USE OF THERMAL ENERGY STORAGE IN COMMERCIAL AIR CONDITIONING SYSTEMS

by

P.K.P. Fernando and Sunil Cooray

1.0 Introduction

With the dwindling sources of global energy, the predicament faced by industries and enterprises hardly needs any emphasis. Peak electric power is short worldwide, because new generating plants will be so expensive to build and operate. With proper application of energy management techniques,it is possible to reduce the peak demand loads imposed on existing generating stations. As air conditioning services is a major consumer of power, any effort to reduce the peak demand for air conditioning will bring about a reduction of the overall peak demand.

At present, Sri Lanka has an installed capacity of 1409 MW with a maximum demand of 812 MW,according to the C.E.B.annual statistical digest 1993.For the year 1992, 28% of the electrical power sold,has been consumed by Commercial and Government buildings. This has been 812 GWh at a cost of Rs. 2100 Million. [1].

Reduced demand charges will be a relief to the generating machines. To the building owner,this will result in lower equipment cost, lower connection charges, and lower operation and maintenance charges. Typical electrical tariffs are shown in table 1.

This paper attempts to introduce thermal storage as a future method to effect load shifting to off-peak hours and load levelling to base values as applied to commercial air conditioning systems. Although off-peak air conditioning using thermal energy storage,has been in use in the developed countries for the last ten years, this will be a technology completely new to Sri Lanka.

2.0 Air Conditioning Loads

Advances in technology has brought about in its wake, an elevation of the socio-economic conditions. In an ideal society ever grateful to the technological revolution,a person may be born into this world in an air conditioned hospital, dine, sleep, and wake-up in an air conditioned residence, travel to work in an air conditioned car,work in an air conditioned office and may even have his dead body preserved in a controlled atmosphere! Rather than a luxury, air conditioning is fast becoming a necessity. Enterprises such as banks, hotels, hospitals, shopping malls, high rise condominiums etc., rely heavily on air conditioned comfort to sustain the productivity, aesthetic interiors, mental attitude of inmates, quality service facilities etc.. Sudden failure of air conditioning at such places will make people panicky and some may even go berserk.

In Sri Lanka the heaviest consumption of energy in large buildings is for air conditioning. According to one source [2], air conditioning loads constitute about 40%-60% of the total electrical load. A recent study using past patterns of power consumption estimates the demand for air-conditioning to be about 253,800 Tons Refrigeration.[3] (one Ton of Refrigeration-TR-corresponds to a cooling demand of 3025 kcal/hr or 12,000 BTU/hr).

Energy efficiency ratio (EER) of an air conditioning system is defined as the energy output in BTU/hr per Watt of energy input. At an overall EER of 13.0 typical for a commercial air conditioning system, the above cooling demand of 253,800 TR calls for an electrical energy level of about 235 MW. i.e. about 16% of the total installed capacity of the country. As the above study has been based on the CEB annual statistical digest of 1993, the figure might now be much higher,as the result of the boom in the construction of large buildings and opening of new industries of late.

Air conditioning demand in a building changes by the hour, depending on the occupancy,related activities,building orientation etc. A maximum or peak load occurs once in a daily cycle. An air conditioning chiller is selected to match this peak. It is an established fact in air conditioning,that during a

Eng. P.K.P.Fernando, F.I.E.(SL), C.Eng, M.ASHRAE., AM.Prod.E., Chief Engineer, Sealine Beach Resort, Qatar.

Mr. Sunil Cooray, *M.ASHRAE., AM.AIRAH., AM.Int.Inst.R., Technical Manager, Ground Source Energy (Pvt) Ltd.*

vast majority of its operating hours,a chiller operates at part-load.A common criterion for comparing part-load performance of different makes of chillers has been established by the Industry and is known as IPLV or Integrated Part Load Value.

$$IPLV = \frac{1}{[\ (0.17/A) + (0.39/B) + (0.33/C) + (0.11/D)\ ]}$$

where

A	=	kw/Ton	at	100%	full Load
B	=	kw/Ton	at	75%	full load
C	=	kw/Ton	at	50%	full load
D	=	kw/Ton	at	25%	full load

Selecting a chiller with a low IPLV matching closely with the cooling demand curve has been the usual method. However with the introduction of variable speed centrifugal chillers,a 30% annual reduction in power is claimed by the manufacturers.When load shifting and load levelling (load lopping) techniques are introduced in to the conventional air conditioning system, a further saving in power is possible.

