Volume 17 Number 4

July - August 2014

AIR CONDITIONING AND REFRIGERATION Journal

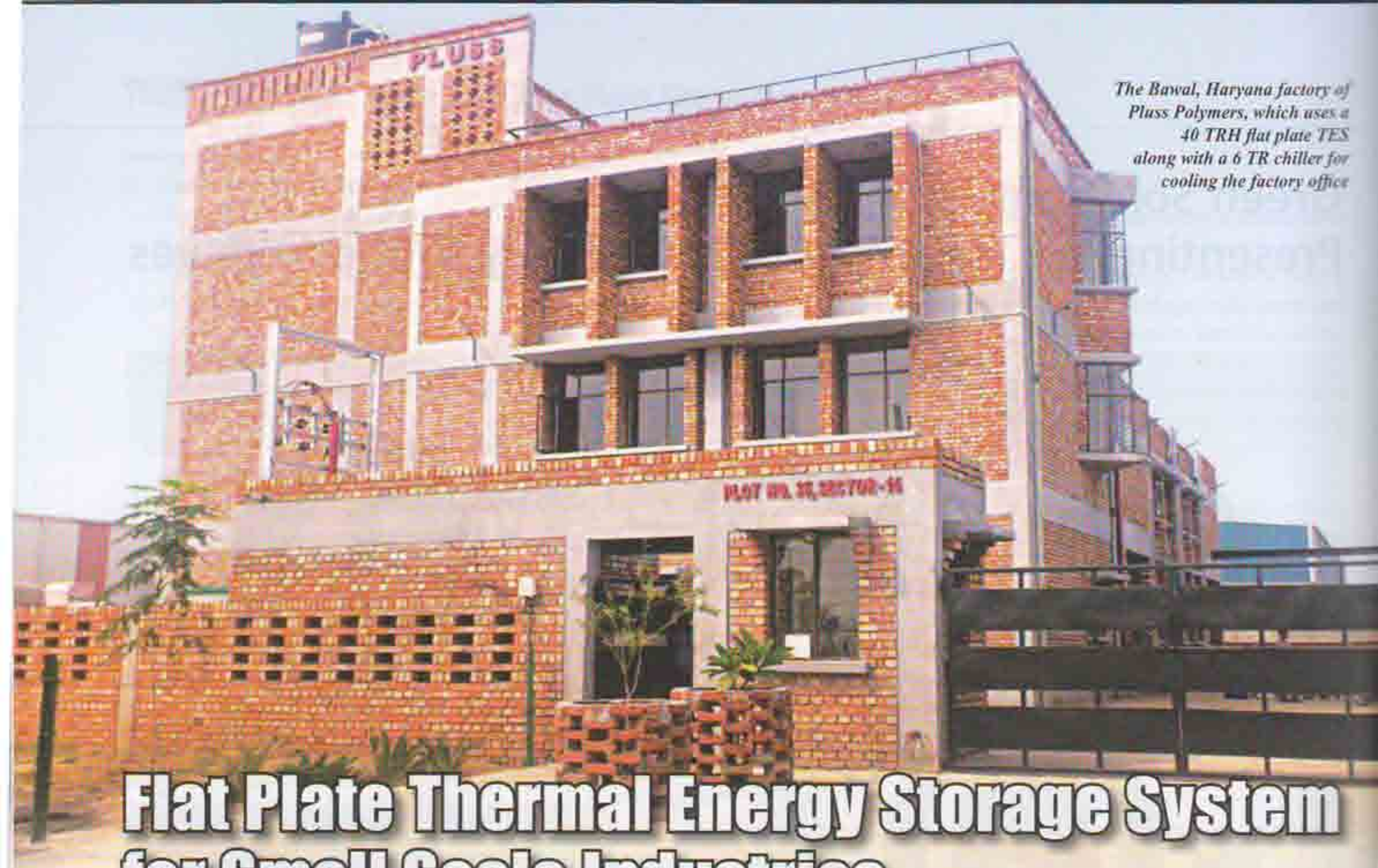
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Thermal Energy Storage Using PCMs

INSIDE

- TES in HVAC Using PCMs
- Flat Plate TES
- TES for Residential Settings
- Fan-Coil Units - Inside Out
- Selection of AHUs - Part 2
- Classroom: Safety Guidelines for HVAC Construction Sites NEW

www.ishrae.in


The Bawal, Haryana factory of Pluss Polymers, which uses a 40 TRH flat plate TES along with a 6 TR chiller for cooling the factory office

