A REVIEW ON THERMAL ENERGY STORAGE IN HEATING, VENTILATION AND AIR- CONDITIONING

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Abstract: In this paper, a detailed study on the various process of storing thermal energy in Heat Ventilation and Air-Conditioning (HVAC) is carried out. Methods including sensible heat storage, latent heat storage and phase changing materials are carried out. Detailed comparison of the Sensible and latent heat storage is given, in which the latent heat storage is proven to be beneficial. The constraints of each methods are discussed which contribute to the betterment of the thermal storage. The applications based on the requirement of the storage are discussed, which gives the required payback time on proper installation. The applicable payback limit is also mentioned along with the different operational strategies. The operational strategies such as full storage and partial storage are elaborated for the better working of the Thermal Energy Storage (TES). Various Case Studies along with the recent trends and cost analysis have been discussed which shows the efficient use of TES in the Heating, Ventilation and Air-Conditioning field.

***IndexTerms* - Thermal Energy Storage (TES), HVAC, Phase-change materials**

I. INTRODUCTION

In the growing country like India or any other developing countries, rapid industrialization and commercialization is taking place where the use of energy is increasing day by day. Be it in any sector, technology has developed to a great extent to make the lives of the people easy and luxurious. In making the lifestyle more advanced, we often neglect that the energy is being used in an in-disciplined manner. It is our duty to conserve the energy by taking the useful measures. As we know that, that the energy conservation task is not simple and hence we have together work for the betterment of the society and the country.

Thermal Energy Storage is required in HVAC, because in most of the developing countries the energy consumption carried out by HVAC is very large [1]. As we all know that India is a three weather country, in which summer is the dominant and hence HVAC has enhanced applications. The use of HVAC system and equipments are widely used throughout the country. The industries are using this application very well. As the power sector is dominantly increasing, the HVAC applications also have huge importance on the industries. As the tariff rates of the electricity are different during the time period of the day, the use of Thermal Energy Storage (TES) can be efficiently use during that time. Hence the installation of TES with the existing HVAC system reduces the power consumption along with the improved economic stability.

TES system has been searching its place in India, basically in the commercial sectors. TES is being used in the industrial sectors, but not to that extent to which it should have been. So in this review the brief study regarding the installation of TES is discussed. Various different types of TES are available in the markets which are favourable for use; both in commercial as well as the industrial sectors. The requirement of the different TES systems depends upon its use in their fields and other similar types of constraints. Even at the time of power loss the energy demand can be fulfilled by the TES if it is properly charged. Basically in the simple words it works as a BATTERY to the HVAC system. Within the minimal requirement of chillers and storage tank or ice bank, TES can be considered as an intelligent move towards the energy consumption rate. TES should be implied in such a way that, the total load incurred would be balanced by both HVAC and TES. This proper blend would help in the fruitful operation of the system imparting higher and stronger life cycle of the system and equipments.

II. LITERATURE REVIEW

In-order to meet the increasing demand of the energy consumption in the sector of HVAC one or the productive ways were being studied for the effective handling of the systems. Many researchers were studying the peak-load operating conditions of the refrigeration and HVAC units. In around 1980 [1] TES was carefully implemented and studied to meet the high peak demand which was being fulfilled by the convention air conditioning systems. It was found effective to store the energy for the further use without any halt in supplying the demands. Basically they introduced the **Thermal Water Energy Storage** (TWES) initially in order to fulfill the increased demands. After successive installation of the TWES and during its implementation it was found that it was not applicable to the appliances where there was a space constraint. Also the capital investment is huge in setting up the TWES.

In the year 2000, [1] **Ice Thermal Energy Storage** (ITES) was introduced. It was used to fulfill the demands more effectively than TWES. The space requirement constraint was also resolved in this type of systems. It stores more energy than the water during its operation and hence the use of it is found most effective. One more way of storing the energy is by the use of Phase-

Change materials, which uses the materials which can change their phase when exposed to high and low temperatures. Phase-change materials are of utmost important because of characteristic of storing the energy and releasing them when required. They are used only in some limited applications because of the less COP involved in their operation. For ice storage technology, special ice-making equipment is used or standard chillers are selected for low temperature duty. Ice storage systems use a standard centrifugal, screw or scroll chiller to make ice [1]. The heat transfer fluid may be the refrigerant itself or a secondary coolant such as glycol with water or some other antifreeze solution. TES basically works on the three main methods [1]:

1. Sensible Heat Storage
2. Latent Heat Storage
3. Phase Change Materials

By the application and proper use of these methods TES is installed in the HVAC system. The requirement of TES is basically the chillers, Ice banks or storage tanks, pumping system and refrigeration unit. With these basic requirements TES can be used in conjunction with the existing HVAC system.

