An experimental investigation on passive cooling system comprising phase change material and two-phase closed thermosyphon for telecom shelters in tropical and desert regions

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\textbf{A B S T R A C T}

Advances in information technology have made the thermal management of telecommunication equipment more challenging over the past several years. As advances are being made the electrical energy consumption of telecommunication equipments is ever increasing and thereby increasing its dissipation rate. In addition such shelters are installed in remote areas, so cooling of telecom shelters becomes a great challenge for thermal engineers. A field study revealed conventional cooling systems are not so effective in terms of energy consumption and in the absence of power grid, shelters installed in such areas require additional capital cost to provide power for cooling system. A new passive cooling system incorporating phase change material (PCM) and two-phase closed thermosyphon (TPCT) heat exchangers has been developed and experimented to provide thermal management for telecommunication equipments housed in telecom shelters. The newly developed thermal system absorbs the equipment dissipated heat during the hottest part of the day, stores it as latent heat and releases it through thermosyphons during the night to the ambient.

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1. Introduction

The GSM or UMTS equipments installed in a normal base telecom shelter or electronic enclosure dissipates large amount of heat. Due to technology compaction and advancement in the communication field, further the introduction of the next generation mobile phone has increased the base stations numbers and de-centralized the shelters moving from protected office environment to remote areas. The remote areas are exposed to rain and humidity, dust and pollutants, significant daily and annual temperature swings, wide solar heat load variations and physical abuse. The electronic equipment housed in the shelters that are heavily influenced by the harsh remote environment, has imposed serious constraints on designing an adequate cooling system. The temperature and humidity are the two major causes of electronics failure in the telecommunication industry [1]. However, if the enclosures are either sealed or its temperatures are much higher than the air dew point temperature, humidity is generally not a problem [2]. Therefore it is inevitable to explore a new cooling technique to create suitable indoor conditions for telecommunication equipment to perform better and for a long life. Thus thermal management of telecom shelters is becoming a major challenge. The temperature and humidity specifications normally required for telecommunication equipment are as follows: temperature range 30–40 °C, relative humidity below 85%.

The cooling system for shelters is being designed to have various equipment configuration dissipating heat rates ranging from 500 to 10,000 W, depending on the size and type of equipment deployed. A large variety of cooling techniques have been proposed to maintain the desired indoor conditions of the shelters. This includes active systems, semi-active, and passive systems. Active systems are conventional method which uses commercial air-conditioners or heat pumps. Semi-active systems use air to air heat exchangers and thermoelectric coolers. Passive systems include standard ventilation and novel methods that use sensible and latent heat storage systems.

Standard ventilation includes natural convection and forced air-cooling. Natural convection is the transport of heat by buoyancy induced flows. The literature on natural convection within enclosures is vast and the selected few are available in Refs. [3–6]. This is the simplest and most cost effective cooling method. However, in remote tropical and desert locations where enclosures are

Abbreviations: PCM, phase change material; TES, thermal energy storage system; TPCT, two-phase closed thermosyphon; GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; ISHRAE, Indian Society for Heating, Refrigerating and Air Conditioning Engineers.

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exposed to very high ambient temperatures and humidity which have adverse effect on the life, reliability, and performance of the equipment. This method proves its inability to maintain the desired internal temperature. Forced air-cooling is also of relatively low cost and simple in design when compared to other cooling methods [7,8]; it requires complex air filtration design in dirty desert environments. This incurs high operating and maintenance costs. The most commonly used method for cooling telecom shelter located in regions of high temperature and humidity is the use of packaged air-conditioners. The major disadvantage of conventional air-conditioners is that they consume large amount of electrical energy. In addition large engine generators are required to supply power to air-conditioner due to the absence of power grids in remote areas and during power failures as a back-up system. This incurs significant capital and/or operating costs. The frequent starting and stopping of air-conditioners due to inappropriate temperature profile and condensation of water vapor evaporating again from the evaporator surface are the other problems surfaced. Marongiu and Clarksean [9] designed and developed a PCM heat exchanger for thermal management of electronic enclosures. These heat exchangers are made of aluminum tube bundles in which encapsulated phase change materials are included. During power on conditions the air from the enclosure is made to flow through the heat exchanger so that PCM stores energy by changing its phase; later, during power off conditions, outside air is used to remove the heat from heat exchanger. Marongiu [10] presented a new method that uses compact heat exchanger made of heat pipes which cool a battery compartment of an outdoor telecommunication enclosure when installed air-conditioning unit is present. In the present work the concept of above said two cooling systems are combined as a single unit. The objective of this experimental study is to examine the thermal performance of a novel passive cooling system for telecom shelters installed in tropical and desert regions that incorporates phase change materials (PCM) and two-phase gravity assisted thermosyphons (TPCT).