Flat Plate Thermal Energy Storage System for Small Scale Industries

By Samit Jain
Managing Director
Pluss Polymers, Gurgaon

Abstract

Thermal energy storage (TES) is an often unrecognized but important component of the developing market for energy storage systems. Most often used to provide cooling capacity for commercial buildings, TES systems are also increasingly seen as an effective means of shifting electricity use from daytime peak periods into less expensive periods of the day or night, saving money and increasing overall system efficiency. Globally, TES is expected to grow substantially through 2020, with worldwide revenues of $3.6 billion and added capacity of 3,824 MW in that year (Pike Research analysis). Newer forms of TES using different temperature phase change materials (PCMs) and advancement in designs to increase the efficiency of storage is the trend. This article attempts to discuss a new type of TES system and its advantages over the present design with a case study.

Flat Plate Thermal Energy Storage

The objective of integrating thermal energy storage in the HVAC system is to store cold/heat energy in the form of latent or sensible heat and release this energy at the desired time. In this article, we will be focusing on latent heat storage which essentially uses a PCM that has several times more energy storage capacity within a given volume as compared to sensible storage solutions. While phase change material itself is an integral part

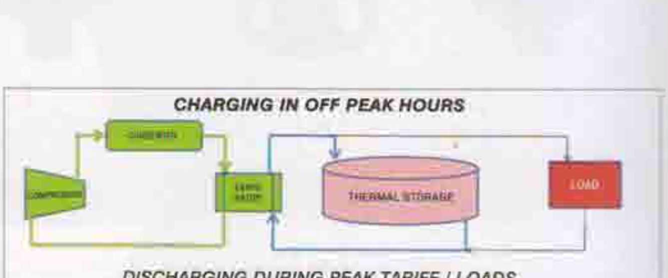


Figure 1: Basic layout of a TES system

About the Author

Samit Jain holds an M.Sc. (Hons.) in Physics and a Bachelor's (Hons.) in Electrical and Electronics Engineering, both from BITS, Pilani. He also holds an M.S. in Electrical Engineering from the University of Hawai'i, USA. He started his career with Tata Elxsi and subsequently worked at Hawai'i and Los Angeles in the area of network communications before returning to India. He has been with Pluss Polymers since 2003, and is currently the Managing Director and heads Marketing and Finance. He is a specialist in TES projects, particularly using PCMs. Samit is passionate about the environment, and is a co-founder and trustee of of Advit Foundation.

continued on page 42

continued from page 40

of the system, the most important factor is the effectiveness and efficiency of heat transfer mechanism which depends on the product design. The name 'flat plate' comes from the fact that the PCM is encapsulated in rectangular cuboid shaped containers. This shape has several advantages over other geometrical shapes in use – i.e. a cylinder or a sphere. The basic layout or the circuit of a TES system *(Figure 1)* may vary very slightly from one system to another.

Advantages of Flat Plates over Other Geometries

A comparison of the three different geometries illustrated in *Figure 2* would show the volume utilization in each case. The grey area represents the PCM formation; the rectangular PCM has a higher PCM density compared with the spherical/ cylindrical formations. Several variations of spherical and cylindrical PCM storage are illustrated in *Figure 3*, in which the light grey area represents the heat transfer fluid and the dark grey area the PCM.

