ENERGY EFFICIENT BUILDING :
THE APPLICATION OF THERMAL ENERGY STORAGE (TES) FOR COOLING LOAD REDUCTION

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This thesis is submitted as a fulfillment of the requirements for the award of the degree of Master in Mechanical Engineering

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To my loving parents, brothers and sister...

"Thank you for your support"

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Abstract

A typical building zone designated as Zone PPU, in UTHM was selected for a detailed study of applying Thermal Energy Storage (TES) for cooling load reduction. Data of electricity bills from May 2005 to December 2007 were collected for analysis of usage trending. The energy consumption index for Zone PPU was also established and compared with MS1525 standard. The energy simulation program TRACE 700 was used to calculate the peak cooling loads for Zone PPU. Two storage systems using ice storage technology were being proposed in this study, which are full storage system and partial storage system. Two economical analysis tools, which are the Simple Payback Period method and Net Present Value method, were used to evaluate whether the proposals are economically viable to be considered. The energy consumption for buildings G1, G2 and G3 (of total floor areas 15,285 m^2) for the year 2007 was 7,261,803kWh, giving an energy consumption index of 475kWh/m^2 per year which was far too much compared to the recommended value of 135kWh/m^2 per year as stated in MS1525 Standard. The analysis results indicated that the TES proposals for the existing cooling load of 1160RT has no attractive payback period and results negative net present value calculating up to the life span (of 15 years) of chillers with proper maintenance, indicating that the TES proposal is not economically viable. In view of the available market references, cooling load of 3000RT and above is required in order to achieve a more economically viable proposal. Therefore, several proposals with proposed capacity ranging from 2200RT, 2900RT, 3600RT and 4200RT have been made so that the most optimum load can be selected for future considerations.

Abstrak

Zon tertentu di UTHM, Zon PPU, telah dipilih untuk kajian aplikasi *Thermal Energy Storage (TES)* dalam pengurangan beban penyejukan dan kesannya pengurangan pada penggunaan tenaga eletrik.. Data bil elektrik dari Mei 2005 ke Disember 2007 telah dikumpulkan untuk analisis trend penggunaan tenaga. Indeks tenaga untuk Zon PPU telah ditentukan dan dibandingkan dengan piawaian MS1525. Program simulasi tenaga TRACE 700 telah digunakan dalam mengirakan beban penyejukan puncak di Zon PPU. Dua sistem penyimpanan, iaitu sistem penyimpanan penuh dan sistem penyimpanan separa, dengan menggunakan teknologi penyimpanan ais telah dicadangkan dalam kajian ini. Dua kaedah analisis ekonomi, iaitu *Simple Payback Period* dan *Net Present Value* telah digunakan untuk menilai sama ada cadangan-cadangan ini adalah menguntungkan dari segi ekonomi. Pada tahun 2007, bangunan-bangunan G1, G2 dan G3 dengan keluasan 15,285m2 telah menggunakan 7,261,803kWh, ini memberi nilai indeks penggunaan tenaga bernilai 475kWh/m^2 /tahun. Ini adalah jauh lebih besar berbanding nilai piawaian 135kWh/m^2/tahun seperti yang dinyatakan dalam MS1525. Keputusan analisis menunjukkan bahawa cadangan *TES* untuk beban penyejukan 1160RT (Ton Penyejukan) yang sedia ada tidak memberi tempoh bayar balik yang menarik. Di samping itu, nilai negatif *net present value* yang dikira sehingga hayat guna chiller yang diselenggara dengan baik, selama 15 tahun, menunjukkan bahawa cadangan *TES* tidak menguntungkan dari segi ekonomi. Berpandukan rujukan pasaran sediada, beban penyejukan 3000RT dan ke atas adalah diperlukan bagi cadangan yang lebih ekonomik. Oleh itu, beberapa cadangan beban penyejukan daripada 2200RT, 2900RT, 3600RT dan 4200RT telah dibuat untuk mendapatkan cadangan beban yang paling optimum untuk pertimbangan masa akan datang.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

