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Economical Analysis of Thermal Energy Storage by Partially Operation

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***Abstract*—**Building Sector is the major electricity consumer and it is costly to building owners. Therefore the application of thermal energy storage (TES) has gained attractive to reduce energy cost. Many attractive tariff packages are being offered by the electricity provider to promote TES. The tariff packages offered higher cost of electricity during peak period and lower cost of electricity during off peak period. This paper presented the return of initial investment by implementing a centralized air-conditioning plant integrated with thermal energy storage with partially operation strategies. Building load profile will be calculated hourly according to building specification and building usage trend. TES operation conditions will be designed according to building load demand profile, storage capacity, tariff packages and peak/off peak period. The Payback Period analysis method was used to evaluate economic analysis. The investment is considered a good investment where by the initial cost is recovered less than ten than seven years.

***Keywords*—**building load profile, energy consumption, payback period, thermal energy storage

I. Introduction

THE rapid development and the increasingly higher standard of living have led to continual rising in demand of electricity energy consumption [1]. Demand for electrical energy has rise parallel with the development. The rise of demand for electrical energy is exceeds the rise of the power being generated. The increase in electricity tariff indicates that the supply of energy has been critical. The electricity tariff is continuing rise up and forecasted higher tariff in the future.

Building sector is the major responsible for this electrical energy demand, which is accounted for haft of total usage globally [2-3]. In Malaysia, building sector is major contributor to electricity energy demand during peak load period [4].

There is a significant difference in electrical energy demand between peak and off peak period. The electrical energy demand is high during peak period but the cost is expensive compared to off peak period.

Therefore TES system has been identified as a proven technology to shift electrical energy demand from peak period to off peak period [5-7]. This system is an opportunity to building owner to reduce electrical energy cost. It takes advantage of cheaper tariff to reduce total electrical energy cost and might reduce the electrical energy cost up to 30 percent. Many building owner have participated in Demand Side Management (DSM) program through application of TES technology [8]. They are interested to incorporate TES in a cooling system to reduce electrical energy cost.

The objective of this paper is to conduct economical analysis implementing centralized air-conditioning plant integrated with thermal energy storage.

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II. Case Study

Rapid growth of University Tun Huseein Onn Malaysia (UTHM) leads to an increase of electrical energy demand. It is expected that UTHM will expand greater in future. Hence, it is critical to study on the efficiency of the electrical energy usage. In 2009, UTHM electricity cost reached to RM 6.3 million, which was the highest amount compared to previous years. In the mean time, current trend shows that in the year 2010, electrical energy cost will be higher than 2009. It is expected it might reach up to RM 12 million per year in the next few years.

The case study focused on the electrical energy consumption in university buildings designated as Block G1, G2, and G3. The block buildings located in main campus of UTHM, Parit Raja, Batu Pahat, Johor, at 2° toward North and 103° toward East. The total floor area of the building is 15,286m²[9].

The equipments used in this building include computers, teaching equipment, laboratory equipments, printers, lamps and air conditioners unit. Blocks G1 and G2 are designed mainly for laboratory usage, whereas G3 is designed for lecture halls and tutorial rooms. Operational hour for chillers were from 0800 to 1700. Operational hour may be extended until 2200 at lecture halls if there is lecture conducted during night time. Table 1 shows detail physical characteristics of blocks G1, G2 and G3.

III. Analyses

Electricity consumption in blocks G1, G2 and G3 were studied by analyzing the actual electricity consumption of the electric bills issued by TNB. Electric tariff bills are issued in the early of every month to UTHM through Unit Eletrik, PPH [9-10]. Basically the bills are separated according to block, location or zone. However, these blocks were considered as one zone and single bills issue for this zone.

TABLE I
BUILDING PHYSICAL CHARACTERISTICS

Component	**Description**
Wall	4 inches heavy-weight brick
U-value	0.480 BTU/hr/ft²/°F
Roof	Steel sheet, 1 inch insulation
Thickness	7mm
U-value	0.214 BTU/hr/ft²/°F
Glazing	Single glass
Thickness	¼ inches
Light blind / dark curtain	
Shading coefficient,	SC 0.95
People	
Laboratory	33.3 sq.ft/person density
Tutorial Room	20.0 sq.ft/person density
Lecture Room/Hall	20.0 sq.ft/person density
Meeting Room	20.0 sq.ft/person density
Discussion Room	20.0 sq.ft/person density
Computer Room	20.0 sq.ft/person density
General Office	143.0 sq.ft/person density
Office	1 person
Lighting	
Type of lighting	Fluorescent tube 36 watts Down light 13 watts
Equipment	Desktop PC or Notebook Laser or bubble jet printer Photocopier Laboratory equipments
Ventilation rate	
Laboratory	20 cfm/person
Tutorial Room	15 cfm/person
Lecture Room/Hall	15 cfm/person
Meeting Room	20 cfm/person
Discussion Room	20 cfm/person
Computer Room	15 cfm/person
General Office	20 cfm/person
Office	20 cfm/person
Infiltration rate	0.3 air changes/hr
HVAC system	
YORK chiller	
Centrifugal type (560RT)	YKCFCFP75CNF
Screw type (280RT)	YSDYCZS45CGES

