Techno-Economical Aspects of Encapsulated Ice Thermal Energy Storage Applications for Air-Conditioning System

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ABSTRACT

Thermal Energy Storage (TES) for air-conditioning application has grown significantly in Malaysia in recent years. For encapsulated ice method, the difference in the amount of ice supplied to supplement the chilled water generated during peak hours plays a major role in ascertaining the result of electricity bill savings and therefore, payback period. Based on actual implementation, a simple simulation program of TES integrated system is created to study its impact on the electricity bill savings, electricity consumption and power shift as compared to the conventional system. Varying the percentage of ice supply, application to cooling capacity of 1000 RT with and without base load, this study finds that electricity bills are saved with the penalty of higher energy consumption for chillers' efficiency of 0.8 and 1.1 input kW per refrigerant tonnage (ikW/RT), respectively. However, reduction in maximum demand of up to 30% is possible.

1. MALAYSIAN ENERGY OVERVIEW

Daily peak demand for electricity in Malaysia currently stands at approximately 13,000 MW [1]. It is forecast that in 2008, the demand will reach 19,000 MW [2] which is 46% more than the capacity generated at present.. Figure 1 shows the trend of increment in terms of electricity sales. Tenaga Nasional Berhad (TNB), the major utility provider in the country, is implementing various steps in order to cope with the expected surge in electricity requirement. One of them is demand-side management (DSM) where the electricity consumption is managed by the demand, or consumer side. The objective

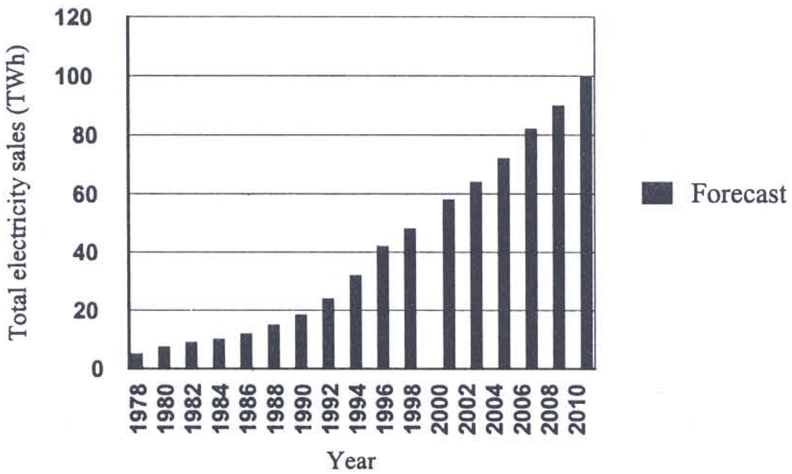

Fig. 1. Energy growth in terms of sales (1978-1998) [1]

to shift peak hour's electricity demand could be achieved should the consumer manages to utilize the energy mostly during off-peak period. Incentives in monetary terms through special tariff are rewarded to the consumers who successfully participate in this program. Being one of the tools for DSM, thermal energy storage application is now rapidly gaining popularity.

2. THERMAL ENERGY STORAGE

Thermal Energy Storage (TES) is the temporary storage of high or low temperature energy for later use [3]. It bridges the time gap between energy availability and energy appliance. Most TES application involves 24-hour storage cycle where the available energy during off-peak hours is charged at lower rate than during the utilization at peak hours. In Malaysia, the tariff offered by TNB, upon successful application to implement TES, is tabulated in Table 1.

Table 1 Structure for Special C2 Tariff [4]

Description	Normal C2	Tariff C2 for TES
Peak energy charge (9 am - 9 pm)	20.8 cent/kWh	20.8 cent/kWh
Off-peak energy charge (9 pm - 9 am) For first seven years After 7th year, convert to normal C2	12.8 cent/kWh	11.8 cent/kWh 12.8 cent/kWh

3. THERMAL ENERGY STORAGE IN MALAYSIA

The emerging TES application in Malaysia is so far at reasonable pace. The first implementation of TES is believed to be the TNB's generation plant in Port Dickson, where 25,000 RTh of TES (ice harvesting method) is used for air inlet cooling [5]. The system commenced operation in 1995. Some of the major TES applications in Malaysia are listed in Table 2.

From Table 2, TNB realized that TES could contribute significantly to the demand shift during peak period based on capacity and current electricity bill paid by the customers. If the trend to utilize TES and other DSM programs continue, TNB is expected to reap savings exceeding RM 42 billion from power generation during the period 2000 to 2010 [6].

