if the percentage of maximum demand was more than 3.3%.

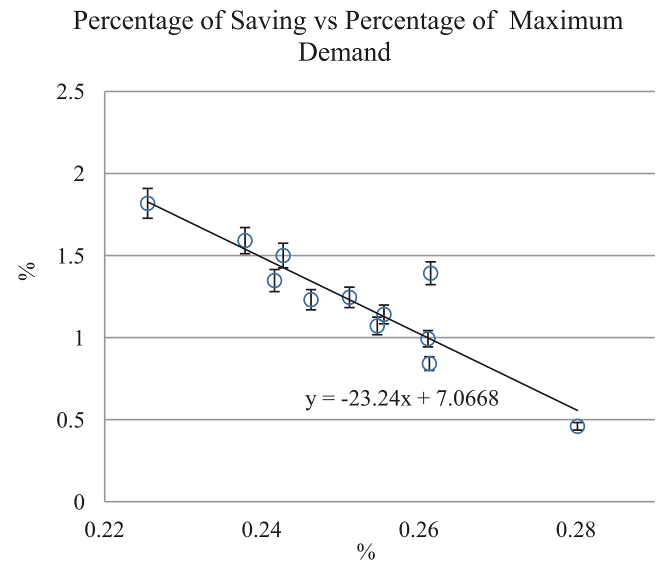

Fig. 7. Variation of saving's percentage (C2–C3) with percentage of maximum demand.

The graph in Fig. 8 shows the intersection occurred when the ratio was 36.24. The intersection indicates the moment starting of negative value in saving (loss) occur, therefore estimated that it not worth to switch from tariff C2 to tariff C3 if the ratio was less than 36.3.

Based on the error bars at the 95% confidence interval, no significant differences were observed between the data points for both Figs. 7 and 8.

4.2. Effect of ice thermal storage (ITS) usage

The ITS facility in the MEP was installed during construction of air conditioning system at new campus, thus required no extra cost for the hybrid cooling application as far as the study is concerned. The 6 h charging period during off peak hour will yield around 5½ h discharging of ITS by considering some losses (assuming ~8% losses). The discharge period depend on the maximum demand that occur each month during year 2011. As stated in literature review, the applicants of ITS facility do not actually cause

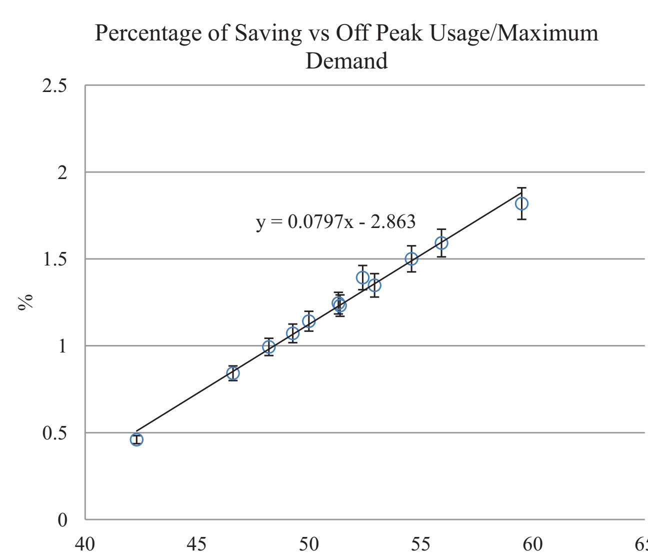

Fig. 8. Variation of saving's percentage (C2–C3) with off peak usage/maximum demand.

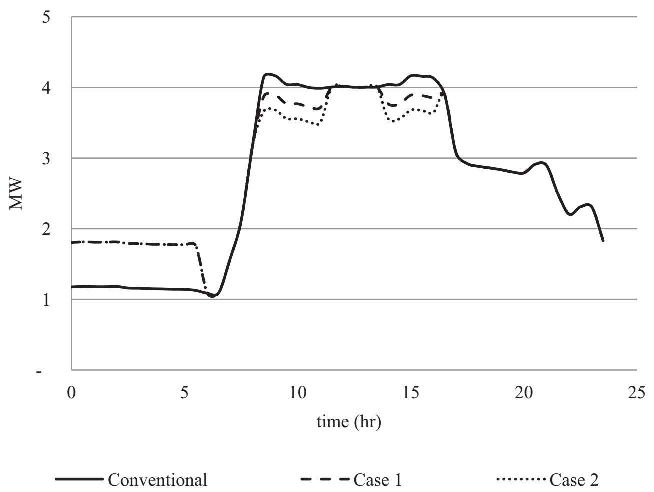

Fig. 9. MIS' electricity consumption with different controlling method for 2nd August 2011.

energy saving, but only take advantage with different rate on off peak and on peak [9,14]. Hence, for the present study, theoretically, the ITS application will only take advantage in tariff C3.

