THERMAL STORAGE AIR CONDITIONING FOR TROPICAL COUNTRIES – ISSUES AND OPTIONS

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Abstract This paper discusses the status and the benefits of thermal storage air conditioning as a load management technique. In the same context different types of thermal storage systems, their operating modes, system optimisation criteria and control strategies have been reviewed. Peak and off-peak electricity rates and demand charges in a number of Asian countries have been analysed to highlight how the same influences introduction of thermal (cool) storage air conditioning. The present study demonstrates the methodology as to how to decide on the peak and off peak differential and the optimum threshold of demand charges for a targeted payback period.

Keywords: Thermal Storage, Air Conditioning

INTRODUCTION

Thermal energy storage for cooling or cool storage air conditioning has become well established in many countries e.g. USA, Japan and Taiwan as a useful load management technique. Cool storage utilizes an inexpensive storage medium with a high specific or latent heat, e.g. water, ice or eutectic salts to store cooling produced during off-peak hours for utilisation during peak hours. Conventional air conditioning chillers or industrial-grade ice making plants may provide refrigeration, which charge the storage tanks during off-peak hours. Circulating chilled liquid from storage through the building's air handling units, fan coils or a secondary heat exchanger provides on-peak cooling. By shifting electricity use to off-peak hours, both utilities and their customers are benefited. Cool storage helps utilities improve load factors, off-peak sales and enable them to defer the need for capacity expansion, whereas the commercial customers lower their electricity bills. Most utilities offer rate incentives to encourage customers to consider this alternative, which has substantially lower life cycle cost, particularly due to longer equipment and system life [Dorgan & Elleson, 1994].

This paper discusses the technical and policy issues involved for large-scale introduction of cool storage air conditioning, particularly in tropical countries, where round the year cooling is needed and in particular instance more than 30% of energy cost could be attributed to air conditioning [Loh, 1988]. The present study demonstrates the methodology as to how to decide

on the peak and off peak rate differential and the optimum threshold of demand charges for a targeted payback period, providing the necessary incentive for switching to cool storage air conditioning. The discussion is preceded by a brief overview of thermal storage air conditioning.

AN OVEREVIEW OF COOL STORAGE AIR CONDITIONING

Apart from the benefits of off-peak rates, cool storage helps to lower operating cost and improve efficiency of the chillers and compressors as they would be operating at full capacity in the night time when ambient temperature is much lower [McCracken, 1984]. Consumers benefit by operating a smaller capacity compressor for long periods at or near its full capacity i.e. more efficiently than some non-storage systems having capacity utilization averaging only about 30%, which drives energy requirements. The savings generated from smaller compressors, pumps, and cooling towers underwrites the extra first cost of the ice storage system. Cool storage is most cost-effective when a high, narrow cooling load profile occurs during the utility's on-peak hours. Moreover, demand peak charges are reduced significantly when the load profile is 'flattened'. Typical high potential candidates for cool storage system are office buildings and retail outlets, while hotels or factory premises where air conditioning is needed round the clock are not suitable for cool storage as their cooling loads are distributed throughout the day and night [Gatley & Riticher, 1985]. Fig 1 shows the principle of storage cooling system. Two additional benefits of cool storage air conditioning are a) option of combining chilled water storage and fire
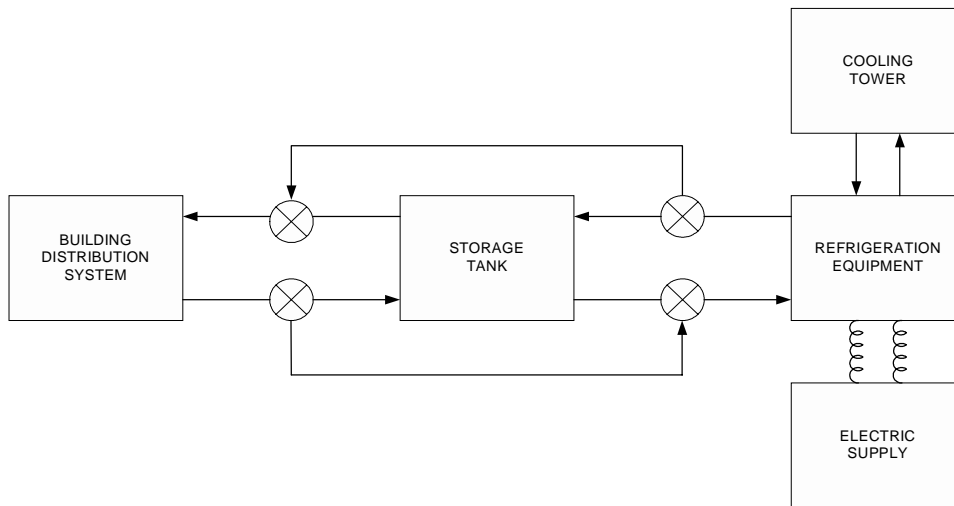
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Figure 1 Principles of storage cooling system

protection storage [Holness, 1993] and b) in the case of ice storage, opportunity to use cold air distribution system that result in a smaller air conditioning distribution system and fan coil units which make up the difference for the extra first cost [Dorgan & Elleson, 1989; Landry & Noble, 1991]