SYMBOL		DESCRIPTION	UNIT
A	-	area	ft^2
BF	-	ballast factor	--
CLF	-	cooling load factor	--
CLTD	-	modified temperature difference value that accounts for the heat storage/time lag effects	°F
$CLTD_c$	-	corrected value of CLTD	°F
DR	-	daily temperature range	°F
LM	-	correction for latitude and month	--
Q	-	heat gain (cooling load)	BTU/hr
Q_s , Q_l	-	sensible and latent heat gains (loads)	--
q_s , q_l	-	sensible and latent heat gains per person	--
SC	-	shading coefficient	--
SHGF	-	maximum solar heat gain factor	BTU/hr/ft^2
TD	-	temperature difference between unconditioned and conditioned space	°F
T_a	-	average outside temperature on a design day	°F
T_o	-	outside design dry bulb temperature	°F
T_R	-	room temperature	°F
U	-	overall heat transfer coefficient	BTU/hr-ft^2-°F
W	-	lighting capacity	watts

LIST OF APPENDIX

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Worldwide, people use about one third of the total energy consumption in buildings – for heating, cooling, cooking, lighting, and running appliances. Building-related energy demand is rising rapidly, particularly within our homes. But there are large differences in household energy use from one country to the next: for example, people in the United States and Canada consume 2.4 times much energy at home as those in Western Europe.

As homes become bigger, each individual house has more space to heat, cool, and light, as well as room for bigger and more appliances. Home appliances are the world's fastest-growing energy consumers after automobiles, accounting for 30 percent of industrial countries' electricity consumption and 12 percent of their greenhouse gas emissions (internet article: Making Better Energy Choices, http://www.worldwatch.org). In developing countries, meanwhile, the potential for appliance growth is enormous: sales of frost-free refrigerators in India alone are projected to grow nearly 14 percent annually.

Yet the same needs could be met with far less energy. Technologies available today could advance appliance efficiency by at least an additional 33 percent over the next decade, and further improvements in dryers, televisions, lighting, and standby power consumption could avoid more than half of projected consumption growth in the industrial world by 2030 (internet article: Making Better Energy Choices, http://www.worldwatch.org). In developing countries, people could save as much as 75 percent of their energy through improvements in building insulation, cooking, heating, lighting, and electrical appliances.

As shown in Figure 1.1, most of the energy consumed by commercial and institutional organizations is used to:

i) Operate auxiliary equipment – devices that supply energy services to the major process technologies during their operation and that are common to most industries. Auxiliary equipment falls into five categories :
   - steam generation
   - permanent lighting
   - heating
   - ventilation and air conditioning
   - electric motors, including pumps, fans, compressors and conveyors

ii) Supply plug load – the electricity demand from all equipment that is plugged into electrical outlets in buildings (principally office equipment, consumer electronics and portable lighting)

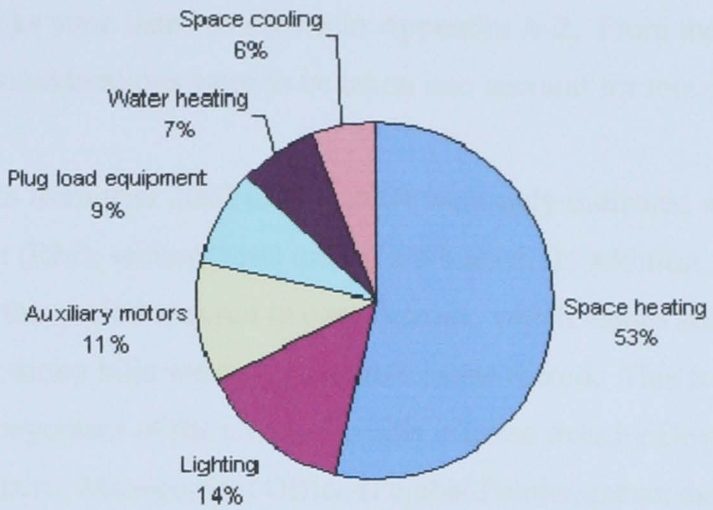


Figure 1.1: Commercial/Institutional Secondary Energy Use End-Use, 2002
(Source: *Energy Use Data Handbook, Natural Resources Canada's Office of Energy Efficiency*)