1. **Sensible Heat Storage:** In Sensible Heat Storage method, the sensible heat capacity of water (1.055 KJ) is used to store it for cooling purpose [1]. The sensible heat of the water is used to store the energy. Water is filled in the large storage tank and when the charging is required the water is utilized from that tank and allowed to pass through the chillers and imparting required refrigerating effect to the space. The space requirement for setting up the Sensible heat storage plan is very large as water is to be stored in that. Depending upon the usage, capacity and requirement of the cooling demand the quantity of the water depends. Here basically tank volume also depends upon the return of the warm air from the HVAC system and the return of the chilled water. Most of the HVAC systems work on the temperature differential of around (-6.7°C). [3]. It also depends on the thermal stratification of the water layers. The Figure [1] shows the working of the sensible heat storage by chilled water. Here during the off-peak hours i.e. is during the night, charging process takes place. Chillers are allowed to run at the full load capacity resulting in the production of chilled water for further use. As the day proceeds and peak demand is obtained the main electricity supply is turned off and thermal energy storage is turned on. For the remaining on-peak hours capacity cooling load is taken by the TES efficiently resulting in the cost saving by the higher prices.

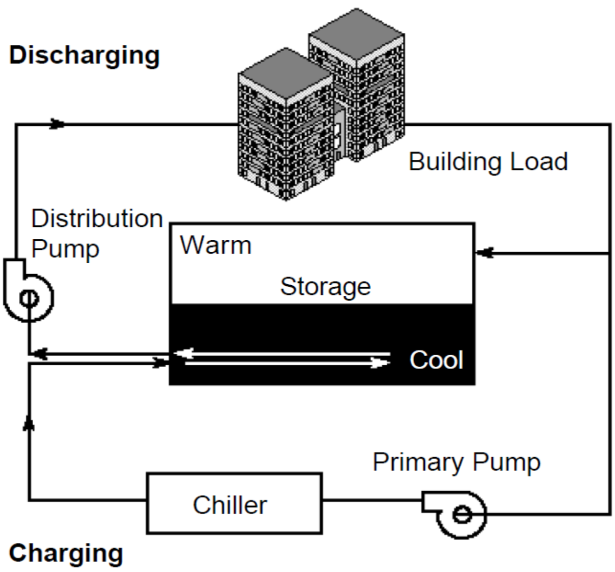

Figure 1: Sensible Heat Storage [1]

2. **Latent Heat Storage:** Latent Heat Storage of ice uses latent heat of fusion of ice (151.928 KJ) to store the thermal energy [1]. It is the most compact type of TES imparting higher efficiency. Only an extra Air Handling Unit (AHU) is required to be connected with the HVAC unit and can be efficiently use. In simple words when the charging i.e. is at the off-peak hours the ice making is required the water is allowed to pass through the chillers which is used to produce the ice. This ice making process needs at least 7-8 hours to manufacture ice as shown in Figure 2. After the process is completed and the peak demand arrives the refrigerant is allowed to pass through the refrigerant tubes which are wounded on the ice. The hot refrigerant is allowed to pass through the ice, resulting in the transfer process and imparting required refrigeration effect. Different arrangements are possible for the melting of the ice i.e. ice-on-coil and coil-on-ice method. Based on the experiment and trial and error it was found that, the coil-on-ice was found more effective. Sometimes when the full conversion of ice from the water is not obtained or some of the water is evaporated an extra arrangement of the fulfilment of the water should be provided.