2. Concept of the present cooling system

The base shelters of next generation telecommunication have to handle a significantly increased heat load, and hence an alternate system which is highly effective, reliable and energy saving has to be explored for cooling telecom shelters. The objective of the present study is to design, simulate and experiment a cooling system that uses the high temperature difference between day and night which prevails in tropical and arid desert regions. This is achieved by developing a suitable cooling system integrated with PCM based thermal storage and thermosyphon as detailed below. During the day time the heat generated from the equipment is stored in the thermal energy storage tank and this stored heat is released to the ambient during the night time through the thermosyphons in the storage tank. This cooling system consists of the following:

- A sealed thermal energy storage unit containing a required number of PCM encapsulated balls immersed in water. This storage unit is kept inside the shelter.
- The storage unit contains a number of thermosyphons and these are designed to have sufficient thermal capacity to reject the day time stored heat from the storage unit to the ambient.

The schematic diagram of the passive cooling system comprising TES and TPCT is illustrated in Fig. 1. The entire unit consisting of TES, thermosyphons and heating element (which simulates the heat dissipation from the electronic equipment) are kept inside an insulated enclosure. As the ambient temperature ($T_a$) during day time is greater than the inside temperature of the shelter ($T_e$), the dissipated heat cannot be rejected to the atmosphere. Therefore the heat dissipated from the equipment ($Q$) is stored in the thermal energy storage unit as a sensible heat in water ($Q_{w}$) and latent heat in PCM ($Q_{pcm}$) as shown in Fig. 1a. During night time the ambient temperature is less when compared to the indoor temperature of the shelter and the stored heat is transferred to the ambient as shown in Fig. 1b. During this mode of operation, the ‘day time’ stored heat in TES is utilized to operate the thermosyphon. However, with the passage of time, the condenser and evaporator reach an equilibrium state corresponding to the ambient temperature. Then the TES is said to have stored sufficient cool energy which would be available to absorb heat from electronic equipment during day time operation.

3. Experimental setup and procedure

An experimental system is designed and fabricated so as to study the characteristics of a passive cooling technique for telecom shelter installed in desert and tropical regions. As shown schematically in Fig. 2, the experimental system mainly includes an enclosure, heater to simulate telecom equipment heat generation, thermal energy storage system, thermosyphon heat exchanger and an environmental chamber to simulate the climate that prevails in desert and tropical regions.
Commercially available copper hard pipe of M type is used to fabricate the two-phase closed thermosyphon system and it can safely withstand the operating pressure levels. This had a nominal outside diameter of 30 mm and an inside diameter of 26 mm. The overall length of the thermosyphon is 1000 mm. The evaporator and condenser lengths are 400 mm and 500 mm, respectively and provided an adiabatic section of length 100 mm is insulated with Teflon. A standard pipe cap is used to seal the bottom and top ends of the pipe. Eco-friendly refrigerant R134a was used as working fluid. The amount of working fluid charged in each pipe is 200 g at 20 °C. This results in a fill ratio of 75%. The fill ratio is defined as the ratio of working fluid volume charged to the evaporator volume. The condenser section of TPCT inside the environmental chamber is provided with circular fins to enhance the condensation process. The evaporator section of the TPCT is immersed vertically inside the TES vessel. A fixture is provided at the adiabatic section to ensure that TPCT is in a vertical position. The condenser section is placed inside the duct of the climatic chamber. Ten similar thermosyphons are arranged in a staggered fashion to form TPHE as shown in Fig. 3. In the thermosyphon locations marked ‘X’, four K-type thermocouples are mounted on the inner surface and one in the adiabatic section. The location of the thermocouples is shown in Fig. 4. Table 3 shows the details of thermosyphon and fin arrangement of condenser section.

