Preprints.org

Article

Not peer-reviewed version

# Thermal Batteries for Overnight Heat

Ocean M. Acero and Alexander V. Tobias *

Posted Date: 15 June 2026

doi: 10.20944/preprints202606.1093.v1

Keywords: phase change material; latent heat; overnight heat source; paraffin wax; waste heat usage

Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC, OpenAlex.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

*Article*

# Thermal Batteries for Overnight Heat

**Ocean M. Acero [1,2] and Alexander V. Tobias [2,*]**

[1] Alameda High School, Alameda, CA 94501, USA

[2] Throop Research Academy, Gaithersburg, MD 20878, USA

* Correspondence: alex@throopacademy.org

**Abstract**

This study examines the technical feasibility of using phase-change materials (PCMs) to provide overnight heat to individuals sleeping outdoors or in tents. Thermal batteries made with PCMs absorb heat at a certain time and place and change phase at a defined temperature, usually from a solid to a liquid or melt. At a later time or different place where the surrounding temperature is below the transition temperature, the phase change reverses and the material releases heat. There is ample wasted heat in our society from residential, commercial, and municipal facilities, data centers, industrial processes, and internal combustion vehicles. Solar radiation could also be used to warm PCM mats during the daytime. We conducted scaled-down tests with a paraffin wax PCM, a standard sleeping bag, and a 3-probe digital thermometer. We heated a PCM with a transition temperature of 72 °F with ~160 °F water to approximate warmed process cooling water, and with a heat lamp to mimic solar heating. The pad, placed in a standard sleeping bag outdoors at an ambient temperature of ~50 °F, maintained the bag's internal air temperature at ~70 °F or >15 °F above ambient for well over 12 hours. Scaling calculations reveal that each full-size pad would only cost about $3 USD. This concept thus appears to have excellent technical and economic viability.

**Keywords:** phase change material; latent heat; overnight heat source; paraffin wax; waste heat usage

## 1. Introduction

Phase change materials (PCMs) are substances that undergo a phase transition at a certain temperature. We are all familiar with solid-to-liquid transitions like ice melting—this is a common type of phase change known as a change of state. Some phase changes are more subtle, involving molecular-level rearrangements not visible to the naked eye [1]. For heating, cooling, and other thermal management applications, certain PCMs are attractive because their phase transitions store or release large amounts of heat energy, known as "latent heat" [2]. In the late 1930s, Maria Telkes and Hoyt Hottel began researching applications of PCMs for solar-heated homes and buildings [3]. Cui et al. categorized different implementations of PCMs in buildings as passive or active depending on whether or not the system requires additional power [4]. PCMs have also been incorporated into automobiles to reduce energy consumption associated with heating and cooling [5]. Because PCMs can store heat and release it at a different time or location, they are sometimes referred to as "thermal batteries."

This project explores the feasibility of using PCMs to help those sleeping outdoors or in tents, either by choice (e.g., when camping) or involuntarily (due to poverty), stay warm overnight. Specifically, we investigated methods of heating scale models of PCM-based sleeping bag inserts during the day and measured how much and for how long they released heat at night.

A somewhat similar application of PCMs is the Embrace sleeping bag launched in India in 2011 to keep premature babies warm in hospitals to free up space in scarce, expensive incubators [6,7]. Some key differences between this work and that of Embrace are: (1) we quantitatively investigated different methods of heating the PCMs; (2) we present performance data for multiple heating

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



methods and PCM substances and; (3) Embrace's product was designed for indoor use and to maintain a temperature close to that of the human body (95–99 °F).

The two types of daytime heating methods we simulated and compared are solar-thermal (greenhouse) and warm or hot "return" cooling water. It is important to the success of this application for the sources of heat to be inexpensive or free and that they generate little to no additional greenhouse gas emissions. Solar energy fits the bill extremely well, but can it be sufficient for this demanding-use case? Regarding process cooling water [8–10], large data centers have attracted substantial media attention over the last few years because many have been built or are scheduled for construction to satisfy the public and corporations' demand for cloud computing, data storage, and artificial intelligence [11]. These data centers generate tremendous quantities of waste heat that is almost never put to productive use and, in some cases, causes environmental degradation [11]. Local data centers thus appear to be an ideal source of daytime heat for PCM-based thermal batteries distributed to nearby unhoused populations to allow them to sleep at a safe, comfortable temperature.