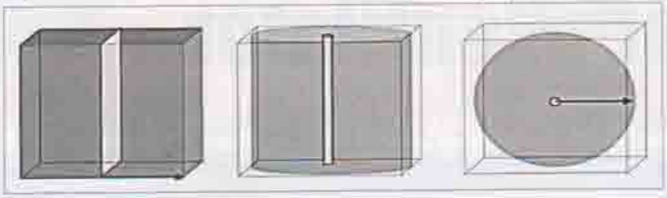


Figure 2: Flat plate, cylindrical and spherical containers

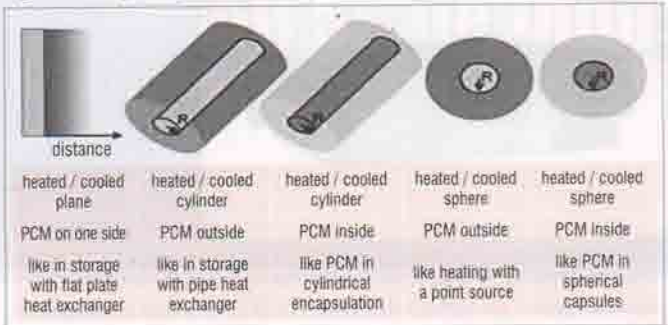


Figure 3: Variations of spherical and cylindrical PCM storage

Studies conducted to test the impact of PCM shape on freezing performance shows that a plane heat exchanger surface is much more effective than a cylindrical or spherical shape. In the graph in Figure 4, the blue, red and black lines represent plane, cylindrical and spherical heat exchanger surfaces respectively. PCM thickness 's' grows the fastest for cooling/ heating from plane/ rectangular geometry than from cylindrical, and the slowest away from a spherical geometry. The location of phase thickness 's' with time relates the heat flux (dQ/dt) to the geometric dimensions. The heat flux or the power of cooling decreases from plane or rectangular geometry to cylindrical geometry to spherical geometry. This is due to the fact that a rectangular geometry has high heat transfer surface to volume ratio. Due to a higher heat transfer area in a rectangular geometry, the thickness of the PCM can be reduced. Lower thickness contributes to higher rate of conductivity as after a certain stage the PCM itself deters the rate of conduction. To compare the difference in the heat transfer ratio between a spherical geometry and rectangular geometry, a comparison was done between two geometries with the same volume. The ratio of the surface area of flat geometry to sphere is 2.26 for the same volume and the reduction in thickness of the PCM is 85% (see *Table 1*), which explains the graph in *Figure 4* that draws a relation between the rate of heat flux and the thickness of the PCM.

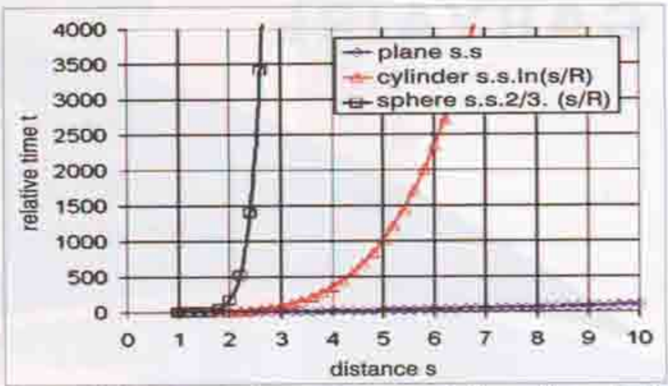


Figure 4: PCM thickness for three container geometries Source: Heat and Cold Storage with PCM, Harald Mehling, Luisa F. Cabeza, Springer Publication

Table1: Heat transfer area and thickness for flat plate and spherical systems

	Flat	Sphere
Size	504mm x 254mm x 38mm	R = 105.5 mm
Total volume (l)	4.916 (0.11TR)	4.916 (0.11TR)
Heat transfer area (m²)	0.32	0 .14
Maximum PCM thickness (mm)	16.12	105.5

A detailed comparison of a flat plate system and a spherical system is given in *Table 2*.

Table 2: Detailed comparison of flat plate and spherical systems

Sr. No.	Parameter	Flat Plates	Spherical Nodules
1	Thermal energy storage, TRH per cubic meters	18.8 TRH per cubic meter latent fixed	11.7 TRH latent fixed
2	Packing ratio	Around 90%	Around 64%
3	Tank volume for a given storage (TRH) value	Lower than nodules by around 27%	Higher than flat plate by around 37%
4	Cost of encapsulation plus PCM, per TRH storage	Flat plat panels have 15% lower cost	Rs. 1350 - 1500
5	Volume of MEG required to fill tank	Lower than nodules by around 83%	Higher than flat plate by around 5 times
7	Surface area to volume ratio (m²/l)	0.065	0.033
9	Penetration distance required for heat transfer	16 mm for 32 mm thick flat plate	50 mm for 100 mm diameter nodules
10	Heat transfer rate	Higher	Lower
11	Charging time	Lower	Higher
12	Discharging time	Lower	Higher
13	Freight and packing costs	Low	High
14	Ease of filling in the tank	Needs time because of arrangement	Faster because no particular arrangement needed

continued on page 44

continued from page 42

Case Study - A 40 TRH Thermal Energy Storage System

The system shown in *Figure 5* and 6, installed in the office at the Bawal, Haryana factory of Pluss Polymers Ltd., consists of a closed tank with flat plate encapsulations containing phase change material with 25% monoethylene glycol as the working fluid. The tank is an unpressurized MS tank with powder coating. It contains diffusers and baffles to ensure ideal flow distribution for the system. Additionally, the power connections, motors, pumps, fans, chiller unit and the PLC controller are housed within an external rectangular body. The control panel is mounted on the outer body of the unit.

