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Thermodynamic comparison and Dynamic Simulation of Direct and Indirect Solar ORC system with PCM storage

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- Thermodynamic modelling
- Validation of the Computational Model for PCM
- Climatic Data of Islamabad-Pakistan
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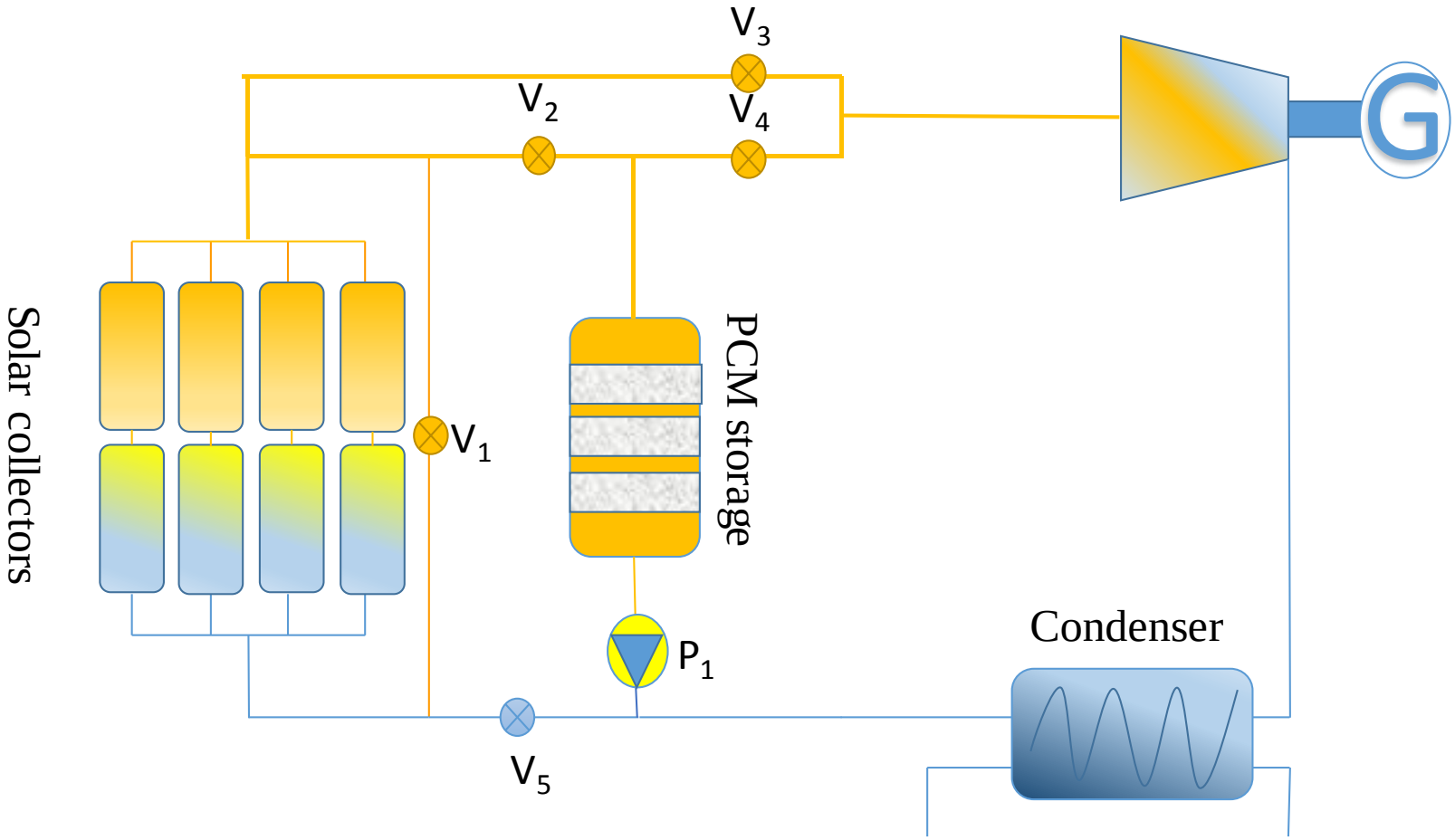
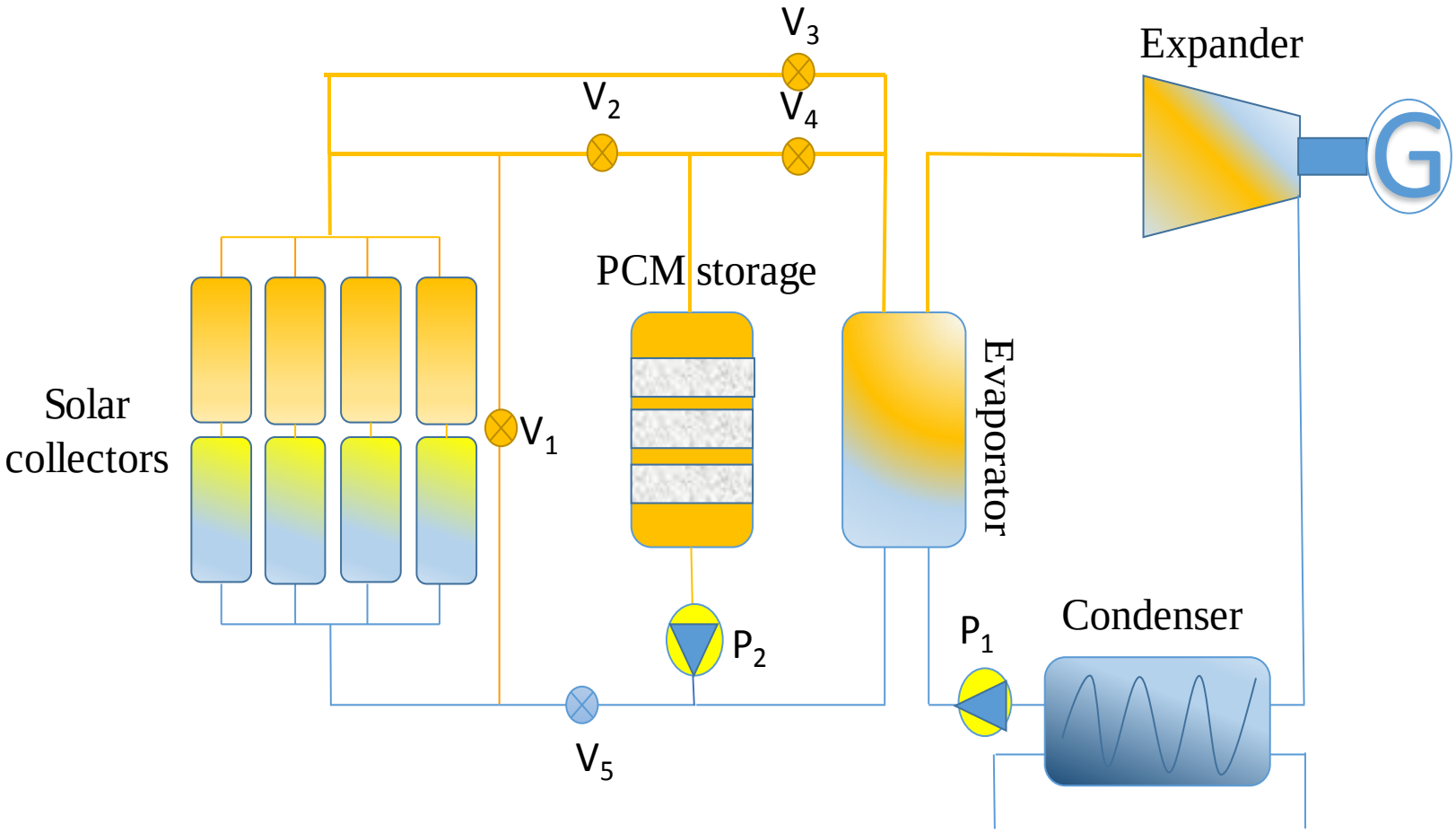
Introduction