A. Electrical Energy Consumption Pattern

Figure 1 shows a continuous increment of electrical energy cost from 2005 to 2009. In 2005 the cost was only at RM513, 140.00. It is the lowest cost due to most buildings was not fully operational. However in 2009 the cost has reached up to RM3, 138,456.00 when all the buildings were fully utilized. Air conditioning contributes to a major portion of the electricity bill [7, 11]. The electricity energy consumption for air conditioning includes air conditioning for office rooms, class room, lecture hall and laboratory room. Electricity consumption for lighting consists of office room, passageway, walkway, lobby, building, toilet, stair and landscape lighting.

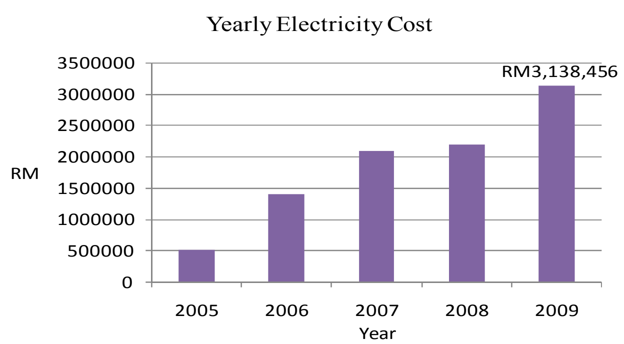

Fig. 1 Magnetization Yearly Electricity Cost as a function of applied field.

While electric consumption for others include office equipments and laboratory equipment such as desktop computer, laptop computer, copier, printer, battery charger, hand phone charger, coffee maker and other small electrical equipments. Previous research result shows electricity consumption for air conditioning was the highest (75%), followed by electricity for lighting (18%) and other office equipments (7%) [10]. Based to this ratio, it is estimated that RM2, 353,842.00 cause by building cooling load.

B. Cooling Load Estimation Method

Cooling load is the amount of heat energy to remove from a space by the HVAC equipment to maintain the indoor design temperature. There are two types of cooling loads; sensible cooling load and latent cooling load. The sensible cooling load refers to the dry bulb temperature of the building and the latent cooling load refers to the wet bulb temperature of the building.

Many factors influence the cooling load such as windows, doors, skylights, walls, partitions, ceilings, roofs, floors, open crawl space, air infiltration, people, equipment, process and appliances [12-14]. Figure 2 is illusion of factors influence in building cooling load.

Equation (1~8) are the formula to calculated building heat gain and building cooling load

Conduction through Walls & Roofs

$$Q\theta = UA\,(CLTD)\theta. \qquad (1)$$

Where;
U: Overall heat transfer coefficient BTU/hr-ft²-F
A: area, m²
CLTD: Temperature difference, cooling load at time θ, (F,C)

Conduction through Glass

$$Q\ g = UA\ CLTD \text{ or } Q\ g = UA\ CLTDc \qquad (2)$$

Where;
U: Overall heat transfer coefficient BTU/hr-ft²-F
A: area, m²
CLTD: Temperature difference, cooling load at time θ, (F,C)

Conduction through Interior Structure

$$Q\ p/f/c = U \times A \times TD \qquad (3)$$

Where
TD : Temperature difference, space (F)

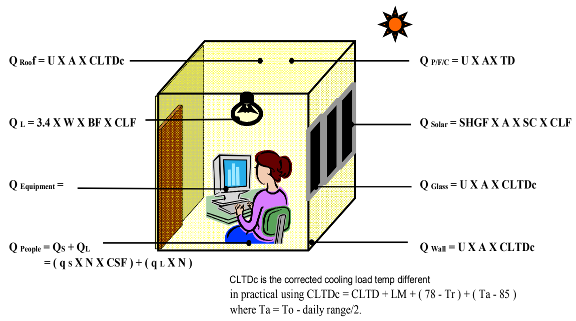

Fig. 2 Factors influence the cooling load

Solar Radiation through Glass

$$Qs = SHGF \times A \times SC \times CLF \quad (4)$$

Where
SHGF : Solar Heat Gain Factor
A : Area of Glass
SC : Shading Coefficient
CLF : Cooling Load Factor