Table 2 Some TES Applications in Malaysia

Projects	Year Completed	Capacity (RT)	TES Method
TNB Generation Plant	1995	25,000	Ice harvesting
One Utama Complex	1995, On-going	4,000	Ice on coil and chilled water storage
IOI Mall Complex	1996	4,000	Ice on coil
Multimedia University	1997	4,000	Ice ball
University Tenaga	1997	4,000	Chilled water storage
Cyberjaya	2001, On-going	20,000	Ice ball
TNB's Bangsar	2001	14,000	Ice ball
MARA University of Technology	2002, On-going	4,000	Ice on coil

4. COOLING LOAD PROFILE

As this study is based on actual model implemented on commercial buildings, the load profile is somewhat similar to the electricity demand curve, i.e., a bell shape [7]. This profile is true for the implementation in tropical countries like Malaysia and covers only the requirement for normal comfort cooling. Two types of profile were chosen. One with base load, where some of the cooling is needed during ice-making or off-peak period, and another without base load, when the chiller only operates during nighttime to charge the ice. No cooling load is required to cool the space during that period. Figure 2 reflects the cooling load profile studied for this purpose. For conventional system where the chillers operate solely to cater the cooling load, chiller load profile is exactly similar to the cooling load requirements. Peak load occurs somewhere around 15:00 hours of the day as it is the time when the building start releasing the heat absorbed during the hottest time of the day. For TES application, maximum demand charges that are charged by electricity provider could be saved as the chilled water during peak period is supplemented by the ice discharged from the storage tank. In the case where full TES is applied, cooling load requirement during peak period is supplied entirely by the ice discharged from storage tank. Full storage is however, rarely practiced as it requires high capital expenditure to construct a big storage tank, depending on the peak load cooling demand.

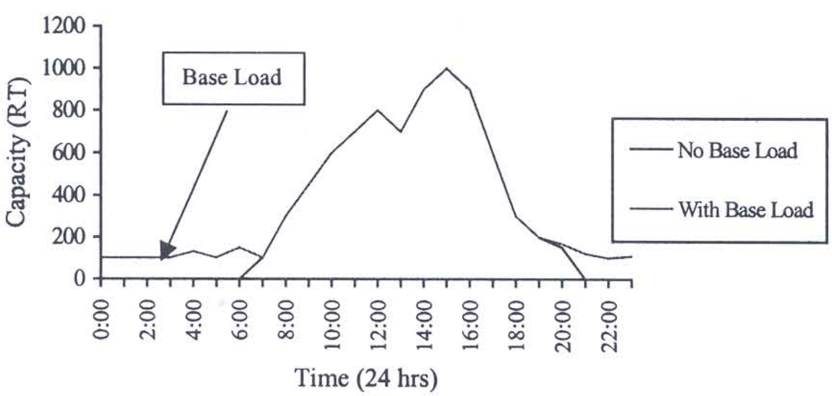

Fig. 2. Typical cooling load profile for commercial buildings in Malaysia

5. METHODOLOGY

A simple program has been created based on quantitative data on actual implementation as mentioned earlier. The basis and limitations for the program were taken as follows:

- 25 working days per month,
- Initial cost for every chiller capacity is RM 2,700.00 per RT,
- Initial cost for every TES tank capacity is RM 380.00 per RTh,
- Maximum demand charge of RM 25.70 for every kW to be included in monthly bills,
- Electricity consumption is calculated for chillers only, and
- Encapsulated ice method is used.

The program simulates both conventional system and TES integration.

5.1 Equipment Selection

Widely available chillers in Malaysian market have been chosen with maximum capacity of 1000 refrigerant tonnage (RT). Those chillers were manufactured by a well-known and reputable company and the efficiency claims are reasonable figures calculated as closely possible to the actual application. Two units of chillers selected according to the suitability and percentage of TES supply were utilized.

5.2 Percentage of TES Supply

Supply of ice to supplement cooling load requirement during peak period was varied by increment of 10%, starting from 10% supply of total peak requirement to 100% ice supply during the entire period, meaning, both partial and full storage applications were studied. Conventional system was also calculated for comparison.

5.3 Simulation Program

Examples of program output are tabulated in Table 3 for conventional system and Table 4 for TES system. Peak period as defined by TNB is from 09:00 hours to 20:59.59 daily. It should be noted that the electricity bills shown in the last column of both tables are the electricity consumption by the chillers only and do not consider the demand charges imposed by TNB. Table 3 is used as basis of comparison for all TES application without base load carried out in this study.