Operating Modes

There are two basic ways a thermal storage system can be sized and the charging and discharging of a thermal storage reservoir can be controlled -a) full storage (load shifting), and b) partial storage (load levelling). Figure 2 shows the cooling load profiles in conventional, partial storage and full storage systems.
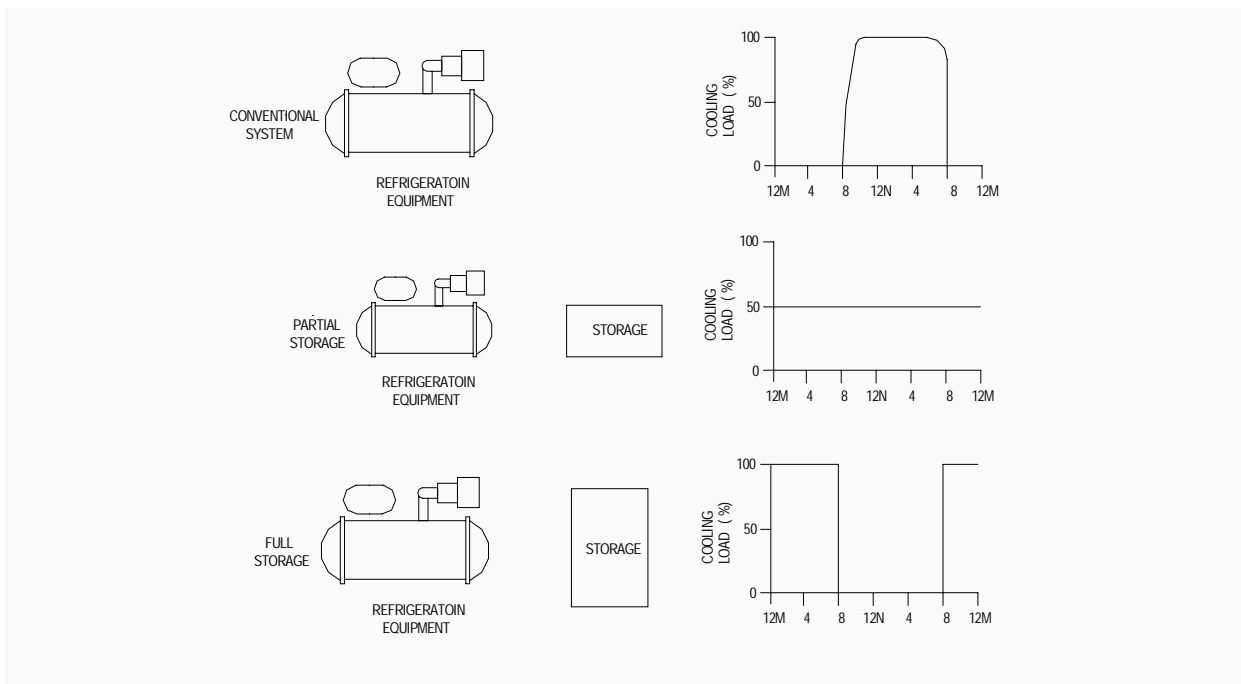

Fig 2 Cooling load profiles in conventional, partial storage and full storage systems

Full storage (load shifting) system

Under this operating mode, the refrigeration equipment charges the storage during the off peak hours and the cooling load is met from storage during the peak period. The advantages of full storage are simplicity in design, maximum reduction in energy bill and simple controls suitable for use with existing refrigeration

equipment. The storage capacity as well as the equipment capacity, however, is the largest and the first cost is highest.

Partial storage (load levelling) systems
These are the more commonly installed thermal storage system. In a partial storage design, the compressor continues to run during on peak hours, but unloaded to

some determined electric demand. On hot days, cooling is provided by both the storage and directly from the chiller/compressor. On moderate days, the storage may be able to satisfy the entire cooling load. Normally, partial storage systems are sized for 50%, but this figure can be varied to suit specific conditions.