The function of the climatic chamber in the present study is to simulate the monthwar temperature inside the chamber by a suitable arrangement. This arrangement consists of a window type air-conditioner, heater, thermostat valve and microprocessor based control system. A microprocessor based control system incorporating the hourly temperature variation for a period of 24 h is used to simulate the climatic conditions inside the climatic chamber. Heaters are connected to the variac system to vary the power supplied to the heater either in ON or OFF mode whereas the A/C unit will be running either with fan/cooling mode accordingly. The A/C system will be turned on or off as per the temperature sensed by an RTD connected to a microprocessor that operates the air-conditioner, heater, thermostat valve and microprocessor based control system. A microprocessor based control system incorporating the hourly temperature variation for a period of 24 h is used to simulate the climatic conditions inside the climatic chamber.

### Table 1

<table>
<thead>
<tr>
<th>Details of TES.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TES volume</td>
<td>26.939 cm³</td>
</tr>
<tr>
<td>No. of balls</td>
<td>130</td>
</tr>
<tr>
<td>Outer diameter of the ball</td>
<td>75 mm</td>
</tr>
<tr>
<td>Volume of each ball</td>
<td>175 mL</td>
</tr>
<tr>
<td>Wt of PCM in 130 balls (0.28 × 130)</td>
<td>36.4 kg</td>
</tr>
<tr>
<td>Volume of water</td>
<td>70L</td>
</tr>
<tr>
<td>Volume ratio (PCM to water)</td>
<td>0.325</td>
</tr>
<tr>
<td>Energy content in PCM</td>
<td>7462 kJ</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Properties of PCM.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PCM material</td>
<td>HS 29</td>
</tr>
<tr>
<td>Appearance (color)</td>
<td>Grey</td>
</tr>
<tr>
<td>Phase change temperature (°C)</td>
<td>28–30</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>1600</td>
</tr>
<tr>
<td>Latent heat of fusion (kJ/kg)</td>
<td>205</td>
</tr>
<tr>
<td>Thermal conductivity (W/mK)</td>
<td></td>
</tr>
<tr>
<td>Solid</td>
<td>1.09 [0–27 °C]</td>
</tr>
<tr>
<td>Liquid</td>
<td>0.54 [28–60 °C]</td>
</tr>
<tr>
<td>Specific heat (J/kg K)</td>
<td>1440</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Details of thermosyphon and fin.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td></td>
</tr>
<tr>
<td>Inner diameter</td>
<td>26 mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>30 mm</td>
</tr>
<tr>
<td>Evaporator section length</td>
<td>400 mm</td>
</tr>
<tr>
<td>Condenser section length</td>
<td>500 mm</td>
</tr>
<tr>
<td>Adiabatic section length</td>
<td>100 mm</td>
</tr>
<tr>
<td>Evaporator volume</td>
<td>0.0212 m³</td>
</tr>
<tr>
<td>Amount of working fluid charged</td>
<td>200 g</td>
</tr>
<tr>
<td>Fill ratio</td>
<td>80%</td>
</tr>
<tr>
<td>Fin</td>
<td></td>
</tr>
<tr>
<td>Radius</td>
<td>17 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>1 mm</td>
</tr>
<tr>
<td>Spacing</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>No. of fins</td>
<td>160</td>
</tr>
</tbody>
</table>

Fig. 2. Isometric view of the experimental setup.
with an accuracy of ±1 °C. Thus the heater and the A/C unit are adjusted through the microprocessor to the desired temperature and flow rate. The condenser section housed in the climatic chamber acts either as a thermosyphon/thermal diode depending on the surrounding chamber temperature. The details of the thermocouples and resistance temperature detector probes used in the experimental setup are shown in Table 4. All the temperature sensors were visually checked for integrity and then connected to the data acquisition system. A data acquisition system is used both to control the temperature in the climatic chamber and to record the temperature at various locations. An AI8000+, microprocessor based data acquisition system supplied by AG measurements was used for this purpose. The data acquisition system is calibrated on temperature measurements according to manufacturer’s calibration procedure and it is found to be ±0.1 °C. This is considered as an elemental uncertainty which needs to be added to other uncertainties involved in the total temperature measurement.

4. Experimental procedure

The following procedure is adopted in the present work to obtain the experimental data systematically in the passive telecom shelter:

(1) The average hourly statistics of dry bulb temperature for 12 months (January–December) given in ISHRAE Handbook for the city Barmer, located in the Thar desert of India is chosen for the study.