The heat gain from lighting

$$QL = 3.4 \times W \times BF \times CLF \quad (5)$$

Where:
W : lighting capacity, Watts
BF : ballast factor
CLF : Cooling Load Factor for Lighting

The heat gain from people

$$Qp = Qs + QL \quad (6)$$
$$Qs = qs \times N \times CLF \quad (7)$$
$$QL = qL \times N \quad (8)$$

Where:
qs : sensible heat gain per person
qL: latent heat gains per person
N : number of people
CLF : Cooling Load Factor for people

C. Electricity Energy Tariff

Tenaga Nasional Berhad (TNB) is main national electricity energy utility provider. TNB has to generate electricity constantly to meet demand at peak period and cause low efficiency during off peak period. Excess electricity energy generated during off peak period was not fully utilized and considered as a waste [16]. TNB is running in lost and low efficiency during off peak period.

TNB offered 27 types of tariff category to their customer. The tariffs depend to customer operation and volume of voltage usage. Out of this tariff, 12 types depend to peak and off peak period [19]. These tariffs promote better customer participation to improve TNB operation efficiency through a program called DSM. Out of this offered tariff, only 6 types applicable to UTHM. However tariff coded as C2 is most suitable and practical for implementing cost saving study in UTHM and currently UTHM are billing according to tariff C1 as shown in Table II.

TABLE II
TNB OFFERED TARIFF

Tariff C1 - Medium Voltage General Commercial Tariff	
For each kilowatt of maximum demand per month RM/kW	23.93
For all kWh sen/kWh	28.80
The Minimum Monthly Charge is	RM600.00
Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff	
For each kilowatt of maximum demand per month during the peak period RM/kW	35.60
For all kWh during the peak period sen/kWh	28.80
For all kWh during the off-peak period sen/kWh	17.70
The Minimum Monthly Charge is	RM600.00

D. Thermal Energy Storage

Thermal energy storage acts like a battery that stores heating or cooling capacity for later use. A common example is the domestic water heater that slowly produces a tank of hot water that can be used quickly when needed. Hot and cool thermal storage are similar in concept. Cooling capacity is stored by removing heat from a storage medium. Storage can be latent or sensible. Water is the preferred medium for cool thermal storage [15].

TES generally involves storage of high or low temperature thermal energy for later use [16]. TES is technology to offset the mismatch of availability and demand; it is advanced energy technology and wide range of applications, such as space heating, hot water, cooling, and air conditioning. Figure 6 and Figure 7 are illusion of cooling load profile, charging and discharging concept.

Basically there are four type of TES tank; there are Horizontal Tank, Vertical Tank, Buried Tank and Concrete Tank. There are two main operating strategies. First is a full load operation strategy and second is a partial load operation strategy [16-18]. Full load operation strategy, the total energy used during peak hours is supplied by the thermal storage while the chillers operate only at nighttime. During this period, the thermal storage tanks are discharged to supply the load. For the rest of the day the chillers operate to supply the load and charge the thermal storage tanks at the same time.

On the other hand, partial storage strategy utilizes chiller and storage tank to cool the building load at the same time. Partial storage operation strategy, only a partial of the peak load is covered by thermal storage. In this operation strategy, the chiller operates continuously for 24 h mostly at the rated capacity. During the periods of low demand, the excess energy is stored, which is used later to cover the peak load

E. Cost Saving Opportunity

The cooling load requirement with partially storage operation strategy is summarized in Table 4. Total refrigerant ton hour was 10080RT and ice storage capacity was 5,040RT. Two numbers of chillers with capacity 580RT each are required for partially storage operation strategy.The 1st ice-making chiller will be operating during off-peak period, which is 2200 hour to 0700 hour to chill cooling medium in storage tank during off peak period when electricity energy cost is cheap [20]. During peak period, which is from 0800 to 2100, the 2nd chiller will be operating to cool the building. Cooling medium will be discharge to support existing chiller to cool the building.

Table III and Figure 3 showed the hourly building cooling load requirement. No cooling load required from 2200 hour to 0700 hour. However there are cooling load required from 0700 hour to 2200 hour. Cool TES system started charging storage tank at 2200 hour until 0700 where cost of electrical energy is cheap. The system started to discharge storage tank at 0700 hour until 2200 while cost of electrical energy is expensive.