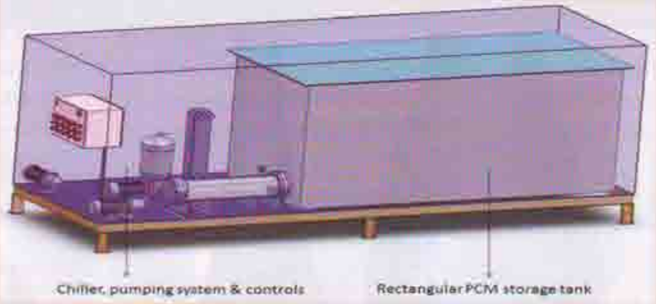


Figure 5: Schematic of a flat plate system

The TES system acts as a thermal battery to store cold energy during non-office hours. This thermal battery discharges either when air conditioning load is at a peak or the cost of operating the chiller (DG operation) is high. The system depicted is fully automatic and operates in two basic modes:

Figure 6: 40 TRH flat plate TES system installation with a 6 TR chiller

Charging

The TES tank with flat panels is charged using -50°C brine. Brine at set temperature is generated by 6 TR chiller and circulated through TES tank for charging the flat panel. The charging process stops automatically when the set temperature is reached inside the tank.

Discharging

During office hours in the factory, discharge mode starts based on FCU signal (at least one FCU ON signal). Based on the signal, brine pump starts to circulate brine through the respective FCU. This begins to pull down the temperature and to maintain the set temperature.

The system is designed to automatically adapt to the load when the demand changes. There will be higher loads during certain times due to unanticipated temperatures or occupancy. The storage augments the cooling power of the system by up to 50%. Even when there is no power available, the system provides several hours of backup capacity using a PCM based battery, which obviates the need to run a diesel generator. The system also has the flexibility to be charged using cheaper power, typically at night. *Figure 7* illustrates the sample load capacity anticipated for the two offices combined. The graph shows power cuts between 1600 and 1800 hours (2 hours).

For such a facility, the system will work as shown in *Figure 8*. During office timings, it will augment the capacity of the system since the load is higher than nominal. During the operation of the DG, it will switch off the main unit and start running the backup operations automatically, thereby using power almost equal to a couple of fans.

Figure 7: Load and power cost profile

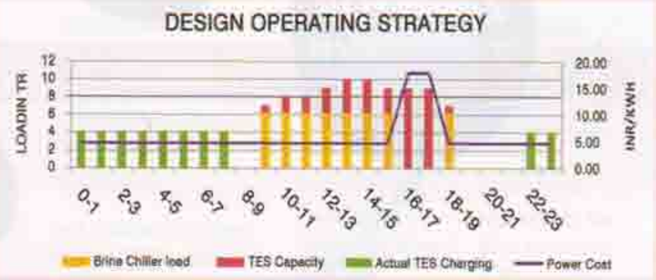


Figure 8: Design operating strategy

Detailed specifications of the thermal energy storage system based air conditioning system are given below. The air conditioning design capacity was 9TR while PCM storage enabled downsizing of the chiller capacity to 6TR. The balance 3TR is produced and stored during the night to take care of any additional load above 6TR and also power failure.

- Air conditioning load : 9 TR (design)
- Chiller capacity (AC) : 6 TR (compressor: Emerson Copeland make)
- Chiller capacity (charge) : 4 TR
- TES tank capacity : 40 TRH (encapsulated flat panels: 480 nos.)
- FCU : 6 nos., brine chilled (1.5TR each)
- Refrigerant : R404a
- Electrical connection : 3 Phase, 415 V
- Fully automatic using PLC
- Primary pump (P1) : Without variable frequency drive
- Secondary pump : With VFD

continued on page 46

continued from page 44

Flat Panel - a Compact System

The above advantages make this system very compact and suitable for a wide range of capacities starting from as low as a 40 TRH system. The PCM storage tank and the chiller unit together are packed in a rectangular cabinet, which makes it installation friendly occupying minimum space in a plant room, outdoor area or even the terrace. A typical flat panel containing a 1°C PCM has the dimensions 500mm x 250mm x 38mm, with a volume of 3.3l. Each such flat panel can contribute to 0.11TR of storage capacity. The flat panel (see *Figure 9*) has protrusions, which maintain an optimum distance between two stacked panels, thereby allowing flow of the heat transfer media, which is a glycol and water mixture. It is designed to offer consistency of flow rate and to ensure that the entire surface contributes to the heat transfer between the PCM and transfer media.