- A thermodynamic comparison between a novel direct solar ORC system (DSOS) and indirect solar ORC system (ISOS) is carried out in this study.
- A phase change material (PCM) heat storage unit is integrated with both systems to ensure the stability of power generation.
- Water and R245fa are selected as a heat transfer fluids (HTFs) for ISOS and DSOS respectively.
- However, R245fa is used as working fluid for both systems.
- Weekly, monthly and annual dynamic simulations are carried out to compare the performance of both systems using hourly weather data of Islamabad, Pakistan.
- MATLAB programming environment is used to simulate both solar ORC systems associated with latent heat thermal storage and ORC unit under time-varying solar radiation conditions.

Direct Solar ORC system



Indirect Solar ORC system



Operating and boundary conditions

- The operation modes of storage system are divided into charging and discharging mode.
- The minimum threshold level of solar radiation system start up, is selected to be 400 W/m^2 otherwise system stops or undergoes to discharging process.
- The initial temperature of PCM is selected to be 373.15 K. This depicts that PCM is in solid phase at the beginning of simulation process.
- The PCM storage system is designed to work at melting point temperature of the PCM. It means that major part of energy is released or absorbed at melting point of PCM.
- HTF mass flow rate during charging mode is selected to be 3 kg/s and it increases with increment in collector outlet temperature. However, HTF bypass mass flow rate is kept constant at rate of 0.5 kg/s in both charging and discharging mode.
- Discharging limit of the storage tank is maintained to 370K which means that the system is allowed to discharge the storage in sensible heat region.

Thermodynamic modelling

The ORC efficiency is defined by the ratio of the net power output to the heat supplied

$$\eta_{ORC} = \frac{W_{net}}{Q_{ORC}}$$

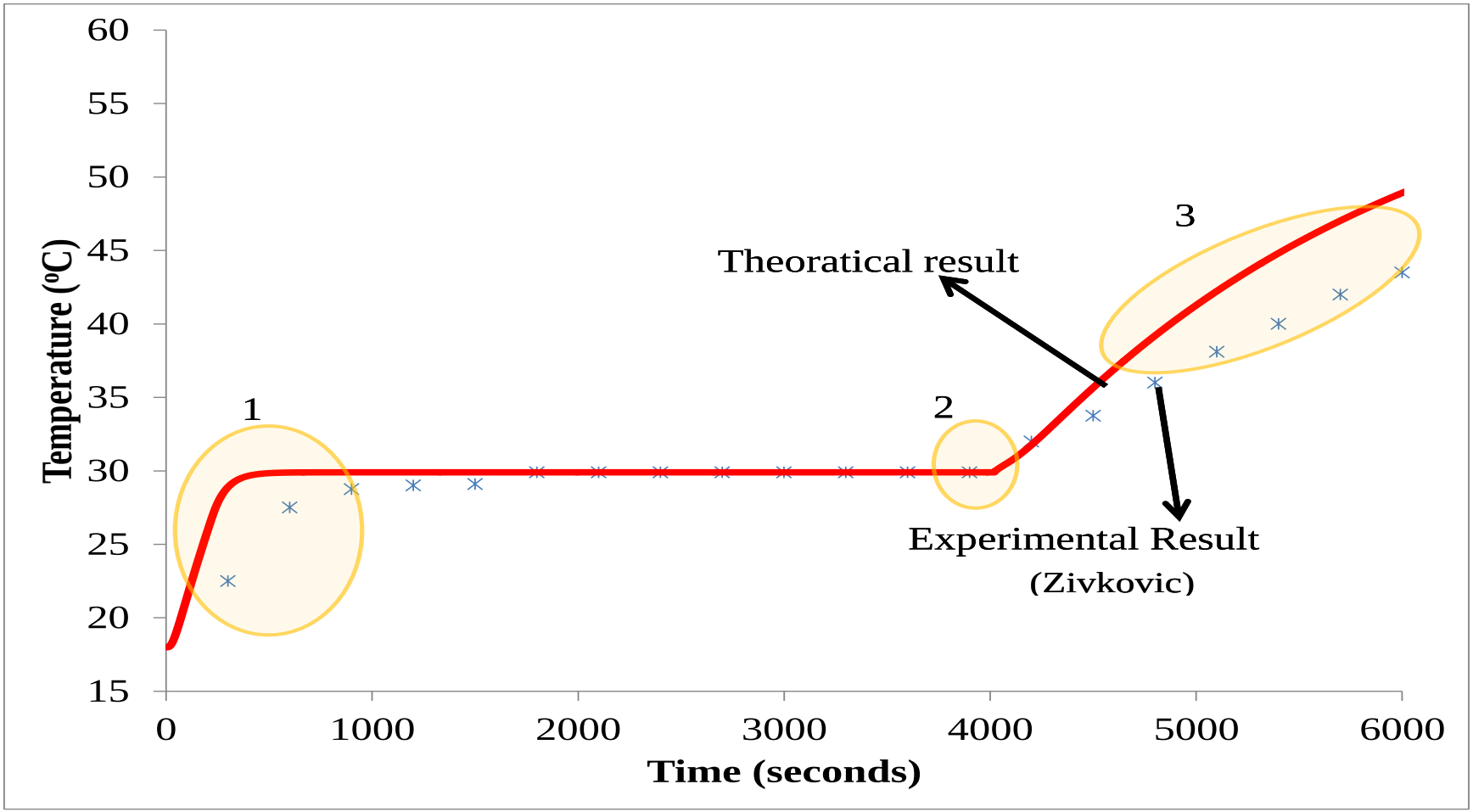
The overall electricity efficiency of the solar ORC is expressed by