(2) The simulated heat load of 100 W of telecom equipment is met from a heater of 200 W and the heater is controlled by a variac and microprocessor based control system. This ensures the continuous heat dissipation inside the enclosure during the test period.

(3) During the test the heater inside the shelter is in the ON mode to have a continuous dissipation. The chosen month temperature profile is simulated during the experiment and the temperatures of the enclosure, water, PCM and thermosyphon are recorded for every 5 min using a data acquisition system. The above experimental trials are repeated thrice for repeatability.

(4) A similar procedure is followed for the remaining months which results in three sets of twelve experimental trials.

(5) The recorded temperature of the enclosure is used to draw the temperature histories. The thermal behavior of the system is studied using the temperature histories and maximum temperature is arrived to know the feasibility of employing the passive cooling system.

(6) The recorded temperature presented is averaged over 1 h interval and subsequently temperature histories are drawn to study the thermal behavior of the system.

Table 4
Details of the temperature sensors.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Temperature sensor</th>
<th>No. of locations</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enclosure</td>
<td>RTD (PT100) 3w</td>
<td>08</td>
<td>0–100 °C</td>
<td>±0.5 °C</td>
</tr>
<tr>
<td>TES Water</td>
<td>RTD (PT100) 2w</td>
<td>07</td>
<td>0–100 °C</td>
<td>±0.5 °C</td>
</tr>
<tr>
<td>TES PCM</td>
<td>Chromel/Alumel (K type)</td>
<td>05</td>
<td>0–275 °C</td>
<td>±0.8 °C</td>
</tr>
<tr>
<td>Thermosyphon</td>
<td>Chromel/Alumel (K type)</td>
<td>05</td>
<td>0–275 °C</td>
<td>±0.8 °C</td>
</tr>
<tr>
<td>Climatic chamber</td>
<td>RTD (PT100) 3w</td>
<td>01</td>
<td>0–100 °C</td>
<td>±0.5 °C</td>
</tr>
</tbody>
</table>
5. Results and discussion

The experimental temperature profile of the components in passive cooling system is discussed in this section in order to evaluate the thermal performance of the passive cooling system. The interdependence of temperature profiles of the various components is shown graphically and the response and relative magnitudes are studied.

5.1. Temperature profile for the month of March

Fig. 5 shows the temperature profile of components in passive cooling system for the month of March obtained from the experiments. It is seen from the simulated ambient temperature curve for the month of March that the maximum and minimum ambient temperatures, $T_a$ are 33.7°C and 19.9°C, respectively. The experimental observations for the month of March are as follows:

- The enclosure temperature, $T_{en}$ is maintained at an average temperature of 31.2°C due to the presence of thermal storage unit employed in the present setup. The maximum and minimum enclosure temperatures are 32.6°C and 30°C, respectively.
- The ambient temperature, $T_a$ is increasing from its minimum value of 19.5°C around 6.00 a.m. However, the temperatures of the water, $T_w$ and PCM in the storage tank decrease even after 6.00 a.m. which indicates the energy discharging still continues. In the storage tank there is a large temperature difference between the upper region and lower region at the end of discharging. The upper region in the storage tank attains its lower temperature of 26.78°C around 8.00 a.m. which shows there is a time lag of 2 h between the start of increase in ambient temperature and the start of increase in upper region water temperature. Further it is also seen from Fig. 5 that the temperature of water and PCM in the lower region starts increasing its temperature immediately after the ambient temperature begins to rise from its lower value. Hence during the time interval between 6.00 a.m. and 8.00 a.m. when the charging begins in the lower region, discharging still continues in the upper region. This is due to the large temperature difference between the water in the lower region and the enclosure space which enables the heat flow to the lower region of the tank. However, the PCM temperature $T_p$ remains constant between 9.00 a.m. and 6.00 p.m.
- Though the temperature of water starts increasing at 8.00 a.m., the temperature difference between the ambient, $T_a$ and the vapor, $T_v$ in the thermosyphon still exists that transfers the heat from the storage tank to the atmosphere through the six TPCT. The discharging of heat to the ambient is completed when the

Fig. 4. Thermocouple locations in thermosyphon.

Fig. 5. Experimental temperature profile of the components in passive cooling system (March).
vapor temperature attains equilibrium with the ambient which happens at 10.00 a.m.
• After 10.00 a.m. the vapor temperature becomes higher than the ambient temperature and hence condensation in TPCT will not occur. Hence after this time the heat dissipated by the equipment in the enclosure will be absorbed by the storage tank. This charging process continues up to 6.00 p.m. Then discharging continues for a period of 16 h (between 6.00 p.m. and 10.00 a.m.).