Improving energy efficiency, for instance in electricity use, will have two benefits: (World Energy Council, 2008)

i) Supply more consumers with the same electricity production capacity, which is often the main constraint in many countries of Africa and Asia.
ii) Slow down the electricity demand growth, and reduce the investment needed for the expansion of the electricity sector; this is especially important in countries with high growth of the electricity demand, such as China and many South East Asian countries.

1.2 PROBLEM STATEMENT

Data of the energy consumption in UTHM from 2002 to 2007 (Appendix A-1) has been collected and graph of yearly energy consumption was plotted (Figure 1.2). There were 14 zones in which monthly electricity bill were account for. The relevant consuming blocks were listed as shown in Appendix A-2. From the data collected, the following considerations were to be taken into account for this project:

i) Data from year 2002 to year 2004 were only indicated with electricity cost (RM), without total unit of kWh used. In addition, the data available for this period was not in complete set, which means some of the electricity bills were not available in the record. This is because the management of the electricity bills is taken over by Development and Property Management Office (Pejabat Pembangunan dan Pengurusan Hartabina) in year 2005 only.

ii) Due to the reason stated in (i), the total unit of kWh for year 2002 to year 2004 was formulated from the total amount charged.

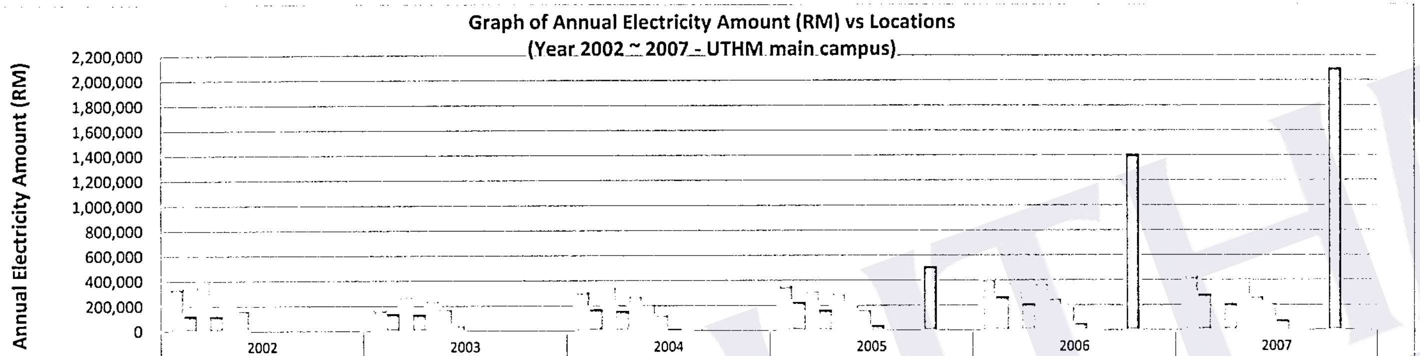
iii) There was a tariff review effective from 1st June 2006. The tariff review is as follows (Table 1.1 and Table 1.2):

Table 1.1: Zoning other than PPU : Tariff B - Low Voltage Commercial Tariff

	Old Tariff (before June 2006)	New Tariff (effective from 1st June 2006)
For all kWh	28.8 sen/kWh	32.3 sen/kWh

Table 1.2: Zone PPU : Tariff C1 - Medium Voltage General Commercial Tariff

	Old Tariff (before June 2006)	New Tariff (effective from 1st June 2006)
For each kilowatt of maximum demand (MD) per month during the peak period	17.30 RM/kWh	19.50 RM/kWh
For all kWh	20.8 sen/kWh	23.4 sen/kWh