$$\eta_{sys} = \eta_{ORC} . \eta_{cl}$$

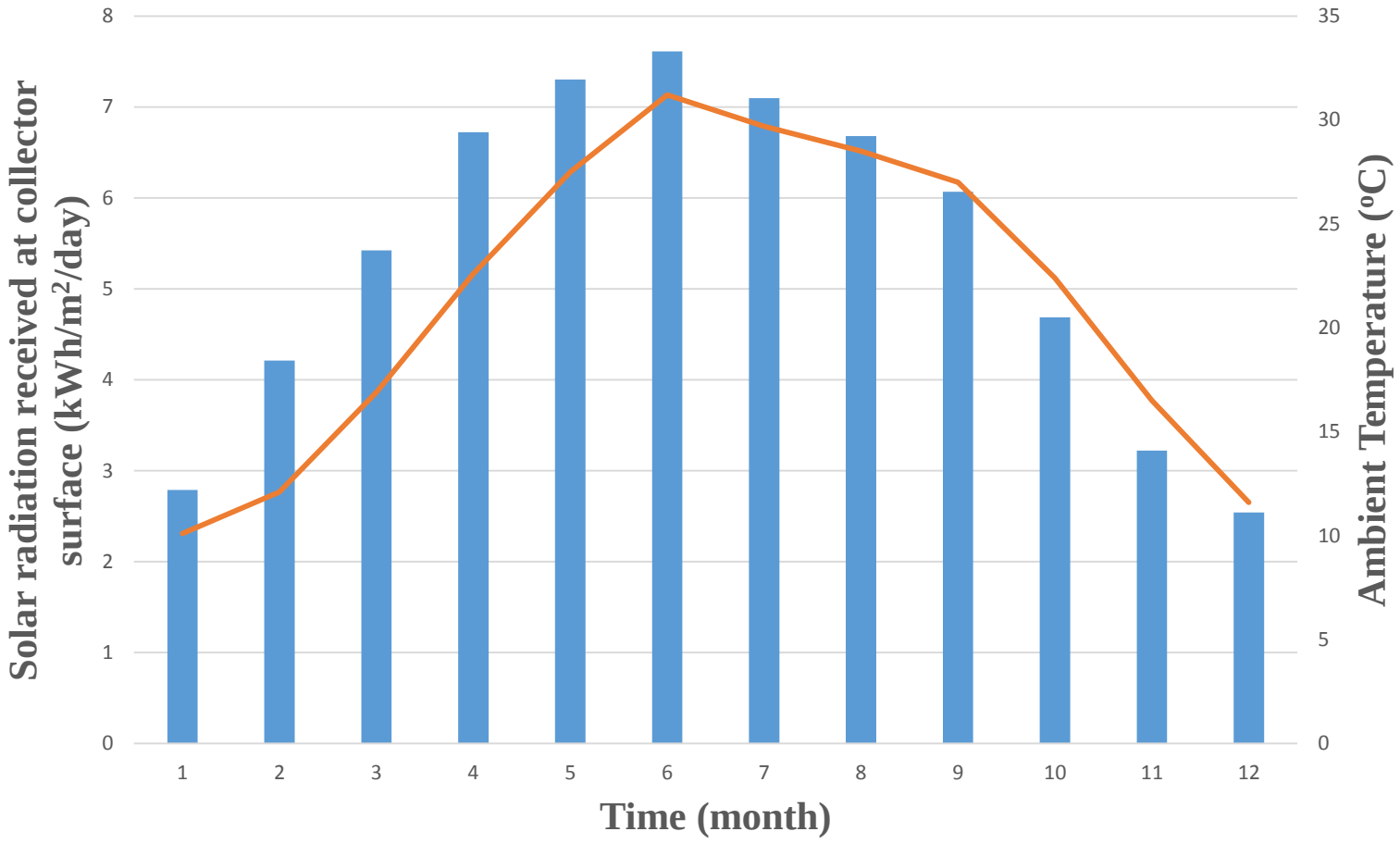
Increment in capacity factor of the systems is calculated by relative increment in working hours by use of PCM storage.