3.0 Load Shifting and Load Levelling

For demand energy management in air conditioning systems using thermal storage,the chiller is used to make ice during off-peak hours. This ice is stored in a thermal storage tank. Water is an appropriate phase-change material used for such purpose.

A typical cooling load demand curve for an office building is shown in Fig.1. In energy management terminology as applied to air conditioning systems, the demand is expressed in Tonhours rather than Tons. Referring to Fig. 1, the demand Tonhours between 9 A.M and 10 A.M will be 50 Tonhours; that between 4 P.M and 5 P.M., 80 Tonhours. Capacity of a thermal energy system is also expressed in Tonhours.

In the demand curve, the peak occurs between 2 P.M and 3 P.M. In a conventional design, a 120 Ton chiller is selected to cater for this peak. Apart from the peak at 2-3 P.M, it is seen that at other times the selected chiller would operate at part load, the lowest being 41% full load, between 8-9 A.M. For this reason a diversity factor can be applied, which yields the diversity as 0.68.

It has to be remembered that during the time between 7A.M. and 5 P.M.(through 12 noon) when the above cooling is demanded, other facilities such as lighting, water, steam, ovens, laundry, office machines, etc., are also demanding power. If a method could be devised to shift the cooling load (totalling to 920 Nominal-Tonhours), to be catered by thermal storage build-up during offhours,this becomes an effective method of energy management. During demand hours for air conditioning, the cooling medium such as circulated water can get chilled by circulating through the ice bank and can feed air handlers, fancoil units etc,in the usual way.

Another scenario for load shifting to off-hours is shown in Fig 2. This is called full thermal storage because the full demand is met by the thermal storage tank alone and the chiller does not operate at all during the demand hours. In this instance the cooling load is shifted to off-hours of 5 P.M to 7 A.M (through midnight) and the load is levelled of to 65.7 Tons.Since the total Tonhours of thermal storage is (65.7 x 14) hours, equal to 919.8 Tonhours this will be normally adequate to meet the imposed demand of 920 Tonhours.

Due to this load lopping,the chiller required is only 65.7 Tons capacity, as compared to the 120 Ton chiller selected by conventional design resulting in 45% reduction in terms of the required capacity.Cost benefits in first purchase value of chiller and ancillaries, operating/ maintenance cost reduction are some obvious advantages.

Another load levelling pattern is shown in Fig.3. Here an appreciably lower chiller of 38.3 Ton capacity will run continuously and;

(a) charge the ice storage during the off hours
(b) cool the load during the demand hours with assistance from the thermal energy storage tank.

The installed chiller capacity is now reduced by 68% over the conventional design. This type of system is called a partial thermal storage system to distinguish it from the full storage system. Partial storage lends itself to further expansion of existing systems without resorting to new chiller purchases. This system can also be used to enhance cooling capacities in an otherwise underdesigned system,or to retrofit thermal tanks into depreciated chiller systems to upgrade the cooling capacity without purchasing a new chiller.

4.0 Thermal Storage Technology

The principle behind thermal storage is so simple that one really wonders why it took such a long time to get 'discovered'. Some others are skeptical about its use. Of course the larger the system Tonnage, the larger is the cost benefit. At one time the worlds' largest eutectic thermal storage system installed at Mc Donnell Douglas Co.in Arizona,U.S.A., had a thermal storage capacity of 10,000 Tonhours. The peak demand summer cooling load is 4200 Tons from which 2200 Tons is handled by the thermal storage tank. In 1991 the $1 Million installation was designed to achieve a simple pay-back period of 4.3 years.[4]

Rather than the use of water-glycol solution to build up ice banks in tanks, nowadays, eutectic salt with 8.3 C phase change temperature is used. This temperature allows the use of normal 4.5-5.5 C chilled water, for charging. Storage space needed by eutectic salts is about 40% less when compared to an ice bank storage tank. Eutectic salts come stored in durable impermeable container packs made of high density polyethylene. Minimum space requirement for eutectic packs is about 0.17 cub.metres. per Tonhour. Eutectic packs do not change in volume during phase change. Chilled water from central chiller flows in to the storage tank between the packs and freezes the eutectic salt. During the demand hours, system water gets circulated through the tank and gets chilled by the thawing storage system.