The discharge of ITS can be 450 RT, 900 RT, 1350 RT or 1800 RT with the existing heat exchangers. In this project, only discharge rate of 900 RT be considered in order to simplify the process for replacing another base chiller. There are three scenario developed for testing in order to find out the scenario that will lead to highest cost saving. The discharge time is fixed at 0900–1130 and 1430–1630 based on the study for occurrence of maximum demand on the year 2011 as shown in Table 2. The three scenarios developed are summarized as follows:

Scenario 1. S1 – charge (0000–0600) and discharge (0900–1130, 1430–1630) ITS daily.

Scenario 2. S2 – charge (0000–0600) and discharge (0900–1130, 1430–1630) ITS daily except weekend and public holiday.

Scenario 3. S3 – charge (0000–0600) and discharge (0900–1130, 1430–1630) ITS daily except Friday, weekend and public holiday.

With the discharge of ITS at the rate of 900 RT, the investigations can be further divided to two cases (Fig. 9): Case 1 is the *most likely case* which is assuming the discharge of 900 RT able to replace an 800 RT base chiller. Case 2 is *optimistic case* which assuming the discharge of 900 RT able to replace a 1300 RT base chiller. Case 2 might be happen when the 1300 RT is under performance which only perform around 60% of the base load.

By combining two cases of ITS application, the range of saving for each scenario compared to conventional method by tariff C3 can be obtained (Table 5). Table 5 shows that the saving of ITS with Scenario 2 was within the range of $1,1388.81–48,112.29 (RM3,673.59–155,200.91). With the total electricity charge of $3,954,885.00 (RM12,757,693.55) (with tariff C3) for year 2011, the saving is within 0.03–1.22%. But, with the contribution of 39% for MEP compare to MIS, the saving in MEP with ITS application Scenario 2 is up to 0.08–3.13%. Here, the saving by applying ITS is not obvious due to the extreme small capacity of the storage facility as compared to the main direct cooling facility. Note that the saving in Table 5 is having wide range figures, yet the actual saving still can fall out from the range predicted. The saving cannot be predicted accurately due to the controlling technique of the system such as late startup of the chillers. Besides, the ITS will have higher performance at night time by taking advantage from the lower surrounding temperature at night period compare to daytime. It means that ITS may able to discharge more than 5½ h per day and by 6 h of charging.

By applying ice thermal storage, the results of which is as shown in Table 6 shows that the demand charge was decreased by discharging the ITS strategically. Anyhow, by applied ITS facility, around half of maximum demand will occurred right after the ITS stop discharged. In reality, although the ITS had stop discharged, it may also cause the late startup of the chiller as well depending on the controlling method of the system. Hence, maximum demand charge may be further decreased.

Table 5
Estimation savings for year 2011 with Ice thermal storage application.

Controlling method	Saving range
Conventional	N/A
Apply ice thermal storage S1	$11,379.55–57,281.52
Apply ice thermal storage S2	$1,1388.81–48,112.29
Apply ice thermal storage S3	$2439.53–39,037.44

Table 6
Estimation percentage of usage and demand charge by different controlling method for year 2011.

	Usage charge (%)	Demand charge (%)
Conventional	82.46	17.54
Apply ice thermal storage Case 1 S2	83.14	16.86
Apply ice thermal storage Case 2 S2	83.00	17.00

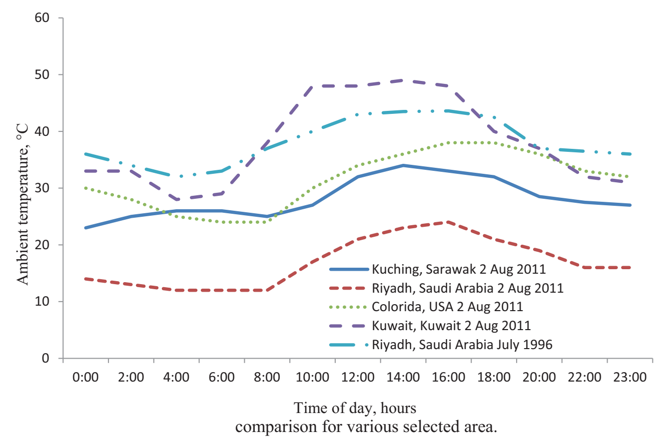

Fig. 10. Ambient temperature profile comparison for various selected area.