$$CF_{inc} = \frac{Wh_{\mathrm{w,pcm}} - Wh_{wo,pcm}}{Wh_{\mathrm{w,pcm}}}$$

Validation of the Computational Model of PCM storage

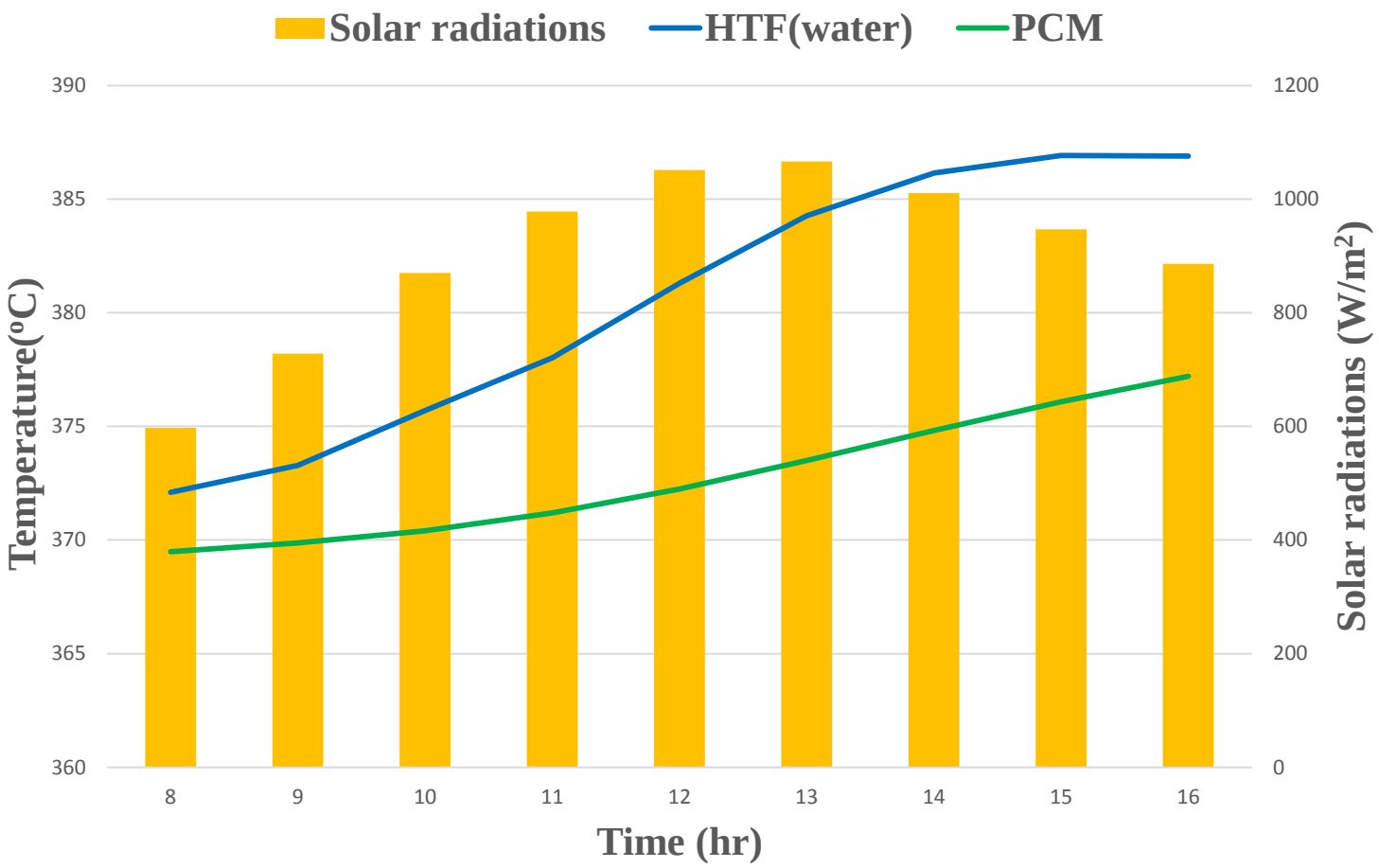


Climatic Data of Islamabad-Pakistan



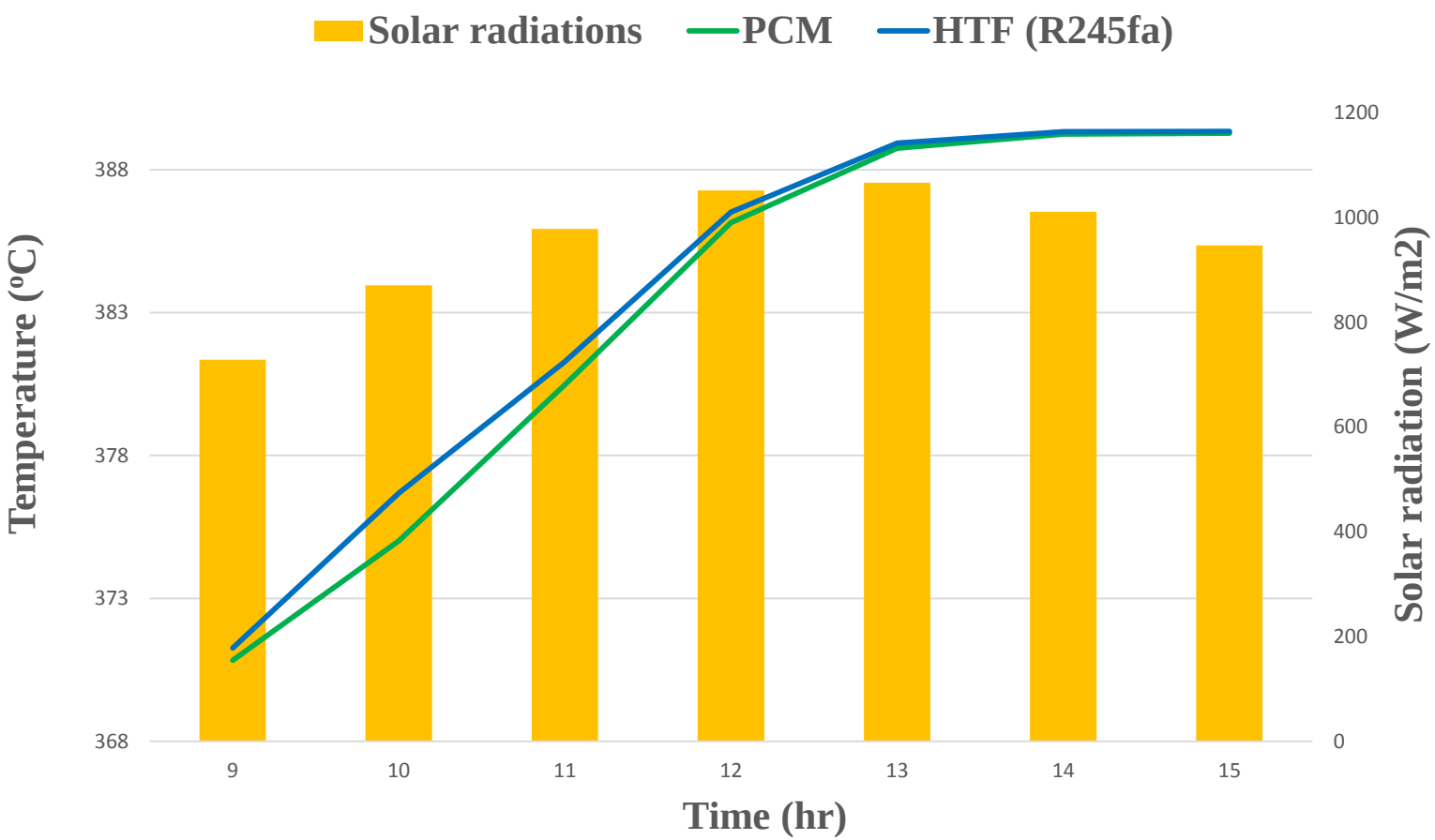
Hottest week of the year

Hourly average daily variation in PCM and HTF temperature during charging mode for ISOS



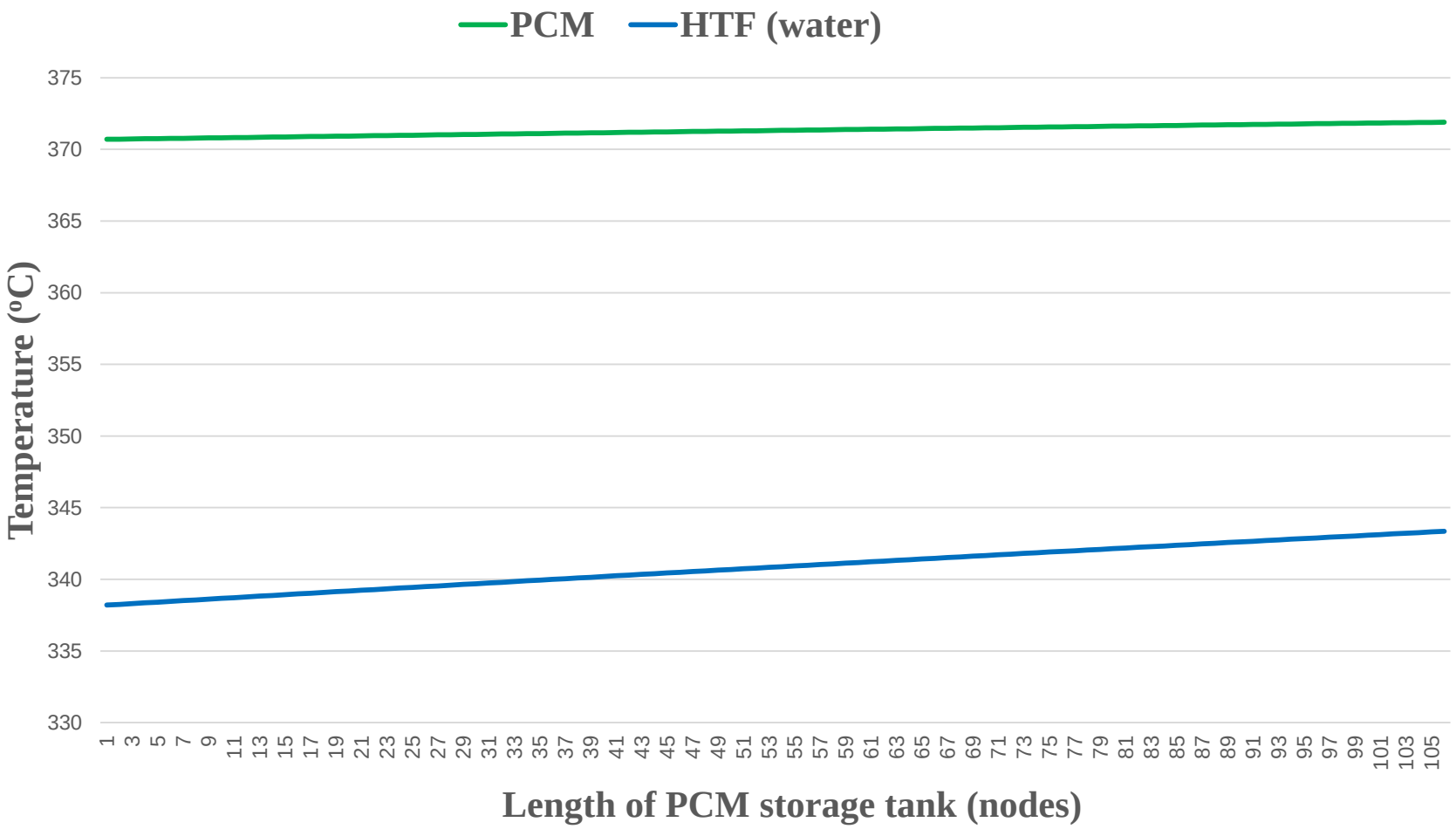
Hottest week of the year

Hourly average daily variation in PCM and HTF temperature during charging mode for DSOS