Thermal storage tanks could be located under large parking spaces, landscaped terraces or overground. Tanks can be of all-welded steel construction, aluminum jacketed with a 5 cm.thick polyurethane layer in between. Concrete tanks has also been constructed.

Direct Digital Control using various temperature sensors, modulating valves, flow sensors, sequence controllers etc., are freely used in the storage system.

During charging, the tank is connected in series with the chiller. When simultaneous charging and cooling is done, the tank is in parallel with the building load. In thermal storage systems, extensive use is made of primary and secondary pumping loops which yield energy saving when the system load requires different dynamic heads to cater for varying chilled water flow. One of the pumps in the secondary loop is operated through a variable speed drive to modulate the chilled water flow.

Some operational aspects common to all thermal storage systems are:-

(a) Chiller producing the cooling may directly service the building cooling load and/ or divert excess cooling to the storage tank.

(b) Storage tank may either accept excess cooling capacity from the chiller or supply cooling to a load.

(c) Building load can accept cooling from the chiller or from storage tank or from both.

When a chiller designed for chill water production at 6.6 C, operates to charge a storage tank, its efficiency will drop. For this reason, chiller capacities has to be 'derated' when estimating the storage Tonhours.

In the example referred to in the graphs,when actual Tonhours = 920; if the 'derating' factor is taken as 0.7 the nominal chiller size required for a partial thermal storage with 10 hr cooling/ 14 hr charging mode will be;

$$\frac{920}{(14 \times 0.7 + 10)} = 46.5 \text{ Tons or } 50 \text{ Tons nominal}$$

Required storage Tonhours would be (920 - 50 x 10) or 424 Tonhours needing about 72 cub.metres of tank space and 106,000 kgs of eutectic salt.

5.0 Some Operational Features

For direct digital control purposes, it is worthwhile to note that during storage tank discharge, the temperature of chilled water will not be constant. At the start of the discharge mode, the tank leaving water will be at 5.5 C which will gradually rise to 8.3 C. The phase change temperature will remain constant for some time until all the salt has thawed. The ultimate control limit for the leaving water is 10 C. To ensure that the water return to the chiller is at 10.5 C, a modulating valve will vary the flow. As the tank discharge water varies between 5.5 and 8.3 C, individual modulating valves normally fitted across each terminal units will also modulate the flow accordingly to ensure proper cooling of the space.

Schematic diagrams for three of the more common operations for thermal energy storage is shown in the Fig.4. The abbreviation used are:-

CHL	- Chiller	TUS	- Terminal Units
TES	- Thermal storage tank	PP	- Primary Pump
SP	- Secondary Pump	BP	- Booster Pump
CHWR	- Chilled water return	PCM	- Phase change material

1) In Fig. 4a, the chiller is in series with the tank and operates to charge the system. The sole purpose of this arrangement is to build the ice bank during offpeak hours.For a 424 Tonhour tank to be fully charged in 8 hrs, with a 3.3 C temperature differential,the booster pump has to be set for 810 l/min.

2) In Fig. 4b, during daytime cooling mode, the tank precools the water returning from the terminal units. Chilled water return has several paths:-

- CHWR at 14 C mixes with water returning from storage tank (exiting between 5.5-10 C). Mixing occurs at point A. Modulating valve downstream of the booster pump maintains the temperature of the mixture at 10.5 C.

- CHWR at 14 C feeds directly to the storage tank exiting at 5.5-10 C.This temperature variation is due to the thawing out of the phase change material.