	2002	2003	2004	2005	2006	2007
MSB-1	339038.60	168677.34	309258.78	353665.07	405855.01	425484.12
MSB-2	126446.22	139619.84	174333.77	228988.39	268245.97	286642.01
MSB-3	397894.64	269782.89	346842.27	310636.40	377747.09	407295.69
MSB-4	123937.89	133374.90	158849.91	165951.11	211712.95	212475.85
MSB-5	216365.91	241118.83	275030.12	294359.06	370366.27	413967.72
MSB-6	165548.43	174967.89	209785.19	196174.58	250146.38	267502.72
MSB-7	0.00	43143.45	123821.40	161270.52	184879.15	212696.02
MSB-8	0.00	0.00	13666.41	42328.08	55454.30	80042.27
MSB-9	0.00	0.00	56428.41	129508.23	151710.55	140202.70
Cafeteria	5309.17	4910.59	7444.68	8313.74	6628.13	5658.83
D. Badminton	4597.03	3839.56	4350.73	6244.94	7244.58	9448.07
PPU	0.00	0.00	0.00	513140.16	1408313.16	2097025.60
Pejabat PALPES	0.00	0.00	2770.94	11717.29	18700.60	14909.85
Pejabat PALPES	0.00	0.00	3036.37	11004.26	15316.72	16815.82

Figure 1.2: Yearly energy consumption in UTHM from 2002 to 2007

Zone PPU started its operation in May 2005 and was the main contributor to the energy consumption of UTHM despite its short length of service compared with other zones. Zone PPU covers areas for Block F2, G1 (FKEE), G2 (FKMP), G3 (lecture halls) and G4 (hostels). Why Zone PPU contributed the most to the total electricity bills of UTHM? What were the main factors contributing to this high electricity bills? Was there any possibility to reduce the consumption? These issues or questions had become the deriving force for undertaking the present project.

1.3 OBJECTIVE

The objective of this project is to investigate the potential of applying Thermal Energy Storage (TES) technique in reducing the cooling load requirement for Technology Complex (Blocks G1 & G2) and Lecture Halls (Block G3) at UTHM.

1.4 SCOPE OF STUDY

The scope of this project was to study energy efficiency in Universiti Tun Hussein Onn Malaysia. In this project, focus was given on the zone with the highest electricity energy consumption, which was Zone PPU (Technology Complex and Lecture Halls - Block G1, G2 and G3).

The scope of the study include:

i) To identify the major area of energy consumption by studying the energy usage pattern.

ii) To identify Building Energy Index (BEI) for Zone PPU and compare with MS1525 standard.

iii) To study energy saving opportunities.

iv) To study possibility of installing thermal storage system as a mean of reducing building cooling load in order to reduce electricity consumption in the selected buildings.

v) To give recommendations for using energy efficiently.

1.5 SIGNIFICANT OF THE PROJECT

The focus of Ninth Malaysia Plan (RMK9, 2006 ~ 2010) is to further enhance the sustainable development of the energy sector to enable it to support economic growth, enhance competitiveness as well as contribute towards achieving balanced development. In line with the thrust of the National Mission to improve the standard and sustainability of the equality of life, emphasis will be directed towards efficient production and utilisation while meeting environmental objectives. The strategies of the energy sector are as follows:

- In ensuring efficient utilisation of energy resources and minimisation of wastage, the focus will be on energy efficiency initiatives, particularly in the industrial, transport and commercial sectors as well as in government buildings… page 393.

- To promote the efficient use of energy, focus was given to the design and installation of energy efficient features in government buildings such as in the Ministry of Energy, Water and Communications… page 401.

- Intensifying energy efficiency initiatives in the industrial, transport and commercial sectors as well as in government buildings… page 402.

- The implementation of energy efficiency (EE) programmes will focus on energy saving features in the industrial and commercial sectors. In this regard, establishing a comprehensive energy management system will be encouraged… page 408.

- To promote greater EE in government buildings, good energy practices such as optimal lighting and air-conditioning will be adopted. Energy audits will be conducted in government buildings to identify additional measures that can be implemented to further improve EE… page 408.