Cooling Storage Media
Three different types of medium used in cool storage systems are: a) chilled water, b) ice, and c) phase change materials (PCM)

Chilled Water Storage
This system uses the sensible heat capacity of water to store cooling energy. In chilled water storage systems the storage water is typically chilled to 4.5 to 5.5°C and stores about 46.6 kJ/kg. Water storage systems can use the same reciprocating or centrifugal compressors that are used for conventional chillers, because the evaporator temperatures needed to chill the stored water are within the same design limits. Because of overall simplicity in design, control installation and maintenance, naturally stratified chilled water system used to be one of the most commonly used systems in the US in the early 80's [ASHRAE, 1984].

Ice Storage Systems
These use the latent heat of fusion to store the required cooling energy and, therefore, utilise lesser space (one fourth to one sixth) to store the required cooling energy as compared to chilled water system. The ice systems have to operate at lower evaporating temperatures (–9 to –3°C), resulting in lower coefficient of performance of the refrigerating plant. In a 1993 survey in USA, it was found that 86.7% of systems employed ice storage systems, despite the fact that its average installation cost was 104.54% higher than chilled water storage and 25.87% higher than eutectic salt storage systems [Potter et al, 1995]. There are two types of ice storage systems: a) **static or ice-on-coil** systems, where ice builds on the heat transfer surface (coils), and b) **dynamic** or **ice harvesting** systems, where ice is periodically removed from the heat transfer surface and deposited into storage reservoirs in crushed or chunk form. Water is then circulated through the reservoirs as needed to meet the building cooling loads.

Phase Change Materials Systems
These are similar to ice storage systems in that they utilize the latent heat of fusion of a solid to store more cooling energy in a given space and, hence, requires less space than chilled water systems of same capacity. The most common phase change medium used is eutectic salt solutions, which freeze at around 8°C, a temperature level that does away with the need of low evaporator temperature required by ice systems.

System Optimisation & Control Strategies
Cool storage air conditioning require careful control of electric demand at the chiller to minimize energy cost in each billing period. Sizing ice tanks and chiller are important and so are the proper control strategies. Care is required also in the matching of storage to chiller for each operating mode. Climate and utility rate structures are basic information for an optimum system design. The daily building load profile needs to be established to determine the chiller size. Ice storage should be used where there are large differences between day and night electric rates. Carey et al (1995) proposed a design procedure to properly size an ice-storage tank for any load profile. It is based on a steady periodic simulation and requires as input the design-day building load and weather profiles. A chiller, with a capacity of only about 40% to 50% of its standard system counterpart, runs at its peak efficiency during the day and for enough hours at night to recharge the ice storage. Considering that partial ice storage systems are the most common types in use, it needs to be decided as to which of the following control strategies to be adopted, prior to sizing the chillers.

Chiller Priority Control
In a chiller priority control of glycol-based ice storage systems, the chiller is made to operate at full capacity during the day, subject to limitations of the building load, and the ice is only melted when and if the load exceeds the chiller's full capacity. This method of control is very simple, since the normal chiller control function can be left intact. Its undesirable feature is that the ice meltdown is not controlled to achieve maximum demand reduction for the air conditioning system.

Ice Priority Control
Ice priority control is a strategy in which the chiller, which acts more as a backup, is made to operate as little as possible during the day which maximizes the demand reducing potential of the ice tanks. Despite the fact that ice priority storage is more desirable from energy savings point of view, its use is relatively complicated because of the difficulty in accurate prediction of the next day's cooling loads.. If the next day's total thermal load could be predicted, it could be possible for the system to charge the appropriate amount of energy in the tank during the previous night

Constant Proportion Control
Under this control philosophy, neither the ice nor the chiller receives priority in responding to the load, rather the ice tanks and the chiller each handle a certain percentage of the building load, which remains constant under all load conditions [Rawlings, 1985].

PROSPECTS OF COOL STORAGE IN TROPICAL COUNTRIES

Current Status
On the Asian scene, Japan, Taiwan and Hong Kong with relatively developed economy have taken the lead in the usage of thermal storage air conditioning. It is interesting to note that Hong Kong has a tariff rate specially meant for ice storage system. There is no