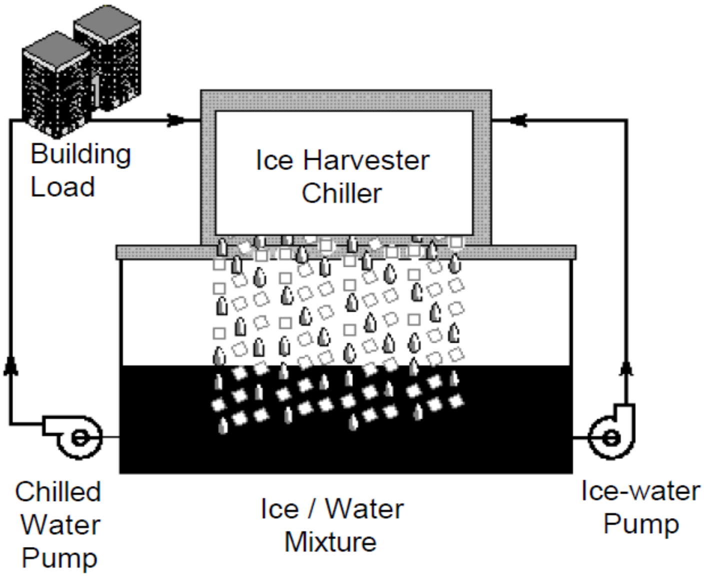

Figure 2: ITES (Latent Heat Storage) [1]

3. **Phase-Change Materials:** Phase changing Materials such as eutectic salts are used for the efficient heat transfer process. These materials are installed in the material, which is being used in the space to be conditioned. These materials absorb the latent heat from the space and releases to the atmosphere. These materials do not require huge space unlike Sensible Heat Storage. They are introduced along with the materials used for the manufacturing the conditioned space. In one of the case it was observed that phase change materials were used to create and maintain the temperature of the space to 18°C.Still the application of these materials is not developed to a greater extent has it has lowest COP. The discharge temperatures are sometimes high as it absorbs (43.2573 KJ). [1]

Another advantage of ice storage is standby cooling capacity. If the chiller is unable to operate for any reason, one or two days of ice may still be available to provide standby cooling. With conventional systems, installing multiple chillers offers redundancy. In the event of a mechanical failure of one chiller, the second chiller supplies limited cooling capacity. The maximum available cooling for the conventional system would, with one chiller out of service, be only 50% on a design day.

TES system can be appropriate when maximum cooling load is significantly higher than average load. High demand charges and significant differential between on-peak and off- peak also helps making TES economic. TES system also can be best looked where there is a need of expanding the existing chilled water system with the conventional chillers [1].

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), has also given the importance for encouraging the use of the TES effectively in the HVAC sector [1]. Most of the countries have started the use of TES and are getting the benefit of better economic reliability. Hence the efficient use of TES is found fruitful across the world and hence it should be encouraged. A detailed comparison has been carried in Table 1, between the chilled water storage and ice storageto understand the operational strategies for each of them.

Table 1: Comparison of Chilled Water and Ice storage systems [1]

Operational Parameters	**Chilled Water**	**Ice**
Temperature difference of 10°C	2.2 Kg of chilled water can store 19 KJ thermal energy	2.2 Kg of ice can store 178 KJ of thermal energy
Density	997 Kg/m^3	920 Kg/m^3
Storage Volume	1	0.12
Chilled Water Supply Temperature	1.1 to 1.7°C	4 to 7°C

It can be observed that the temperature controlled by the ITES is less as compared to TWES. The storage capacity discussed above by the ITES is less than the TWES and hence the applications are wide of ITES. Also the energy storing capacity of the ITES is higher than TWES which imparts better cooling capacity. Hence from the data it can be concluded that, ITES is more suitable option. TES operates either on the Full-storage or Partial-storage in accordance with load which is transferred during on peak-load. When the load is efficiently shifted to the off-peak hours and the chillers are allowed to operate at the full load, that operation is determined by the full storage. The load is shifted effectively when the chiller is allowed to run at the full load capacity as shown in Figure 3. The major portion of the cooling load is meet by the storage and remaining load is meet by chiller directly.

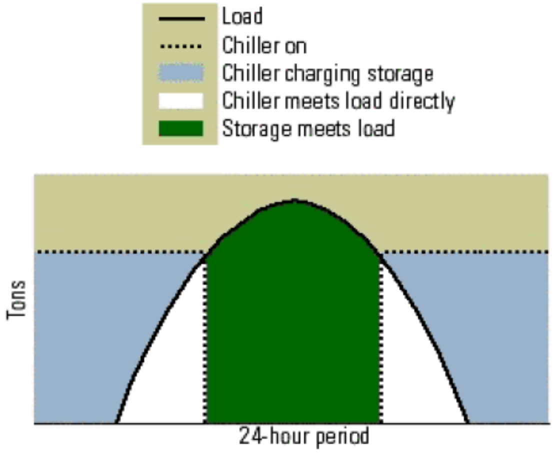

Figure 3: Full Storage [3]

When the chiller capacity is less than the design load the partial storage occurs. Here the chiller runs at 24hr capacity and the excess is stored. Here the storage meets the load with lower portion and the chiller meets the higher proportions of the loads as shown in Figure 4. The chillers are allowed to operate at the partial storage.