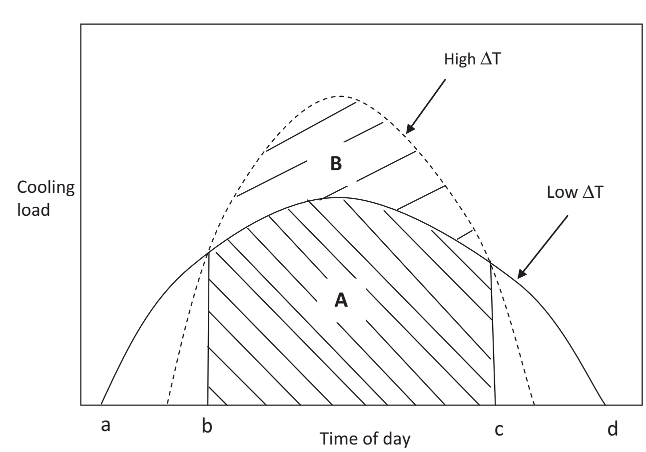

Fig. 11. Cooling load meets by storage profile for a full storage scheme. The region of total load meet by storage (indicated by shaded area) are A and A + B for the low ΔT and high ΔT profile, respectively. Chiller meets load directly at the regions under each graph from a to b, and c to d.

A view on typical days for the day and night-time differential in ambient temperature ΔT profile is as given in Fig. 10, it shows that the local tropical condition (present study) is having narrower ambient temperature difference as compared to other countries. As far as the present study is concern, the ΔTs are 8, 12, 14, and 21 °C for Kuching (Sarawak), Riyadh (Saudi Arabia), Colorado (USA) and Kuwait (Kuwait), respectively. In general, bigger ΔT will contribute to higher energy savings as more cooling load can be met by the storage (see Fig. 11). Conversely, a country with lower ΔT region will generally have lower cooling load that can be met by the storage.

5. Conclusions

In this paper, a few operating schemes are investigated to study the saving potential in total electricity charge for UNIMAS' new campus, in particular with respect to the tariff change and with the thermal storage application. One of the findings emerge from this study is the significance of contribution of demand charge to total electricity charge in tariff C2 and tariff C3. Effort had been put on to decrease the maximum demand especially when applying tariff C3 which has the highest charge for maximum demand. This project indicated that tariff C3 is the best option to implement based on the data available for year 2011. From the analysis, it was found that, UNIMAS can save up to $49,271.81 (RM158,941.32) on year 2011 by switching to tariff C3. The saving is inversely proportional to the percentage of maximum demand charge by refer to tariff C2.

Also, this project explains the influence of ITS application to the electricity charge. The ice thermal storage facility (ice thermal storage, heat exchanger, brine chiller, brine pump, etc.) are not in use due to neither energy saving nor cost saving with current tariff applied. But, by switching to tariff C3, ITS application is estimated to be able to save up to $1.138.81–48,112.28 (RM3,673.59–155,200.91) for year 2011, when the ITS is subject to charge and discharge every weekday excluding public holiday. The saving was calculated to be in the range of 0.08–3.13% with respect to total usage of MEP. There can be more saving gain by imposing more detail study on the controlling system. Overall, by switching tariff to C3 as well as the application of the ITS facility, a saving up to total of $19,410.62–97,384.09 (RM162,614.91–314,142.23) for year 2011 is estimated. The total saving is 1.26%–2.43% compare to total electricity charge of MIS with $4,004,156.81 (RM12,916,634.86) for year 2011. The saving can be done without any initial cost, without changed the human behavior for users, as well as without scarified users comfort.

In summary, it was found that, due to the local tariff status, marginally saving can be achieved in the range of 0.08–3.13% if a new tariff is adopted; and a total of further saving of 1.26–2.43% if ITS is operated. This marginally saving is mainly due to the local tariff conditions which is less favorable as compared with those reported in the literature and experience elsewhere (e.g. in Refs. [9–11]). Furthermore, while there are significant day and night-time differential in ambient temperature that exists in other countries, the local tropical condition is having less favorable, relatively narrow ambient temperature difference over the day-night periods.

6. Recommendation for further study

In order to further reduce the electricity charges in UNIMAS buildings, there are few methods can be considered such as (1) study on the controlling method in relation to the ITS applications via fuzzy logic investigation and/or development of a framework employing Axiomatic design methodology for improvement of UNIMAS's district cooling system, and (2) optimal operation strategy of the hybrid based on minimum operating cost of the systems at various combined working conditions and suitable storage schemes. Also, reduction of electricity charge during student's semester break can bring about further savings.