A strong emphasis was given by government in RMK9 plan to improve energy efficiency especially in government buildings. Hence, this project would become our response to government's plan.

The commercial customer presents a particularly poor load profile to the utility. Thus, commercial customers pay averagely 65% more for their electricity than industrial customers. Air-conditioning equipment is the main contributor to poor commercial load profiles.

The ASHRAE *Air Conditioning Systems Design Manual* contains a detailed analysis of energy consumption for a 264,000 ft^2 (24526 m^2) building operating under an Ontario Hydro rate structure. The chiller equipment contributed 31% to the peak demand but consumed only 8% of the annual kWh. Annual load factor for the building was only 37%. Partial and full thermal storage systems could have improved the load factor to 44% and 55% respectively (Brian Silvetti, PE and Mark MacCracken, PE, 1998).

This project was aimed to study the possibilities to reduce the energy consumption by the application of Thermal Energy Storage (TES) in selected buildings at Technology Complex (Blocks G1 & G2) and Lecture Halls (Block G3) of UTHM.

CHAPTER II

LITERATURE REVIEW AND THEORY

2.1 BACKGROUND

Energy efficiency in buildings means use less energy for heating, cooling and lighting. It also means buying energy-saving appliances and equipment for use in a building. The important concept for energy efficiency in buildings is the building envelope, which is everything that separates the interior of the building from the outdoor environment: the doors, windows, walls, foundation, roof, and insulation. Various approaches could be done to improve the building envelope. Cooling and lighting systems typically use the most energy in a building in our country. The addition of efficient controls, like a programmable thermostat, can significantly reduce the energy use of this system. For commercial buildings, maximizing the use of Building Energy Management System (BEMS) can provide the best approach to energy-efficient cooling. Today, most common appliances and electronic devices are available in energy-efficient models – air conditioner, washing machines, fans, refrigerators, copiers and computers. Several energy-efficient lighting options, such as compact fluorescent light bulbs, are also available.

2.2 INTRODUCTION TO THERMAL ENERGY STORAGE (TES)

Thermal energy storage (cool storage or chilled storage) is a technology that reduces electric costs by shifting space cooling activities to off-peak times, when electricity rates are lower. Water is chilled or ice is made during the night to either replace or augment building cooling equipment during the day. As shown in Figure 2.1, the storage can be incorporated in an air conditioning or cooling system in a building. In most conventional cooling systems, there are two major components (Dincer and Rosen, 2001):

(i) A chiller – to cool a fluid such as water

(ii) A distribution system – to transport the cold fluid from the chiller to where it cools air for the building occupants

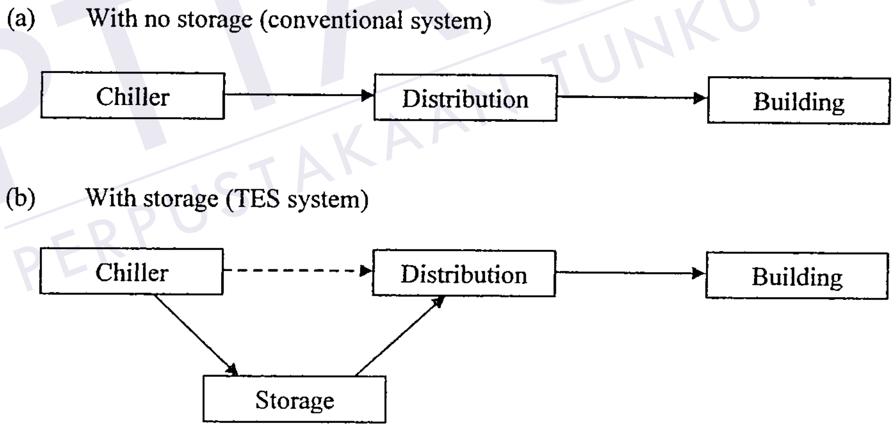


Figure 2.1: Schematic representation of two building cooling TES systems: (a) with no storage and (b) with storage

(Source: Dincer and Rosen, 2002, "Thermal energy storage systems and applications", pg. 246)

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