TABLE III
DESIGNED BUILDING LOAD PROFILE

Time		Building	Existing	Cool TES		Duration
From	*To*	Load	Chiller	*Charging*	*Discharging*	
0000	0100	0		560		Off peak
0100	0200	0		560		Off peak
0200	0300	0		560		Off peak
0300	0400	0		560		Off peak
0400	0500	0		560		Off peak
0500	0600	0		560		Off peak
0600	0700	0		560		Off peak
0700	0800	280			280	Off peak
0800	0900	280			280	Off peak
0900	1000	280			280	Peak
1000	1100	840	560		280	Peak
1100	1200	840	560		280	Peak
1200	1300	840	560		280	Peak
1300	1400	840	560		280	Peak
1400	1500	1120	560		560	Peak
1500	1600	1120	560		560	Peak
1600	1700	1120	560		560	Peak
1700	1800	840	560		280	Peak
1800	1900	840	560		280	Peak
1900	2000	280	0		280	Peak
2000	2100	280	0		280	Peak
2100	2200	280	0		280	Off peak
2200	2300	0	0	560	0	Off peak
2300	0	0	0	560	0	Off peak
Total RTH		**10080**	**5040**	**5040**	**5040**	

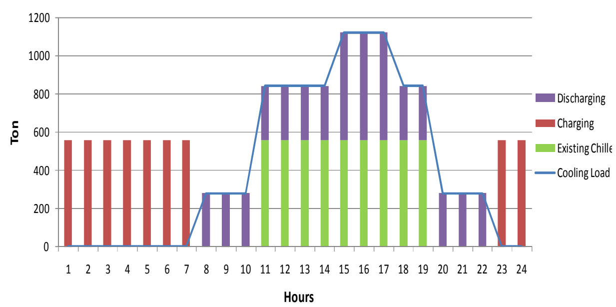

Fig. 3 Charge and discharge profile with cool thermal energy storage system.

Table IV and Table V showed energy required for running air condition system by existing air condition unit and proposed cool TES system. There are 451.4 kWe energy powers saving during peak period. Finally this power saving manage to reduce maximum demand charge.

Power saving = 975.6 – 524.2
= 451.4 kwe
Maximum Demand rates
Effective 1st July 2008 = RM36.60 per kw
Demand charge saving = 451.4 x 36.60
= RM16, 520.22 per month
Operation Cost Saving = RM195, 713.29
(948,646.60 – 752,933.31)
Maximum Demand Saving = RM384, 811.31
(16,520.22 x 12)
Maintenance Cost = RM24, 600.00
Total Saving from TES = RM369, 355.95

F. Economical Analysis

The Payback Period analysis method was used widely in economic analysis. Payback Period defined as the length of time required to recover an initial investment through cash flows generated by the investment. The Payback Period gives the level of profitability of an investment in relation to time. The shorter the period is the better the investment opportunity. The Payback Period is a tool that is easy to use and understand, but it has its limitations. Payback period analysis does not address the time value of money, nor does it go beyond the recovery of the initial investment.

$$\text{Payback period} = \frac{\text{Initial cost}}{\text{Yearly return}} \quad (9)$$

The Payback period is calculated by using (9), where by this equation is based on the initial cost and yearly return. All the value using this equation is positive and the result of the economics analysis is positive. Smaller result showed better result compare to bigger result. Below is the example of calculation of payback period.