Figure 9: Flat panels have protrusions to maintain distance between panels

Power Tariff Policy and Cost Saving Opportunity

In many parts of India, time of the day (TOD) tariff is now applicable. The objective is to reduce the peak load demand. Power generation capacity is limited and the government is introducing incentives to promote the use of electricity generated smartly. With differential tariffs according to the time, TES is poised to play a very important role to save costs as well as contribute towards managing India's electricity demand. Using TES, one can store the amount of cooling required when the tariff is low and use it when the tariff is high, thereby reducing electricity costs and shifting demands of electricity. Also, during power outages one saves by not using DG for running HVAC systems, further reducing the cost of electricity.

Given below is a brief case study of a commercial mall of approximately 1000TR air conditioning capacity, to show how the electrical load shift happens.

Option 1: 100% Chiller System

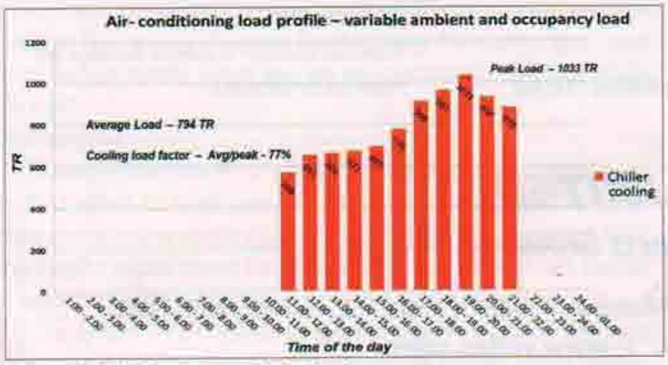


Figure 10: HVAC requirement in Option 1

Option 2: 52% Chiller + PCM Storage

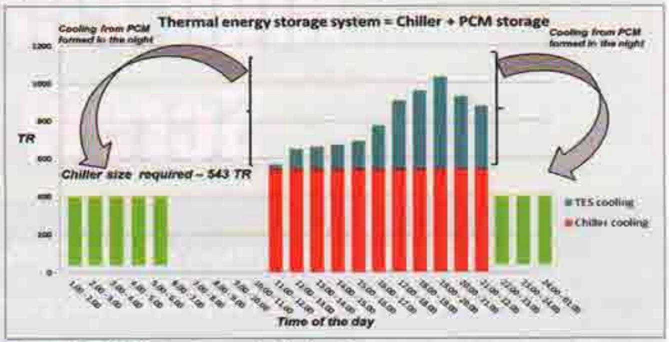


Figure 11: HVAC requirement in Option 2

A comparison of the connected electrical load of these two systems shows that there is a reduction by 42% for Option 2, which means lower electrical demand for HVAC system, smaller DG sets and downsized equipment as shown in *Table 3*.

Table 3: Comparison of connected electrical load between Option 1 and 2

	Conventional system (kVA)	System with Thermal storage (kVA)
Chillers	963	489
Primary Pumps	56	69
Secondary Pumps	111	109
Condenser Pumps	123	61
Cooling Tower	41	20
Total Power (kVA)	**1294**	**748**

The reduction of 42% in the HVAC system corresponds to more than 20% reduction in the connected load of the entire mall, which is illustrated in *Figure 12*.

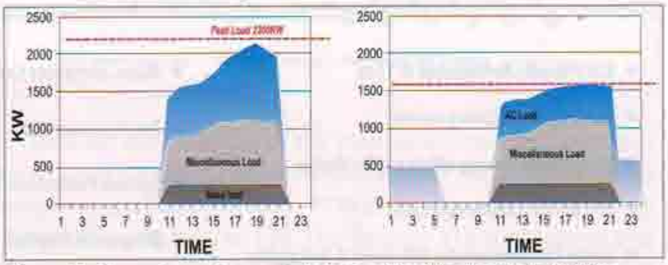


Figure 12: Comparison of connected electrical load for the whole building

For the end user, this reduction in the electrical load translates to a saving of 30% in the annual bill for the contractual electrical demand.

Conclusion

With the objective to reduce peak load demand for better demand management, time of the day (TOD) power tariff is being used as an instrument to incentivize smart use of power. With differential tariffs based on TOD, thermal energy storage is poised to play an important role. Flat plate TES systems using PCMs have an edge over other geometries for achieving this objective.

❖