charge for demand up to the level of the demand during 0700 to 2300 hours. This rebate is only available to ice storage system and to the largest 300 bulk tariff customers. Fig 3 shows graphically the difference in peak and off-peak electricity tariff rates and Table 1 lists the demand charges in a number of countries in Asia.
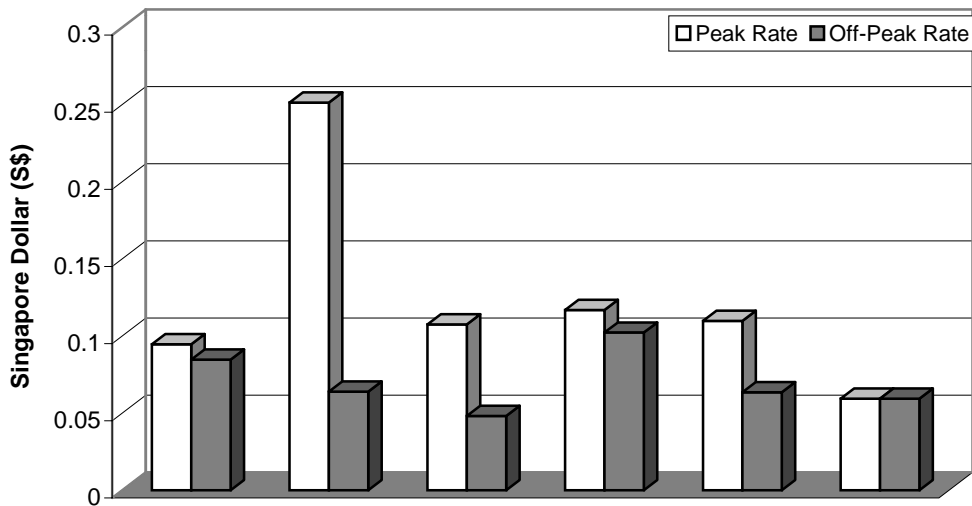

Fig 3. Peak and Off-Peak electricity tariff rates in some Asian countries

Table –1: Electricity Demand Charges in some Asian countries*

Country	Singapore	Japan	Taiwan	Hong Kong	Malaysia	Thailand
S$/kW/mo	8.00	21.975	9.79	11	12.5	3.5-16.9!

! Based on the time interval (3 times interval) # Conversion Rates based on Strait Times value dated 19.2.97
* Tariff rate (February 1997) sources are from Internet sites of various electricity companies

In Singapore the rebate for electricity tariff for off-peak hours are merely 10.6% as against 0% in Thailand 74.6 % in Japan and 55.2% in Taiwan. Furthermore, demand charge in Japan and Taiwan are 174.7 % and 28% higher respectively than that of Singapore. So obviously, while there is huge incentive in switching to cool storage air conditioning in Japan and Taiwan, justifiably, to date no thermal storage system is in use in Singapore. In Thailand there is no off peak rates and as such the issue is virtually dead If the rates are compared between two neighbouring countries of Malaysia and Singapore, it is observed that rebates in Malaysia 297.2% higher than in Singapore and the demand charge is 56.25% higher.