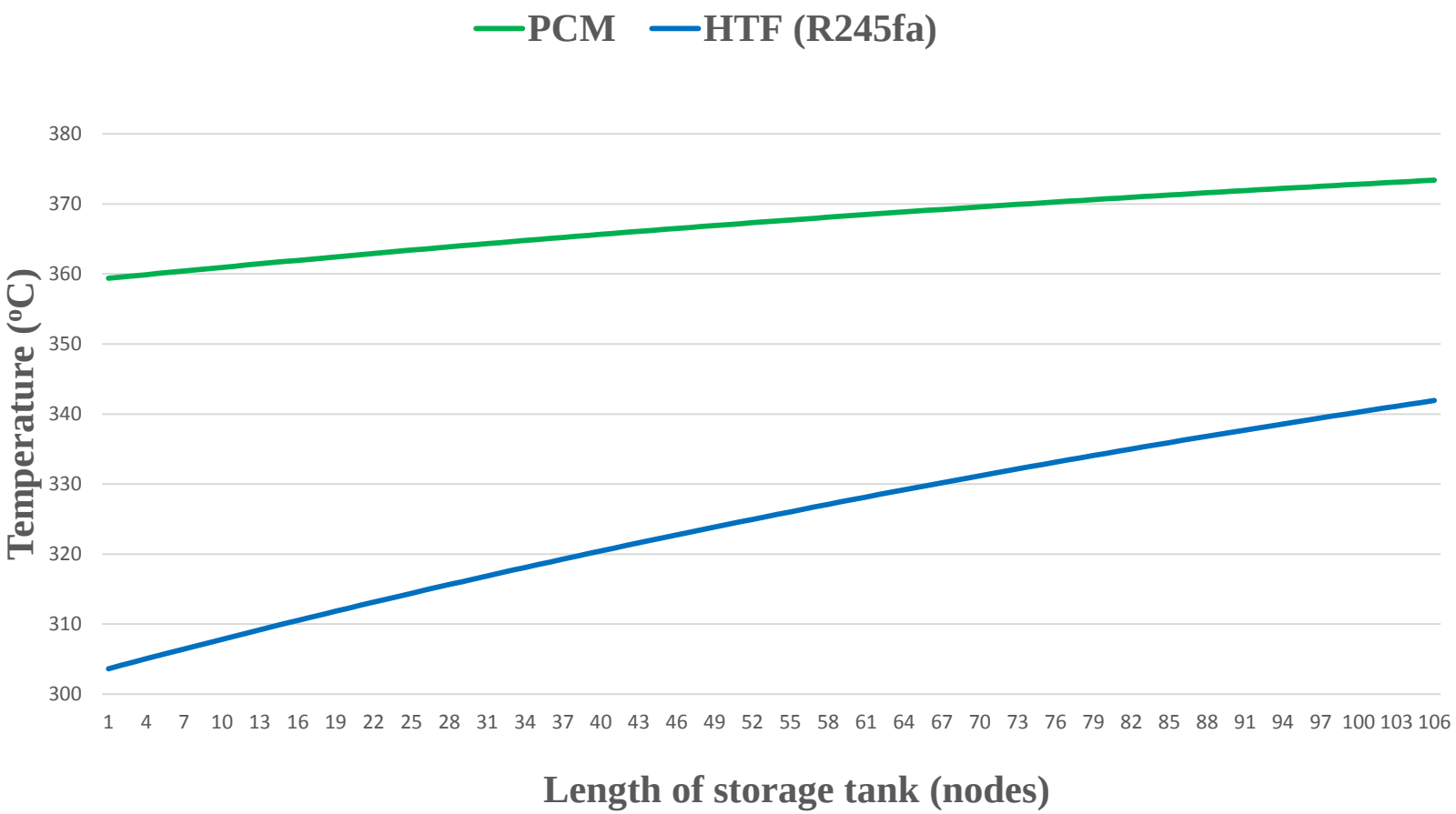
Hottest week of the year

Hourly average variation in temperature of PCM and HTF during discharging mode for ISOS