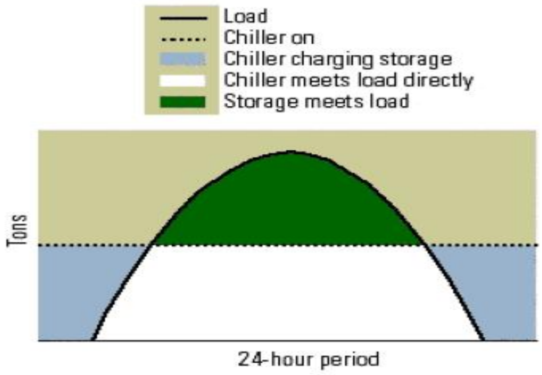

Figure 4: Partial Storage [3]

B. Rismanchi et. al carried out the detailed cost analysis of the building operating with thermal energy storage system with new modified ice thermal energy storage system [4]. The modified Ice Thermal Storage which uses the chillers, pumps, cooling towers ice tank, valve fittings, electrical & control system, glycol and chemical treatment with the conventional AC systems are retrofitted with it. As the climate of the Malaysia ranges from 20°C to 32°C, the main peak hour in the buildings ranges from morning 8am to 7pm. During this the electrical tariff demand is almost $6.6/ref ton per year using the TES and 8.3$/ref ton per year for retrofitting Ice thermal Storage. By calculating the various loads in the buildings and the maintenance and operating costs of the installed systems it is found that the payback time of the ITES with load levelling is around 1 to 3 years and ITES with full storage is about 3 to 6 years. The charging of the chillers during off peak time hours is at the tariff of 0.06/ref ton per year. This is the main reason of the power consumption.

Table 2: Cost comparison between operational strategies of ITES. [4]

Installation Cost				**Total Cost (over 20 years)**			**Total Costs Savings (over 20 years)**	
	Conventional System	Full Storage	Load Levelling	Conventional System	Full Storage	Load Levelling	Full Storage	Load Levelling
50 %	661	1755	723	38,941	31,716	37,743	7226	1199
25%	331	877	361	19,471	5,858	18,871	3613	599
10%	132	351	145	7,788	6,343	7549	1445	240

Here the amount of the cost savings of conventional system with the different percentage of retrofits is shown. The chillers should be allowed to run at the full storage capacity in the ITES in order to obtained required cost saving.

Alessandro Beghia et. al discussed the efficient control of HVAC systems using Ice thermal energy storage [5]. The normal thermal energy storage TWES works between the limit of 7°C to 12°C. The cooling capacity of the Ice cooled TES is as much as by 18% excess than water cooled TES. A typical HVAC system model shown in Figure 5 has been considered for the process of cooling. Here during the charging process the chiller is used to freeze the water and it is stored in the Ice-bank below it. The valves regulate the flow during the required demand. During the discharging process that is the on-peak demand the cooling load is allowed to meet the ice bank where it melts the ice and imparts the required cooling at the destination. Ethylene Glycol is used to cool the water in ITES to ice during charging and use the energy during discharging of the Ice bank to impart cooling.

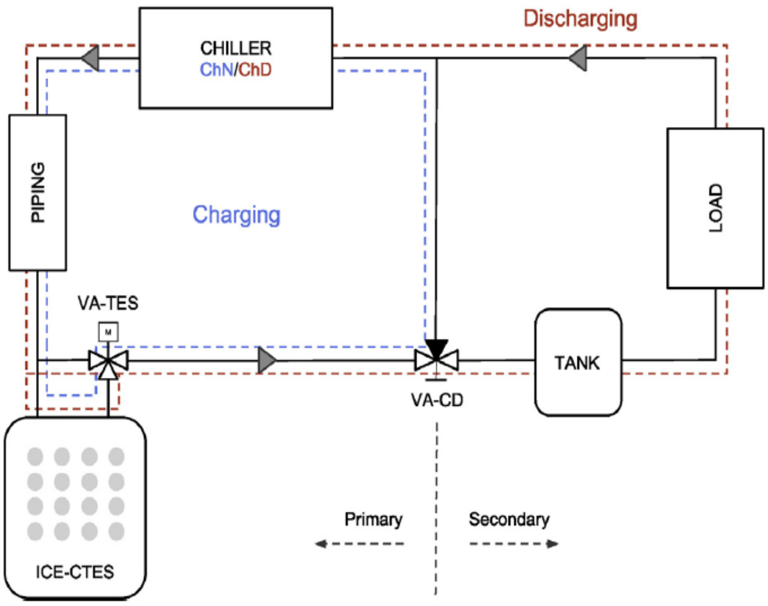

Figure 5: HVAC structure [5]