Acknowledgments

We greatly acknowledge Datu Dr. Hatta Solhi for sharing his concern and idea on electrical consumption. We are grateful to the following personnel for their useful assistance and fruitful discussions, in particular: Mr. Lawrence Abdullah (Senior Engineer, Asset and Management Division, UNIMAS), Mdm Dayang Duwiningsih bintiAbang Abdullah (Electrical Engineer, Asset and Management Division, UNIMAS), Mr. Pelle Tunggi (Assistant Mechanical Engineer, Asset and Management Division, UNIMAS), Mr. Jong Fung Swee (Senior Mechanical Engineer, JKR Sarawak), and Ms. Liew Sze Xia (Electrical Engineer, Sarawak Electricity Supply Cooperation). Data provided by the Asset & Management Division UNIMAS and Sarawak Electricity Supply Corporation (SESCO) is very much appreciated.

Appendix A.

		Units (kWh)	Charge, RM ($)	Total, RM ($)
C1	First 100 U	100.00	40.00 ($12.4)	
	Next 4900 U	4900.00	1666.00 ($516.46)	
	Surplus	3,471,296.28	1,041,388.88 ($322,830.55)	1,043,094.88 ($323,359.41)
C2	Total usage	3,476,296.28	869,074.07 ($269,412.96)	
	Maximum demand	8882.91	142,126.59 ($44,059.24)	1,011,200.66 ($313,472.20)
C3	On peak usage	3,032,208.54	758,052.13 ($234,996.16)	
	Off peak usage	444,087.74	63,948.64 ($19,824.08)	
	Maximum demand	8882.91	177,658.24 ($55,074.05)	999,659.01 ($309,894.29)

Maximum demand occur during: 04-08-2011, 0900–0930 (Thursday).

Appendix B.

	Tariff C1 RM ($)	Tariff C2 RM ($)	Tariff C3 RM ($)	Reality RM ($)
January	1,051,672.87 ($326,018.59)	1,011,709.62 ($313,629.98)	998,073.86 ($309,402.90)	1,011,710.50 ($313,630.26)
February	969,180.42 ($300,445.93)	942,602.01 ($292,206.62)	929,477.08 ($288,137.89)	942,598.00 ($292,205.38)
March	1,167,927.57 ($362,057.55)	1,113,511.42 ($345,188.54)	1,093,264.62 ($338,912.03)	1,113,517.50 ($345190.43)
April	1,144,220.66 ($354,708.41)	1,101,428.88 ($341,442.96)	1,084,904.64 ($336,320.44)	1,101,425.50 (341,441.90)
May	1,118,815.96 ($346,832.95)	1,079,084.66 ($334,516.24)	1,065,800.35 ($330,398.11)	1,079,087.00 ($334,516.97)
June	953,808.85 ($295,680.74)	937,148.27 ($290,515.96)	932,840.68 ($289,180,61)	937,149.00 ($290,516.19)
July	1,000,574.86 ($310,178.21)	973,056.14 ($301,647.40)	964,865.35 ($299,108.26)	973,048.75 ($301,645.11)
August	1,043,094.88 ($323,359.41)	1,011,200.66 ($313,472,20)	999,659.01 ($309,894.29)	1,011,202.00 ($313,472.62)
September	1,138,714.74 ($353,001.57)	1,101,249.83 ($341,387.45)	1,087,535.27 ($331,135.94)	1,101,253.50 ($341,388.56)

Appendix B (*Continued*)

	Tariff C1 RM ($)	Tariff C2 RM ($)	Tariff C3 RM ($)	Reality RM ($)
October	1,258,840.75 ($390,240.4)	1,208,525.66 ($374,642.9546)	1,189,293.93 ($368,681.11)	1,208,526.00 ($374,633.06)
November	1,229,441.94 ($381,127.00)	1,191,329.05 ($369,312.01)	1,178,565.34 ($365,354.64)	1,191,323.25 ($369,310.21)
December	1,281,089.76 ($397,137.83)	1,245,788.67 ($386,194.49)	1,233,413.41 ($382,358.16)	1,245,732.75 ($386,177.15)
Total	13,357,383.26 ($4,140,788.81)	12,916,634.87 ($4,004,156.81)	12,757,693.54 ($3,954,884.00)	12,916,573.75 ($4,004,137.86)

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