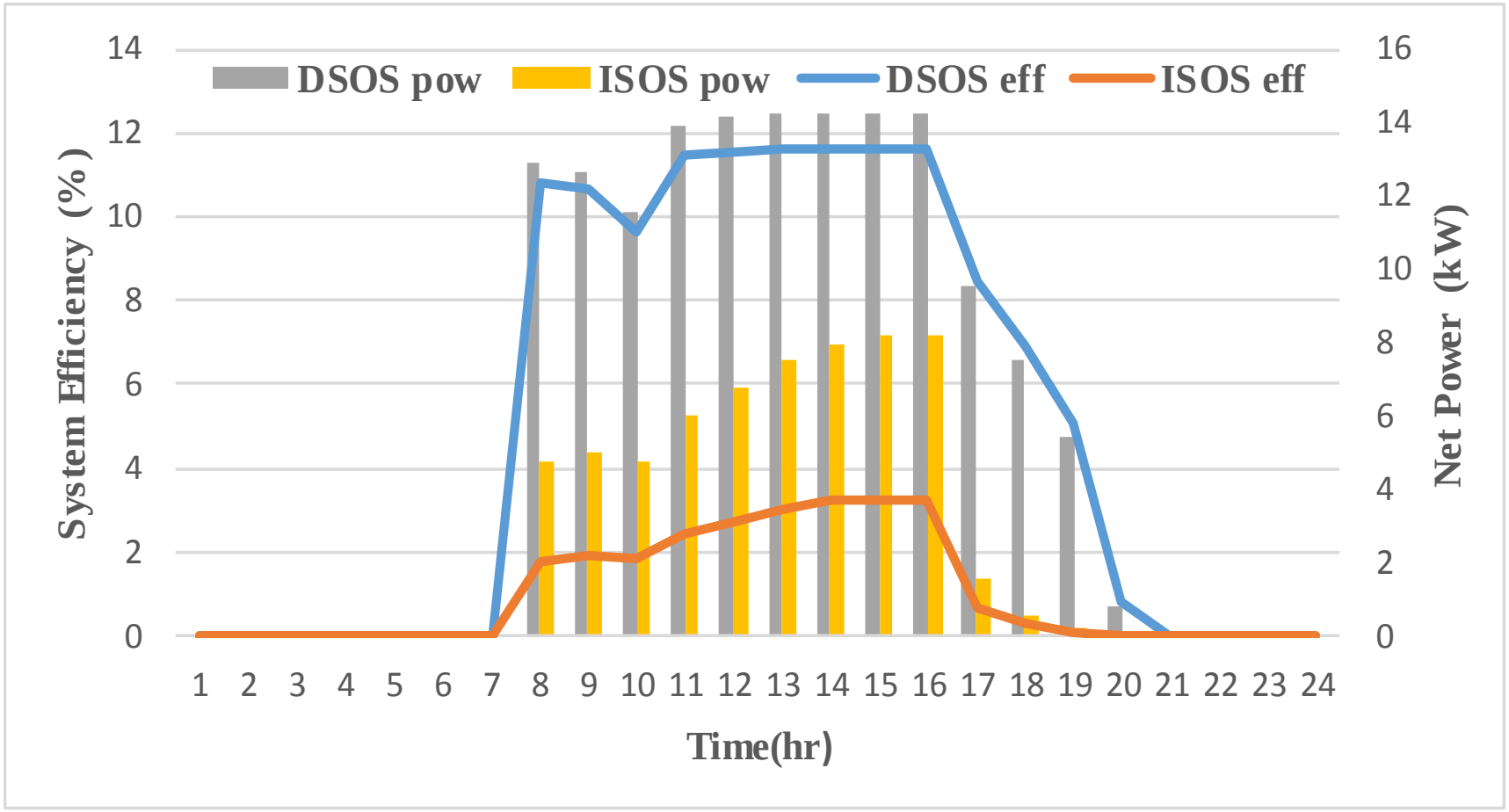
Hottest Week of Summer

Hourly average variation in temperature of PCM and HTF during discharging mode for DSOS