- CHWR at 14 C mixes with 6.1 C chilled water before entry to secondary pump. In actual practice, a bank of secondary pumps will be used, one of which will be a variable speed pump controlled by the pressure differential between chilled water supply and return. In this instance 6 C water from the chiller and 14 C chilled water returning will mix together.The temperature of the mixture will be controlled by the variable speed pump so that the chilled water will enter the terminal units at 7.5 C.

  Note that the chiller operates at a constant capacity,since the water returning to the chiller is maintained at 10.5 C and the primary pumps are of constant speed drive.

3) In fig.4c, for simultaneous cooling of the space and charging of the thermal storage tank,the tank will be in parallel with the chiller. When the booster pump is set for 810 l/min,and if a cooling load of 50 Tons exists, the primary pump should run at a water flow rate of 1155 l/min.

Some properties of phase change materials is given in table 2. Even in as early as 1975 H.G. Lorsch recognized the benefits of thermal storage but was unable to find a phase change material at that time. The concept of thermal storage developed rapidly due to the recent developments in the phase change materials.

6.0 Conclusion

Thermal energy is in worldwide use now. Well defined and established design procedures are available in the HVAC industry. No apology is made for collating various sources of data on thermal energy storage,as this is an idea new to the local engineering community. It is hoped that we have created enough interest into the concept of thermal energy storage so as to encourage someone to generate much heat and light on the matter.So that in the near future, thermal energy storage concept will be taken up by planning engineers, architects and energy managers of this country.

7.0 Acknowledgements

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8.0 References

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Table 1 - C.E.B. Tariff (1994)

Other categories	General Purpose	Industrial purpose	Industrial purpose (Time of day)	Hotel purpose	Hotel purpose (Time of day)
Supply at 400/230V Contract demand less than 50 kVA	3.65	2.76	2.21	3.64	
Unit Charge (Rs/kWh)	4.05	3.05	2.30 (off peak) + 6.40 (peak 6 pm) to 9 pm	4.05	
Fixed Charge (upto 10 kVA) Rs.	+ 33 or	+ 33 or	+ 33 or	+ 33 or	
Fixed Charge (above 10 kVA) Rs.	157	157	157	1157	
Supply at 400/230V Contract demand 50 kVA and above	4.30	3.21	3.00	4.15	3.11
Demand Charge/month (Rs/kAV)	196	170	78	196	78
Unit Charge (Rs/kWh)	+ 4.00	+ 2.90	+ 2.75 (off peak) + 6.45 (peak 6 pm to 9 pm)	+ 4.00	+ 2.80 (off peak) 6.55 (peak 6 pm to 9 pm)
Fixed Charge Rs/month	+ 313	+ 313	+ 313	+ 313	+ 313
HT supp.at 11kV,33kV and 132 kV	3.82	2.71	2.80		2.88
Demand Charge/month	183 +	150 +	72 + 2.60 (off peak) + 6.15 (peak 6 pm to 9 pm)	183 + 3.85	72 + 2.75 (off peak) + 6.20 (peak 6 pm to 9 pm)
(Rs/kVA) Unit charge (Rs/kWh)	3.85	2.80			
Fixed Charge Rs/month	+ 313	+ 313	+ 313	+ 313	+ 313

Table 2 - Properties of Phase Change Materials

Properties	41 Eutectic	47 Eutectic	Water
Phase change point C	5.0 - 5.5	8.3 - 8.8	0 - 0.5
Lutant heat of fusion kJ/kg	123	95	334
Density kg/cub.M	11472	1472	1000
Storage density cub.M. per Tonhour	0.113	0.170	0.510
Charging temperature C	1.7	5.0	-3.3
Tank leaving temperature C	4.5 - 5.5	8.3 - 10	1.1 - 2.7