The operation of TPCT is studied by representing these specific T–t curves separately as shown in Fig. 6. It shows the difference between experimental vapor temperature and ambient temperature \((T_v - T_a)\) with respect to time along with the ambient temperature variation with respect to time as reference. During the day time (between 10.00 a.m. and 6.00 p.m.) the difference between vapor and ambient temperature is almost zero indicating that there is no heat transfer from the condenser section of thermosyphon to ambient. Also the water temperature in upper region of TES is lower than the ambient temperature. This causes no heat addition to the evaporator section of the thermosyphon. Further on the condenser side the vapor temperature is nearly equal to ambient temperature which does not permit the vapor in the condenser section of the thermosyphon to get condensed. During this period as the time increases there is a slight increase in vapor temperature exceeding ambient temperature and giving an average rise of 0.2 °C. This happens due to the presence of 2 kW heaters in the climatic chamber to simulate the required outside temperature profile and the fan in “ON” mode. During this period, the entire working fluid in the thermosyphon is in the vapor state and since the thermal conductivity of vapor is very poor, the possibility of heat getting transferred from atmosphere to evaporator section through the condenser section is very minimum. The thermosyphon may be constructed to behave as a perfect thermal diode that permits heat transfer only in one direction and not in reverse direction. During the time interval 06.00 p.m. to 9.00 a.m. the temperature difference between thermosyphon and ambient is significant with an average value of 5 °C which indicates that the heat stored in TES is released to the atmosphere through thermosyphons.

**Fig. 6.** Difference between experimental vapor and ambient temperature (March).

**Fig. 7.** Temperature profile of ambient and PCM (March).
Fig. 7 shows the variation of PCM temperature with respect to time along with the ambient temperature variation so as to study the thermal behavior of the PCM during charging and discharging process. During the day time (between 10.00 a.m. and 6.00 p.m.) when the thermosyphon behaves as thermal diode, the temperature profile of the PCM is a typical ‘plateau’ as the phase change process occurs at 29°C. The phase change occurs from solid to liquid absorbing the heat dissipated by the telecom equipment. This lowers the increase in internal energy of the air inside enclosure and thereby maintaining the enclosure temperature below 40°C. It corresponds to the charging period for the PCM. During the time interval 06.00 p.m. to 9.00 a.m. when AC and fan is switched ON to simulate the outside temperature, the release of heat from TES to atmosphere takes place as there is a significant temperature difference between vapor in the thermosyphon and the ambient. It is already seen from Fig. 5 that there is a sharp decrease in temperature of the water in upper region and lower region of TES. Hence the temperature of the PCM begins to fall after the plateau. This is the discharging period for the PCM corresponding to the solidification process.

Fig. 8 shows the temperature difference between the water in upper region and water in lower region of TES with respect to time along with the ambient temperature variation for reference. There is a small stratification in the TES between 9.00 a.m. and 6.00 p.m.

The major reasons for this near zero stratification are:

1. During this period the amount of heat removal through the thermosyphon is very small.
2. There is a uniform heat addition to the storage tank from the enclosure portion which heats the water in the lower region as the temperature difference is higher between lower region and enclosure.

Fig. 9. Experimental temperature profile of the components in passive cooling system (May)
(3) The bottom region of TES is filled with PCM spherical balls which enhance heat receiving capacity when the PCM is undergoing phase change.

During this period since the PCM is changing its phase, the melting temperature is nearly constant. This shows the transfer of heat from the water to the PCM for its phase change and hence suppressing the stratification. Subsequent to the completion of phase change process (solid to liquid) it is found that there is increase in temperature of the water in the storage tank causes thermal stratification.