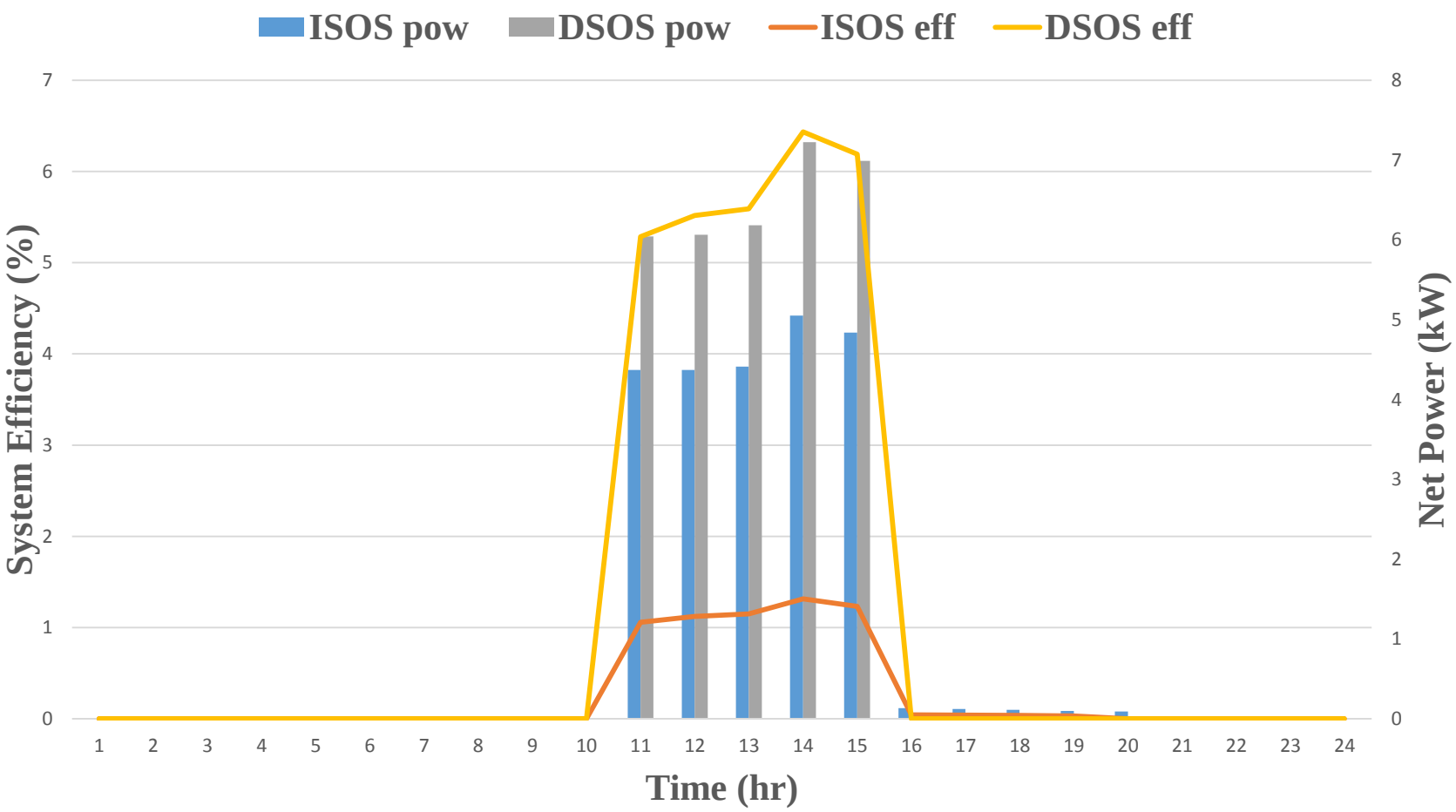
Hottest Week of Summer

Overall system efficiencies and power output



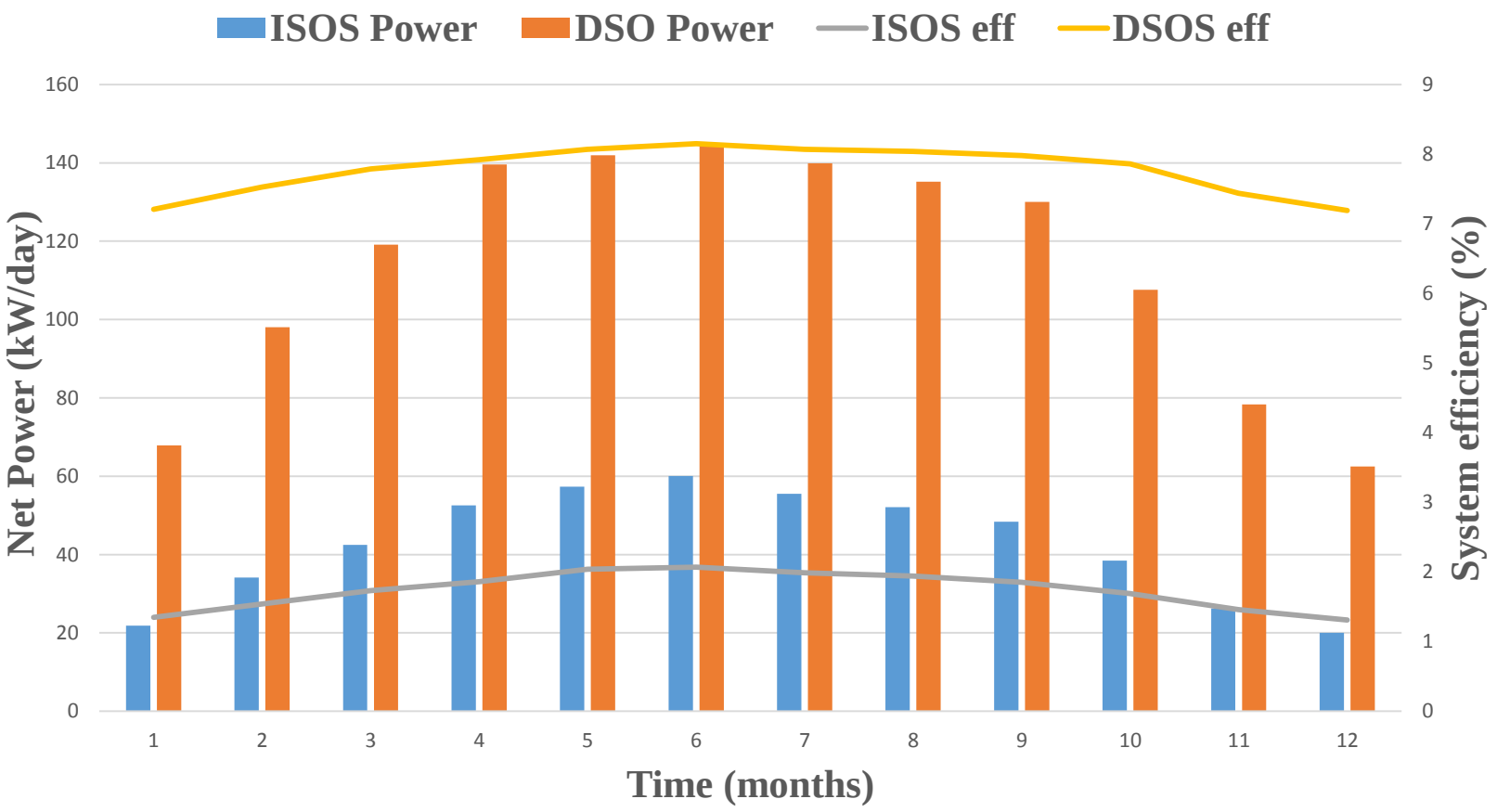
Coldest Week of winter

Overall system efficiencies and power output



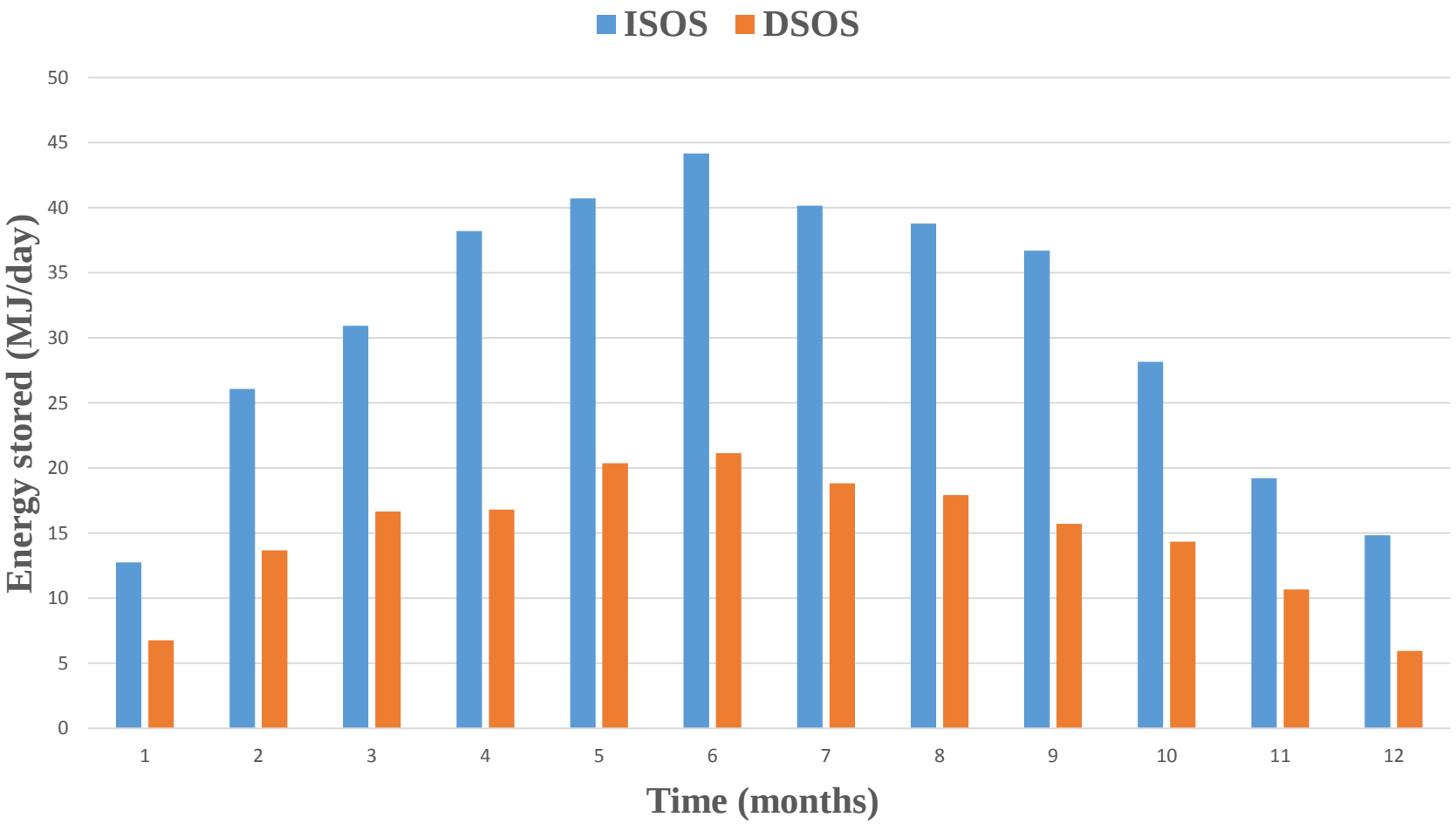
Performance during every month of the year