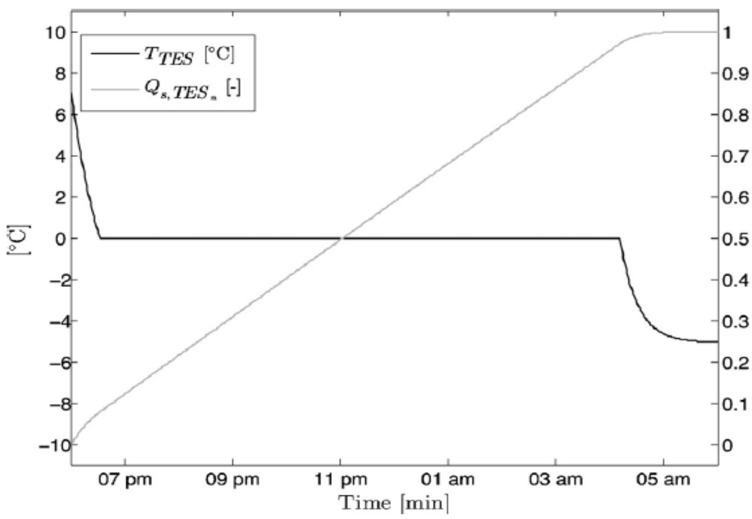

Figure 6: Graph showing Temp. of ITES & effi. of ITES w.r.t. Time. [5]

The graph shown in Figure 6, the temperature of the water during discharged time is 7°C. The conclusion says that by using Ice thermal storage in the system the power usage is reduced by the considerable amount of (30%-35%). If the cooling requirement is high than the chiller capacity, than the external power requirement is needed. Hence the chiller should be designed by keeping appropriate cooling load..

Motoi Yamaha et. al analyzed the use of phase changing materials in HVAC system [6]. Various phase change materials such as paraffin waxes, fatty acids and eutectic salts are used and studied in order to understand the thermal cooling capacity of these materials. Also the experiment of ICE-on-COIL experiment was carried out in order to utilize the latent heat of water for cooling purpose. By the experiments it was found that the latent heat of these materials is about 160kJ/kg to 200kJ/kg.

Hence the mixture of (paraffin waxes and fatty acids) is used for heating and cooling purposes. After the experiment was carried out the result was obtained as the mixture of (paraffin waxes and fatty acids) had the melting point of 17.5°C and freezing point was found to be 18.5°C. Different values of freezing points can be obtained by varying the concentration of the phase change materials. In this experiment the phase change material tank were proposed in the air duct system in order to obtain the cooling system. During the off peak hours the PCM were charged and during the on peak demand the heat was absorbed by producing the required refrigeration effect.

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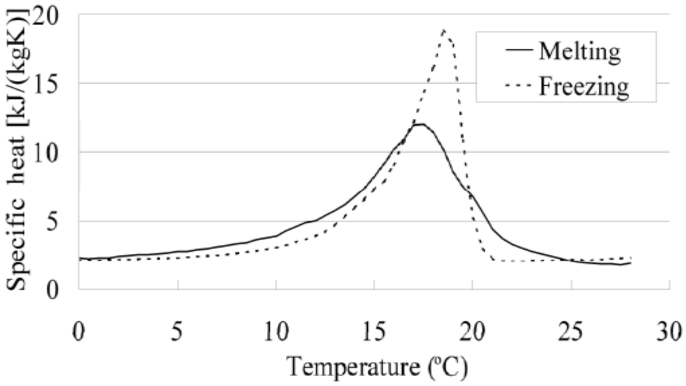

Figure 7: Graph showing Melting and Freezing Temperature of PCM materials. [6]

III. FEASIBILITY AND COST EFFICIENCY OF TES.

The major advantages, along with the payback time for TES have been discussed, depicting the positives by retrofitting the TES with the conventional system.