5.2. Temperature profile for the month of May

Fig. 9 shows the temperature profiles of various components in the passive cooling system for the month of May (peak summer) obtained from the experiments. It is seen from the ambient temperature curve for the month of May that the maximum and minimum temperatures are 40.90°C and 26.75°C, respectively. The experimental observations for the month of May are as follows:

- The enclosure temperature is maintained at an average temperature of 37.67°C due to the presence of thermal storage unit employed in the present setup. The maximum and minimum enclosure temperatures are 38.70°C and 36.03°C, respectively.
- Though the average temperature of the enclosure is higher by 6°C compared to the month of March, the trend of the temperature profiles of the components is similar except for the PCM. It is seen from Fig. 10 that the phase change temperature of PCM increases above its melting temperature (29°C) during the period 11.00 a.m. to 5.00 p.m. This is due to the fact that the storage capacity...
5.3. Temperature profile for the month of December

Fig. 11 shows the temperature profile of components in passive cooling system for the month of December obtained from the experiments. It is seen from the ambient temperature curve for the month of December that the maximum and minimum temperatures are 30.30 °C and 18.60 °C, respectively. The experimental observations for the month of December are as follows:

- The enclosure temperature is maintained at an average temperature of 28.55 °C due to the presence of thermal storage unit employed in the present setup. The maximum and minimum enclosure temperatures are 30.25 °C and 27.10 °C, respectively.
- It is seen form Fig. 12 that the PCM does not attain its melting temperature 29 °C throughout the day which indicates that the sensible heat storage alone is sufficient to store the heat dissipated by the electronic equipment during the day. The stored heat
is released to the atmosphere through thermosyphon to maintain the enclosure temperature at 28.73 °C during night.

5.4. Monthly maximum and minimum enclosure temperature variations

The month wise maximum and minimum enclosure temperature variations along with the ambient maximum and minimum temperatures shown in Figs. 13 correspond to the experimental values. The relative values of temperature shown in a table beneath Fig. 13 show that the temperature inside the enclosure is high in the month of June with maximum and minimum temperatures 40.00 °C and 37.85 °C, respectively.

6. Green shelters

In geographic locations where free cooling is suitable, telecom shelter with conventional air-conditioner system can be converted into green shelter by replacing the conventional cooling technique with the passive cooling system of the present study. Carbon footprint is the greenhouse gas emission caused directly or indirectly by a single individual, organization, event or product. Burning a litre of diesel will cause 2.7 kg of CO₂ emission. A typical shelter with the passive cooling system of the present study. Carbon footprint of a shelter fitted with an air-conditioning system consuming 22,776 kWh can save approximately 14 tonnes of carbon foot print every single year Therefore the replacement of conventional air-conditioning system with passive cooling system makes the telecom shelter as a green shelter.

7. Conclusion

A passive cooling system for telecom shelters installed in desert and tropical regions using thermosyphon integrated with PCM based TES has been developed and experimented to study the feasibility of its application. The key results and conclusions of the study are summarized below:

(i) The geometric dimensions of the thermosyphon and fill ratio are designed based on the heat dissipation of telecom equipments and from temperature data available. Also the operating limits of the thermosyphon are evaluated to overcome the physical constraints that are encountered during operation.

(ii) During the charging period, i.e. between 9:00 a.m. and 6:00 p.m. in the month of March the thermosyphon functions as a thermal diode which does not permit heat entering from the atmosphere to the storage tank. However, the continuous heat dissipated from the equipment is absorbed by the PCM–TES system and thereby maintaining the required enclosure temperature.

(iii) During the discharge period approximately between 6:00 p.m. and 9:00 a.m., the temperature difference between the thermosyphon and ambient is significant which drives the heat from the storage tank to the ambient.

(iv) Upon comparing the results for the months of March, May and December, the capacity of PCM in the present case is sufficient for the month of March, just sufficient for the month of May and excess for the month of December. Hence, careful design should consider the heat load requirement of electronic equipments and the cost of the PCM–TES system.

(v) A typical shelter fitted with an air-conditioning system consumes 22,776 kWh. However, a passive cooling system replacing the conventional air-conditioning system run by power grids or diesel generators can save approximately 14 tonnes of carbon foot print every single year Therefore the replacement of conventional air-conditioning system with passive cooling system makes the telecom shelter as a green shelter.

(vi) A passive cooling system incorporating PCM based TES system and thermosyphon heat exchangers for cooling telecommunications enclosures is viable and reliable for shelters installed in desert and tropical regions. It has the following advantages:

- The present system does not require power; therefore it is a highly efficient system for remote areas where there is no power grid and the maintenance is minimum.
- The enclosure air is totally isolated from the atmospheric air thus ensuring a dust free and salt free atmosphere.
- It is a low cost cooling system and eco-friendly.

References