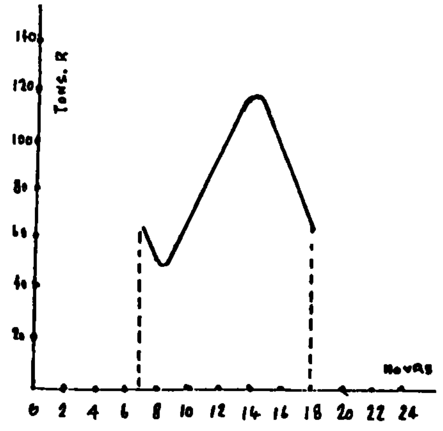

Figure 1 - Cooling Demand Curve

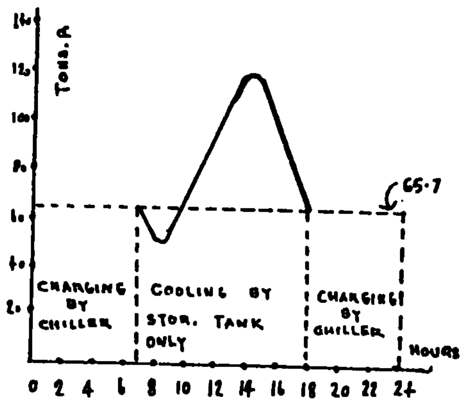

Figure 2 - Full Thermal Storage

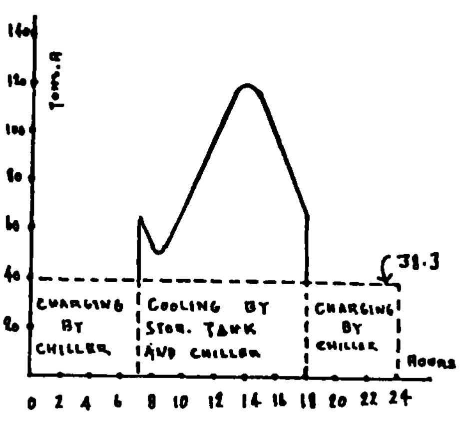

Figure 3 - Partial Thermal Storage

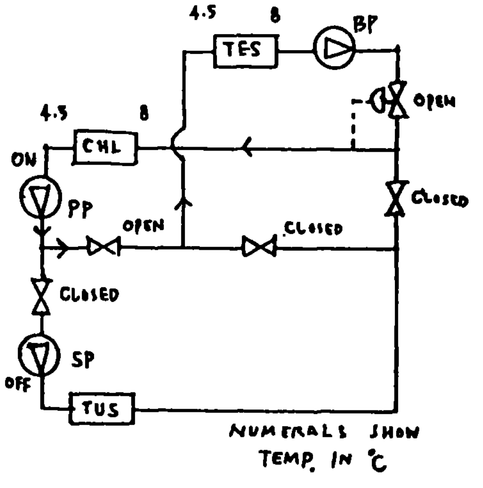

Figure 4a

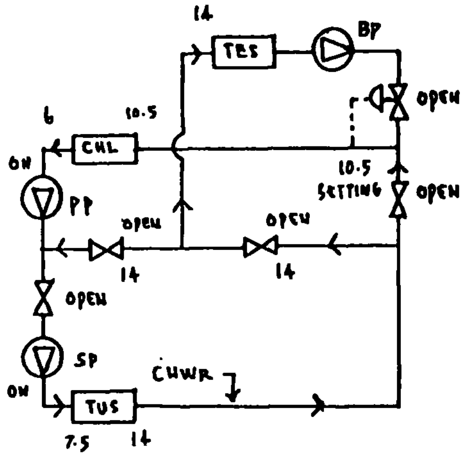

Figure 4b

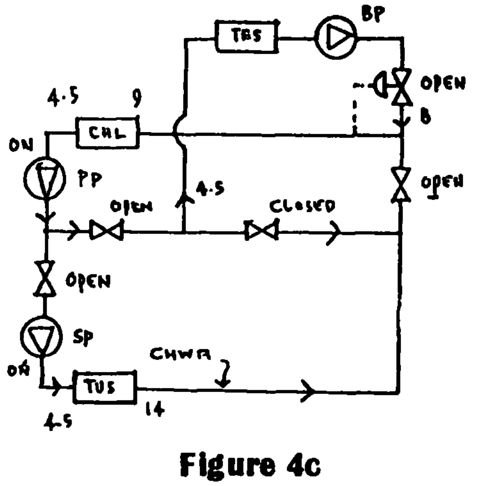

Figure 4c