- **Advantages obtained by the installation of TES:**

With the efficient use of TES the power consumption in the electricity can be considerably reduced. The installation of TES along with the conventional air system saves the power consumption as it takes the load during the off peak hours. When the TES is designed along with convention air systems it provides more space in the construction as the materials required are smaller in size. As the TES would be majorly active during the night where the ambient temperature would be comparatively low and hence the heat transfer rate would be more efficient. TES also provides the flexibility in the operation because during the maintenance and damage of the equipments, it will provide the required cooling loads. The savings on the electricity will be obtained as the TES operates at the lower tariff rates. High energy storage capacity obtained within the considerable amount of volume. The life of the Air-handling unit is drastically improved as the cooling load is being shifted effectively on TES imparting higher economic stability of the device. As the main component used in the TES is water, the pollution rates are almost negligible and hence it helps in keeping environment pollution free. The operation of the TES is very simple and can be easily man handled.TES handler is usually situated at the roof, it is less noisy than conventional systems. Many predictive based techniques of controlling the temperatures by introducing various sensing device, are found to be useful and has increased the efficiency of TES. The Air-handling Unit is allowed to run at the full capacity which in turn increases the COP of the system. In the construction of the high rise buildings, if the TES is designed with the conventional air conditioning the space requirement obtained is more and hence it would offer more symmetric design and better operation. The amount of the energy stored by the TES is quite more, hence sometimes it is also used in imparting cooling after the peak load is satisfied which is again the cost saving advantage. This happens mostly in ITES.

- **Payback time of the TES:**

The payback time means the amount of the time in which the money invested in the installation of TES is again achieved. TES requires a healthy economic investment initially because the requirement of the TES is different for certain different applications. The area required to install the TES is very large specifically for the Thermal Water Energy Storage. Also it requires well equipped refrigeration plant which satisfies the cooling demand of the system. The chillers used in TES should be regularly maintained as they are the most working components in the whole arrangement. All this things requires quite huge economic budget, but as the efficiency obtained after the installation of TES is extremely good so the payback period ranges significantly between 3-4 years. [3] With the use of the various retrofits the payback period is significantly reduced. Now a- days the use of the retrofits are increased as they can be easily installed with the conventional air conditioning systems. The payback period should not only be judged by the return of the investment in a given time but also on the fact that in the long run process which TES is better in providing better economic stability. A healthy investment is that in which both economic and operational stability are equally achieved.

- **Limitations while using Thermal Energy Storage:**

. The place where the maximum cooling demand is the average demand there the TES is not at all advisable. The space available for the installation of the TES is not sufficient. Maximum cooling demand keeps on changing or occurs frequently during the day because TES also requires the adequate time for the formation of ice for the cooling purpose. It is not advisable for the small peak loads, because then it increases the payback time which will result in the economic instability. If the peak load or high demand is of very less time, there the TES investment is not applicable. It would rather increase the investment.

IV. CONCLUSION

On the whole the Thermal Energy Storage in Heat Ventilation and Air Conditioning is the most important aspect of designing new technology. It has given some of the best results leading to the better consumption of the energy along with the cost savings. It is a subject which gives the better way of preventing the energy losses with huge economic benefit. Ice thermal energy storage is found to be the most efficient with requiring less amount of space and storing the greater amount of the energy than water thermal energy storage. On the other hand the setup of the ITES is found to be complex due to the better capacity chiller requirement and the power requirement is quite high. WTES has the easy operation possible with it. It can be easily introduced with the existing conventional systems without any much intervention in the setup. Phase change materials have found the applications in the limited area due to their high discharge temperature.

Thermal Energy Storage is widely used in the countries like America, Japan, Malaysia, Canada etc. as the electricity is available at lesser rates during night in both household and industrial sectors. One of the important applications of the TES is the District Cooling System in which the required cooling demand is fulfilled by the centralized huge TES containing chilled water and cooling the air with help of it. Also the space consumed by it would be less, hence imparting better space for the other engineering construction. With the effective use of the TES, it can impart the required efficiency by proper design of the chillers, storage tanks, pumps etc. TES must be used where the load demand is very huge, low electricity tariff rates during the night, appropriate space requirement etc. The payback time is usually found to be 6-7 years depending upon the operational strategies. The % of the retrofits contributes to the valid payback time fulfilling all the constraints. Overall Thermal Energy Storage is found to be extremely useful if designed with proper equipments used in it.

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