Table 3 Sample Output for Conventional System without Base Load for 1000 RT Cooling Capacity

Time	Load (RT)	1000 RT Ch 1 (RT)	0 RT Ch 2 (RT)	Supply by TES (RT)	Total RT	Chrg/ dischrg (RTh)	Ch 1 (ikw/ RT)	Total power (kW)	Tariff (RM/ kWh)	Bill (RM)
0	0	0	-	-	0	-	0	0	0.128	0
1	0	0	-	-	0	-	0	0	0.128	0
2	0	0	-	-	0	-	0	0	0.128	0
3	0	0	-	-	0	-	0	0	0.128	0
4	0	0	-	-	0	-	0	0	0.128	0
5	0	0	-	-	0	-	0	0	0.128	0
6	0	0	-	-	0	-	0	0	0.128	0
7	100	100	-	-	100	-	0.8	80	0.128	10.24
8	300	300	-	-	300	-	0.8	240	0.128	30.72
9	450	450	-	-	450	-	0.8	360	0.208	74.88
10	600	600	-	-	600	-	0.8	480	0.208	99.84
11	700	700	-	-	700	-	0.8	560	0.208	116.4
12	800	800	-	-	800	-	0.8	640	0.208	133.1
13	700	700	-	-	700	-	0.8	560	0.208	116.5
14	900	900	-	-	900	-	0.8	720	0.208	149.8
15	1000	1000	-	-	1000	-	0.8	800	0.208	166.4
16	900	900	-	-	900	-	0.8	720	0.208	149.7
17	600	600	-	-	600.	-	0.8	480	0.208	99.84
18	300	300	-	-	300	-	0.8	240	0.208	49.92
19	200	200	-	-	200	-	0.8	160	0.208	33.28
20	150	150	-	-	150	-	0.8	120	0.208	24.96
21	0	0	-	-	0	-	0	0	0.128	0
22	0	0	-	-	0	-	0	0	0.128	0
23	0	0	-	-	0	-	0	0	0.128	0
								6160		1255

From Table 3, the following information could be obtained:

- Cooling load during peak period: 7300 RTh
- Power consumption during peak period: 5840 kWh
- Maximum demand: 800 kW (times RM 25.70 per month for demand charges)

Therefore,

- Initial cost for chillers: 1000 RT x RM 2700/RT = RM 2,700,000.00
- Total annual bills: (RM 1255 x 25 days) + (800 kW x RM 25.70)
  = RM 51,935 x 12 months
  = RM 623,220.00

Table 4 Sample Output for TES System without Base Load (50% TES Supply) of 1000 RT Cooling Capacity

Time	Load (RT)	340 RT Ch 1 (RT)	507 RT Ch 1 (RT)	Supply by TES (RT)	Chrg/ dischrg (RTh)	Ch 1 (ikw/ RT)	Ch 2 (ikw/ RT)	Total power (kW)	Tariff (RM/ kWh)	Bill (RM)
0	0	0	304	-	1217	0	1.1	334	0.118	39.5
1	0	0	304	-	1521	0	1.1	334	0.118	39.5
2	0	0	304	-	1825	0	1.1	334	0.118	39.5
3	0	0	304	-	2129	0	1.1	334	0.118	39.5
4	0	0	304	-	2433	0	1.1	334	0.118	39.5
5	0	0	304	-	2738	0	1.1	334	0.118	39.5
6	0	0	304	-	3042	0	1.1	334	0.118	39.5
7	100	100	304	-	3346	0.8	1.1	414	0.118	48.9
8	300	300	304	-	3650	0.8	1.1	574	0.118	67.8
9	450	340	-	110	3540	0.8	-	272	0.208	56.6
10	600	340	-	260	3280	0.8	-	272	0.208	56.6
11	700	340	-	360	2920	0.8	-	272	0.208	56.6
12	800	330	-	470	2450	0.8	-	264	0.208	54.9
13	700	330	-	370	2080	0.8	-	264	0.208	54.9
14	900	330	-	370	1510	0.8	-	264	0.208	54.9
15	1000	330	-	670	840	0.8	-	264	0.208	54.9
16	900	330	-	570	270	0.8	-	264	0.208	54.9
17	600	330	-	270	0	0.8	-	264	0.208	54.9
18	300	300	-	0	0	0.8	-	240	0.208	49.9
19	200	200	-	-	0	0.8	-	160	0.208	33.3
20	150	150	-	-	0	0.8	-	120	0.208	25
21	0	0	304	-	304	0	1.1	334	0.118	39.5
22	0	0	304	-	608	0	1.1	334	0.118	39.5
23	0	0	304	-	913	0	1.1	334	0.118	39.5
								7255		1119

From Table 4, the following information could be obtained:

- Initial cost: (847 RT x RM 2700/RT) + (3650 RTh x RM 380)
  = RM 3,673,900.00
- Total annual bills: (RM1119 x 25days) + (272 kW x RM 25.70)
  = RM 34,965.40 x 12 months
  = RM 419,584.20

Therefore, annual savings can be calculated as:
= RM 623,220.00 – RM 419,584.20
= RM 203,635.80

Comparison of Table 3 and Table 4 results in:

- Electricity bill saving: RM 203,635.80 per year
- Total power increase: 1095 kWh
- Maximum demand reduction: 528 kW (60% reduction)
- Total power shifted: 2920 kWh
- Payback period (using simple payback analysis - the difference in initial cost of both systems divided by annual savings): RM 973,900 / RM 203,635.80 = 4.7 years

5.4 Simulation Output for 1000 RT without Base Load

In the case of 1000 RT capacity without base load as shown in Table 3, chiller 1 is used to cater only for non-TES application (conventional) where chilled water is produced at 6°C and therefore, the efficiency is 0.8 ikW/t. Chiller 2 operates solely for ice-making process (charging), where chilled water mixed with anti-freeze solution (brine) is produced at much lower temperature, i.e., –5°C. This results in chiller's efficiency penalty to 1.1 ikW/t.

6. RESULTS AND DISCUSSION

Table 5 tabulates the summary of simulation output for 1000 RT of TES system as compared to conventional air-conditioning system. The range of electricity saving is around 12% for 10% TES supply without base load application while 100% TES supply (full storage) achieves 53%. Application with base load saves approximately 11% for 10% TES supply up to 44% for full storage. Despite the benefit of bill saving, consumption for electricity shows an increment for all cases. The percentage of increased electricity consumption without base load ranges from 4% to 36%. With base load application, the increment is smaller ranging from 3% to 31%. Moreover, the total power shift also grows proportionately with the increase in capacity TES percentage. For 50% TES supply, reduction in maximum demand of up to 40.2% or 2920 kWh is achievable.

Table 5 Electricity Bill Saving, Increased Electricity Consumption and Total Power shifted for Capacity of 1000 RT using TES

Percentage of TES supply (%)	Electricity bill saving (%)		Increased electricity consumption (%)		Power shift to off-peak period (kWh)	
	1000 RT No base load	1000 RT With base load	1000 RT No base load	1000 RT With base load	1000 RT No base load	1000 RT With base load
10	12.12	10.87	4	3	584.00	616.00
20	18.56	16.72	7	6	1168.00	1232.00
30	23.4	21.23	11	9	1752.00	1848.00
40	28.65	25.59	14	12	2336.00	2464.00
50	32.7	29.92	18	16	2920.00	2920.00
60	36.83	33.75	21	19	3476.00	3644.00
70	40.65	37.11	25	22	4004.00	4180.00
80	43.92	40.17	28	25	4544.00	4699.20
90	47.27	41.05	32	28	5065.60	5224.00
100	52.59	44.36	36	31	5840.00	5840.00

Figure 3 reflects the percentage of bill saving benefit from TES application. It shows that when no base load is applied, the system obtains more savings as compared to those with cooling requirement during off-peak period. The savings increases proportionately to the rise of TES supply percentage. It could be observed that the gap between base load and no base load application grows wider as it reaches 100% TES supply.

As for Fig. 4, the consumption of electricity grows proportionately with the capacity of TES supply. It is caused by bigger chiller capacity required to make the ice during off-peak period. It also shows that application without base load utilizes less electricity by 1% to 7% as compared to application with base load.