Overall system efficiencies and power output



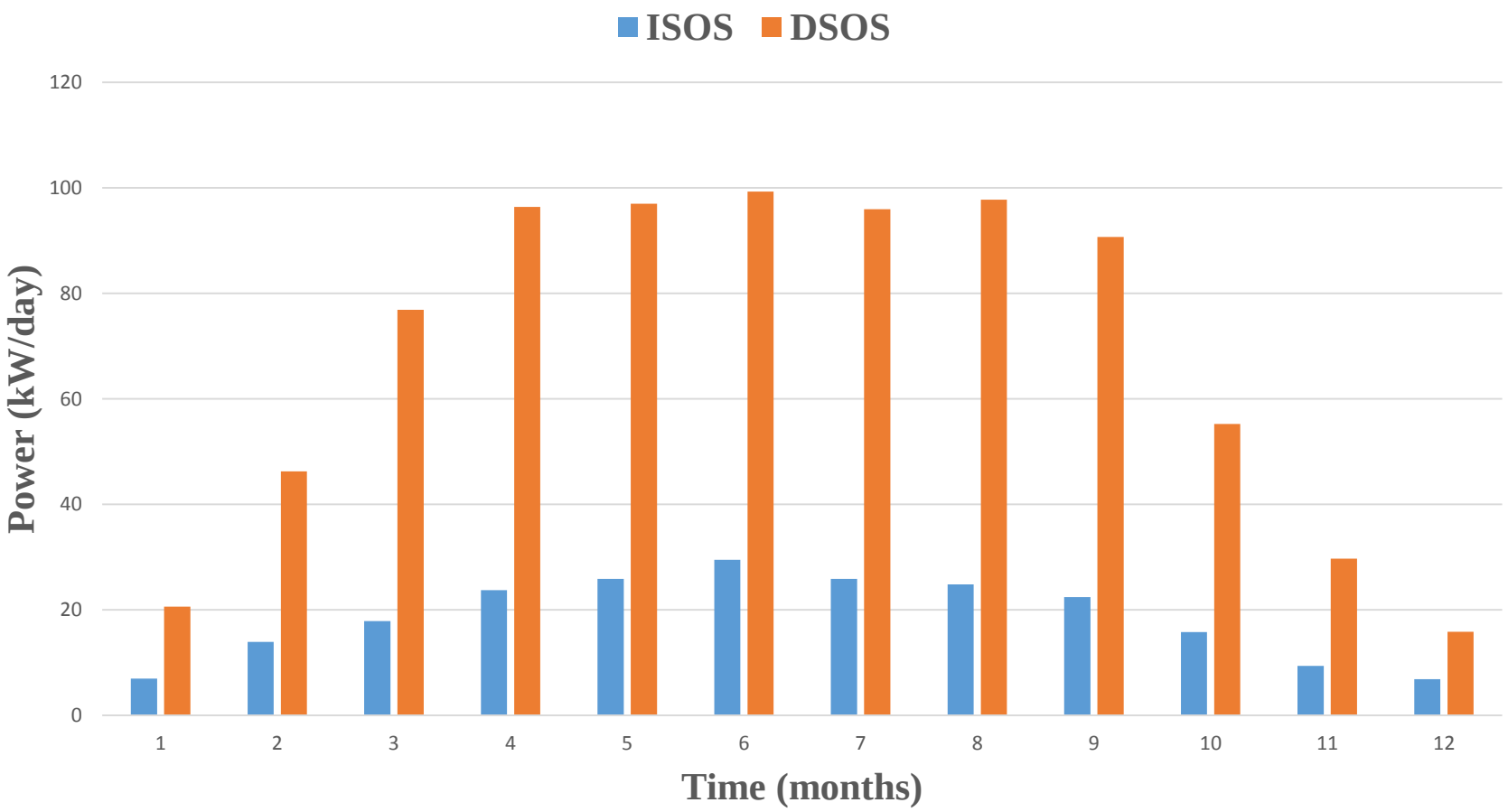
Performance during every month of the year

Amount of energy stored during charging mode



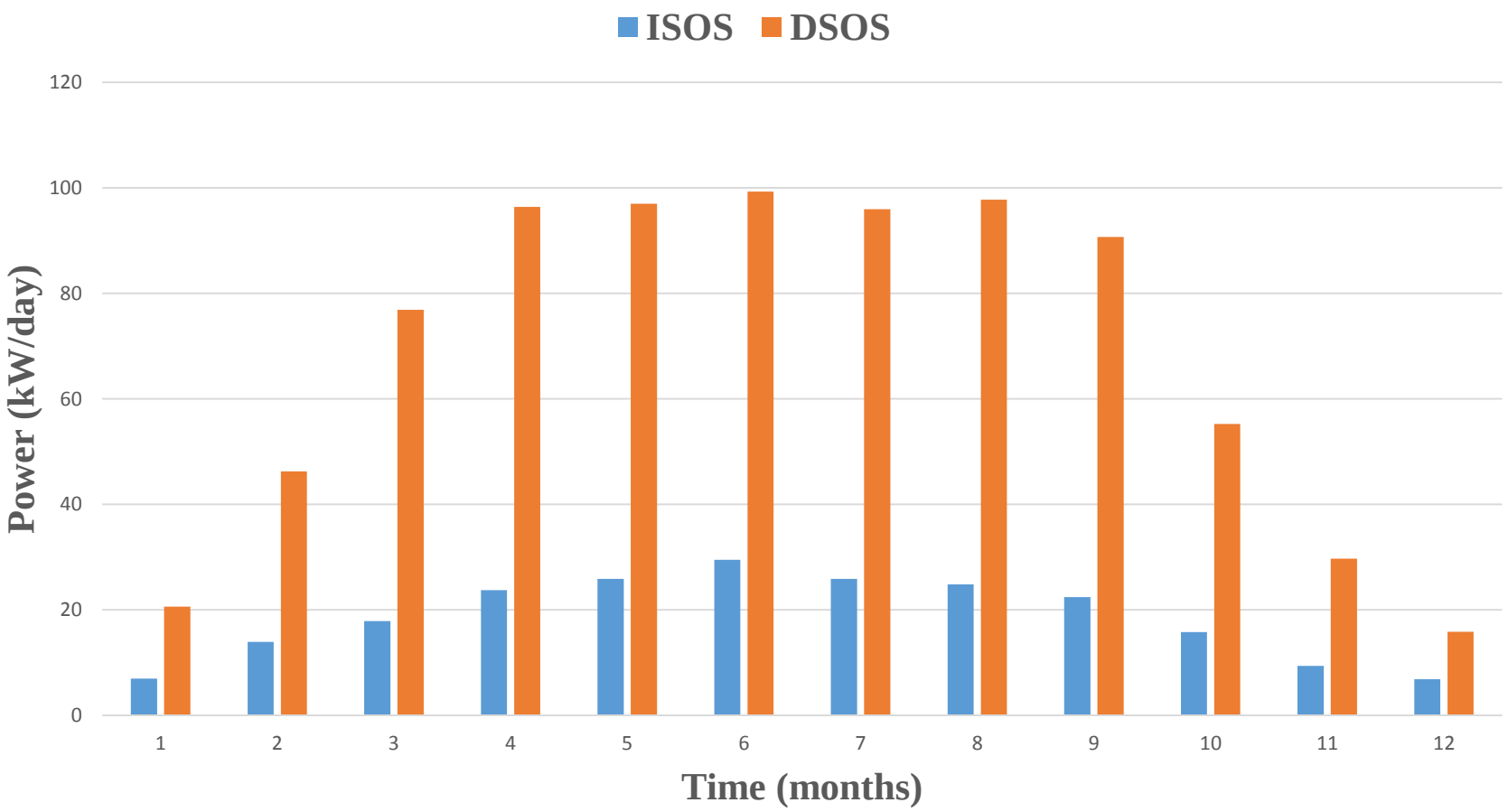
Performance during every month of the year

Power transferred to HTF during discharging mode



Performance during every month of the year

Increment in capacity factor



Conclusions

- ISOS has shown 1.71% system efficiency and able to provide 34.02 kW/day power while DSOS has shown 4.5 times higher system efficiency and 2.8 times higher power on annual basis.
- Average annual amount of energy stored by PCM during charging phase for ISOS is 4.24 MW/day higher than DSOS .
- However, in comparison with ISOS, DSOS has delivered 33.80 kW/day more power to HTF during discharging phase of the PCM on annual basis.
- Maximum benefits of PCM storage are observed during the summer season compared to the winter season at selected operating conditions.
- Furthermore, average annual increment in capacity factor by using PCM storage are found to be 21.71% and 17% for DSOS and ISOS respectively