TABLE IV
DESIGNED BUILDING LOAD PROFILE

	Existing System	Proposed TES Chiller		Unit
		Day Cooling (Existing CH + Ice tank)	*Night Charging*	
EXISTING PLANT				
Peak Cooling	1,120	560	0	RT
Chiller Set	2	1	0	
Chiller Capacity	560	560	0	RT
kW/RT	0.7	0.7	0	
Chiller Power	392	392	0	kWe
Total CH Power	784	392	0	kWe
CHWP Head (ft)	70	70	0	
CHWP Flow (USGPM)	1,775.00	1,775.00	0	
CHWP kWe	44.04	44.04	0	
Total CHWP kWe	88.07	44.04	0	kWe
CWP Head (ft)	98	98	0	
CWP Flow (USGPM)	1,363.00	1,363.00	0	
CWP kWe	35.27	35.27	0	0.745
Total CWP kWe	70.54	35.27	0	kWe
Cooling Tower				
Fan - Motor	16.5	16.5	0	kWe
Set	2	1	0	
Total CT kWe	33	16.5	0	kWe
NEW CENTRAL TES PLANT				
Peak Cooling	0	560	580	
Chiller Set	0	0	1	
Chiller Capacity	0	0	580	
kW/RT	0	0	0.68	
Chiller Power	0	0	394.4	
Total CH Power	0	0	394.4	kWe
CHWP DISTRIBUTION				
CHWP Head (ft)	0	150	0	
CHWP Flow (USGPM)	0	584.35	0	
CHWP kWe	0	23.14	0	0.745
CHWP – Qty	0	1	0	
Total CHWP Distribution kWe	0	23.14	0	kWe
Chiller GlycolP Head (ft)	0	0	60	
Chiller GlycolP Flow (USGPM)	0	0	2,000.00	
Chiller GlycolP kWe	0	0	38.02	0.745
Chiller GlycolP- Qty	0	0	1	
Total Chiller GlycolP kWe	0	0	38.02	kWe
Ice Tank GlycolP Head (ft)	0	70	0	
Ice Tank GlycolP Flow (USGPM)	0	599.2	0	
Ice Tank GlycolP kWe	0	13.29	0	0.745
Ice-Tank GlycolP- Qty	0	1	0	
Total Ice Tank GlycolP kWe	0	13.29	0	kWe
CWP Head (ft)	0	0	60	
CWP Flow (USGPM)	0	0	2,500.00	
CWP kWe	0	0	39.61	0.745
CWP - Qty	0	0	1	
Total CWP kWe	0	0	39.61	kWe
Total kWe	975.6	524.2	472	kWe

TABLE V
SAVING BY PARTIALLY STORAGE SYSTEM

Operation Cost	Conventional	TES	
	Day Mode	*Day Mode*	*Night Mode*
On Peak Ton Hr	9,800.00	9,800.00	0
Daily On Peak KWHr	8,536.61	4,587.10	0
On Peak Rates	0.296	0.296	0
Daily On Peak Cost	2,526.84	1,357.78	0
Off Peak Ton Hr	280	0	4,760.00
Daily Off Peak KWHr	243.9	0	3,873.89
Off Peak Rates	0.296	0.182	0.182
Daily Off Peak Cost	72.2	0	705.05
Daily Operation Cost	2,599.03	1,357.78	705.05
Total Annual Operation Cost	948,646.60	495,590.63	257,342.68

Initial cost = RM 21350, Yearly return = RM 19068.

$$PP = \frac{\text{Initial cost}}{\text{Yearly return}} = \frac{\text{RM 2, 000,000.00}}{\text{RM369, 355.95}} = 5.41$$

From this calculation the payback period for this measure is about 5.41 or equal near to 65 months. This investment is considered a good investment where by the initial cost is recovered in less than seven years.

IV. Discussion

From 0700 hour, the occupants start to enter the building. Heats in the form of latent and sensible are emitted and cooling load requirement starts ween 0 to 280 RT. After 1000 hour the cooling requirement starts to maintain between 840 RT until 1400. Then cooling requirement reaches 1120 RT at the peak load of the day at 1400 hour, due to higher outdoor temperature. The cooling requirement decreases to 840 RT at 1700 hour as the occupants start to leave the building. Then it is continuing reduce few hours from 1800 hour as the out-campus classes begin and back to zero at 2200 hour. During nighttimes, ice charging process takes place from 2200 hour to 0700 hour. The ice chiller produces 560RT per hour and the cooling energy is stored in the ice cell. The total cooling load required per day is 10,080 RTh. With the total storage capacity of 5,040 RTh, the left behind load has to be catered by the chillier. From the economic analysis conducted, found that the initial investment will recover in 5.41 years and is considered as a good investment. Furthermore this investment supports global warming issue by produced less pollution.

V. Conclusion

A good TES plant management is the key element to a successful cool TES system implementation. Poor design operation strategy may cause a disappointing savings performance. It might more higher cost than the conventional system. From the designed partially operation strategy TES, It found that energy cost saving per year will be RM369, 355.95 and 5.46 payback period. This result can be achieved by utilized the ice charging process to its nominal tank capacity of 5,040 RTh. In conclusion from the research carried out, found there are opportunities of cost saving improvement by implementing centralized air-conditioning plant integrated with thermal energy storage.

Recommendation

Several recommendations are consider for further works. There are; economical analysis according others country energy tariff such as Asean country's energy tariff rate, modeling, experimental and conducted economical analysis by other evaluation method.

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