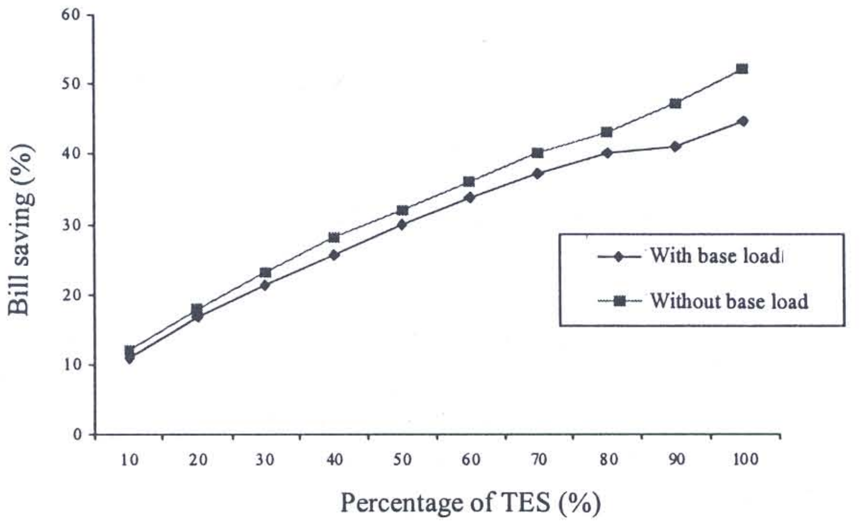

Fig. 3. Percentage of bill saving vs. TES supply

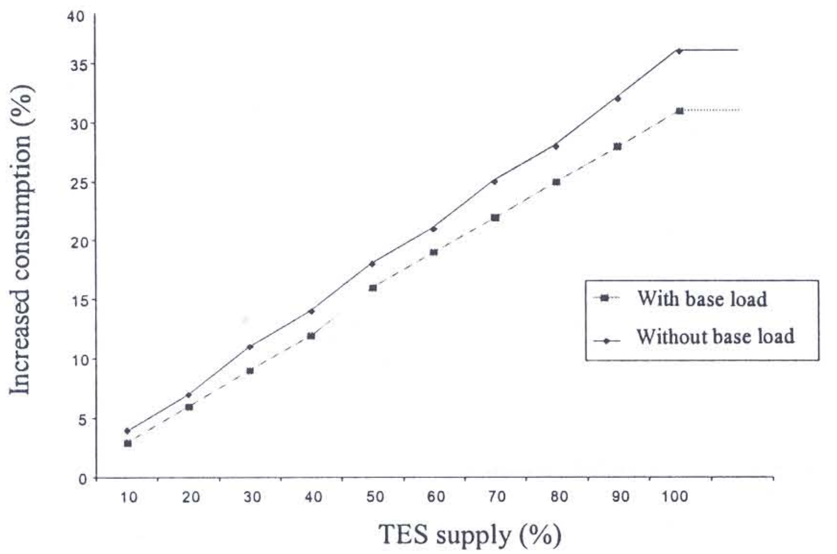

Fig. 4. Increased electricity consumption vs. TES supply

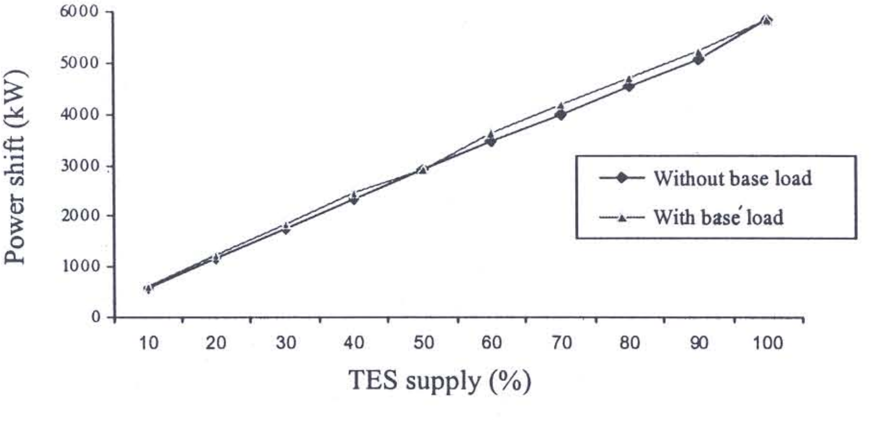

Fig. 5. Power shift vs. TES supply

Figure 5 highlights the shifting of electricity from peak period to off-peak period. The graph is almost in straight line and proportionate to the amount of TES.

7. CONCLUSIONS

This study discloses the fact that the amount of electricity bill saving grows proportionately with the percentage of TES supply during peak period. Less TES supply, however small the initial investment is, gives only up to approximately 12% of saving compared to when conventional system is utilized. With full storage, bill saving of up to 52% is achievable.

It is also expected, since air-conditioning system utilizes about 65% of total electrical consumption in normal buildings, that reduction of current peak demand in Malaysia of approximately 4,000 MW or 30% is achievable should the energy shifting strategy is successful. On the other hand, despite common belief that TES application gives energy savings, this study shows the increment of electricity consumption in all cases. This issue could be solved once the efficiency of chiller during ice making is improved. Until then, TES could only contribute to the load shifting exercise where peak demand is lowered and economically sound due to the lower tariff.

8. NOMENCLATURE

ikW/RT	=	input kilowatt per refrigerant tonnage
kWh	=	kilowatt-hour
MW	=	megawatt
RM	=	Ringgit Malaysia (Malaysian currency: US$ 1 = RM 3.80)
RT	=	refrigerant tonnage
RTh	=	refrigerant tonnage hour

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