Case Study

A study was carried out for a six-storey office building in Singapore, where there is need for year-round air conditioning, to ascertain the feasibility of cool storage air conditioning vis a vis conventional system. Ice storage system was considered for 50%, 60%, 70%, 80% and 100% storage. The lowest pay back period was 14.8 years for 60% storage while that for 100% was 22 years. Obviously in view of prevailing tariff structure, switching to cool storage air conditioning was not a desirable proposition. Applying the tariff rates and demand charges of Taiwan, however, the pay back period reduces to mere 5 years. The study points out the fact that additional investment is viable with user-friendlier tariff incentive. Figure 4 shows how payback period varies with percentage discount between peak and off-peak rates for various demand charges for a typical storage (50%). Figure 5 shows how with existing tariff rates, varying demand charges affect the payback periods.
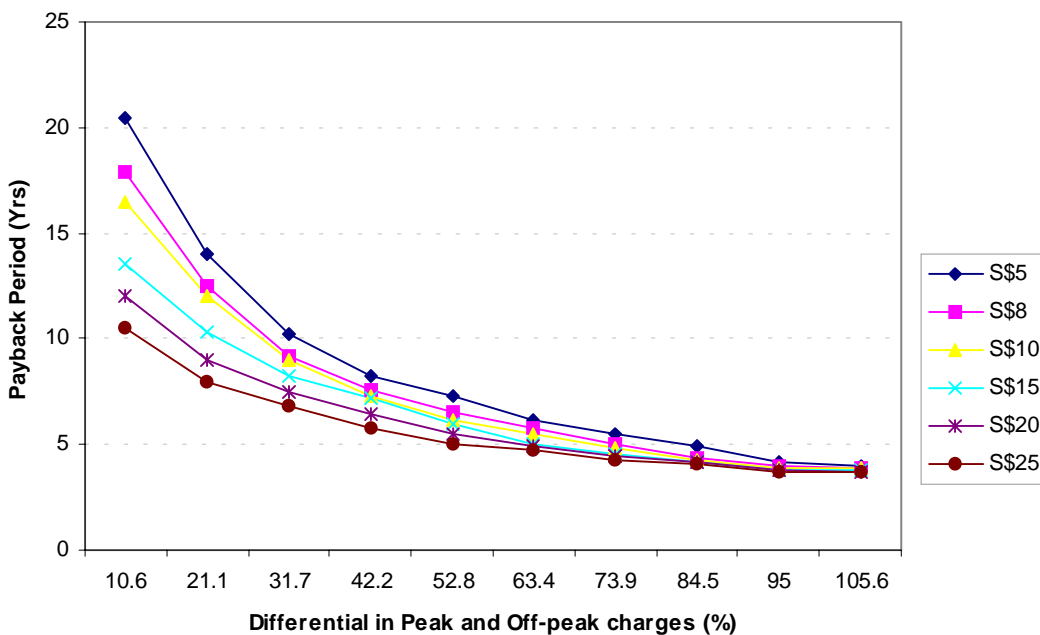
Fig 4. Graph of payback period vs. percentage discount between peak and off-peak rates for various demand charges (50% storage)
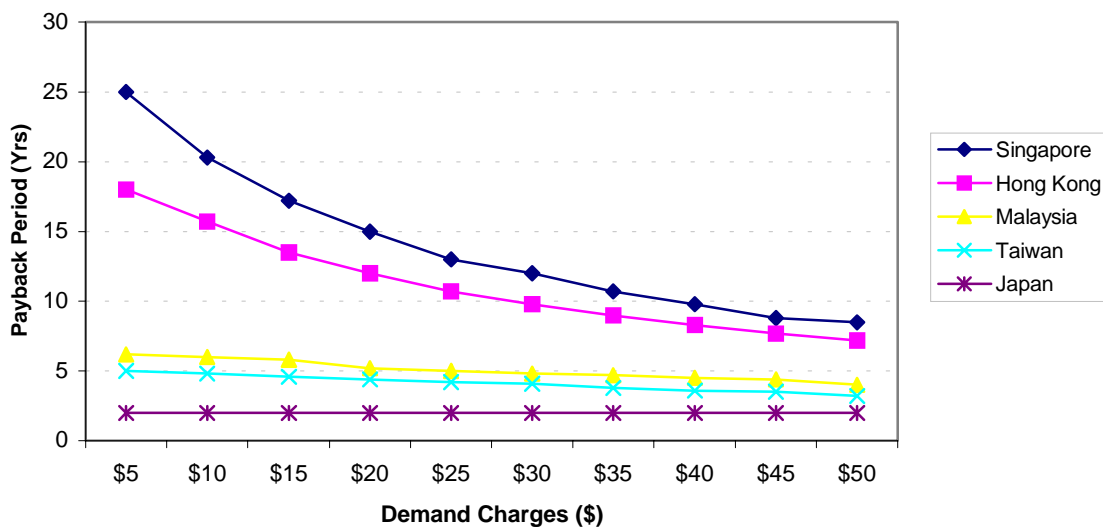

Fig 5. Graph of payback period vs. demand charges for various Asian countries (100% storage)

Recommended Policy Guidelines

The study indicates that some user-friendly policies in respect of tariff need to be in place to provide the necessary incentive for consumers to switch to cool storage air conditioning. The relevant measures recommended are:

1. Introduction of time of use charges
2. Levying higher demand charges
3. Increasing the differential between peak and off-peak charges

Referring to similar graphs as Fig 4 & 5, appropriate tariff differential and/or level of demand charges can be chosen based on the payback period targeted. Alternatively graph similar to Fig 5 can be referred to

for arriving at decision for revising demand charges without changing current tariff structure.

CONCLUDING REMARKS

For tropical countries electricity bills for air conditioning is much higher because of the fact that it is needed virtually round the year and secondly load is higher because of higher ambient temperature. So reducing electricity charges for consumers is a pressing need and so is deferment of capacity expansion for suppliers of power. Switching to cool storage air conditioning is a win win option for both consumers and suppliers of electricity. However, large-scale thermal storage air conditioning would only be viable when substantial rebate for electricity usage during off-peak hours is available and higher demand charges are levied. The present study demonstrates the methodology as to how to decide on the peak and off peak differential and the optimum threshold of demand charges for a targeted payback period. In a specific case study, payback period for 50% storage in a Singapore project reduces from 22 years to less than 5 years when tariff structure of Taiwan is applied.

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