## 2. Materials and Methods

The primary PCM tested was a Cryopak-22 PCM warm pack. This is a paraffin wax-type PCM and has a phase transition temperature of 22 °C (71.6 °F). A fresh pack was used for each temperature monitoring trial, though this was most likely not necessary [12]. Each Cryopak had a mass of 167 g (5.9 oz) and dimensions of 13 cm × 10.4 cm × 2 cm. The retail price paid for each Cryopak was $6.25 USD. A comparable 167 g mass of Vaseline brand petroleum jelly in a zipper lock plastic bag was also tested as a potential alternative PCM material.

The PCMs were heated in two ways: immersion in warm water at about 160 °F to simulate return water from a cooling loop, and by placement ~3 inches from a 75-watt heat lamp (TFNN, WGD-001) to simulate a solar greenhouse. The return cooling water simulation fully melted the PCM pack within 15 minutes. The heat lamp fully melted the PCM pack after 30–60 minutes.

To maintain a constant volume of air inside the sleeping bag across experiments, an 8.6-liter box was placed inside the footbed of the bag (Figure 1). At the beginning of a timed PCM trial, a melted PCM pack was placed in the box within the sleeping bag. Temperatures were measured with a SUPCO DVT4 multi-probe device with digital display. Probe #1 was placed under the PCM to measure its surface temperature while Probe #2 was suspended in the box to measure the air temperature inside the sleeping bag. The sleeping bag was then wrapped around the box in such a manner that the air volume within the sleeping bag was essentially the volume of the box. Probe #3, internal to the thermometer, measured the temperature of the outside ambient air. Temperatures were then recorded over 24 hours.

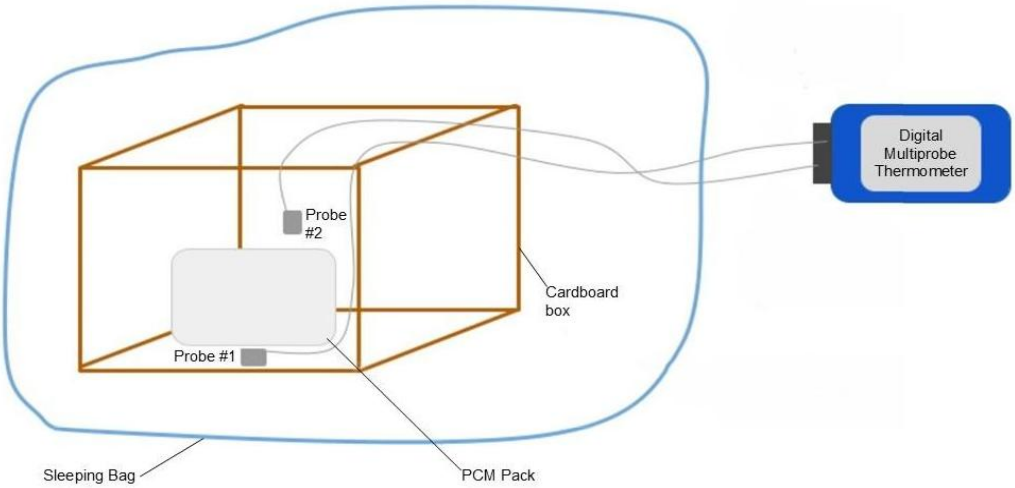


**Figure 1.** Diagram of temperature monitoring system.

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



For each timed trial, the recorded temperatures from the three probes were plotted versus time. Four primary trials were run: water-heated Cryopak-22, lamp-heated Cryopak-22, lamp-heated Vaseline, and a no-PCM control.

## 3. Results

Figure 2 is a plot of the no-PCM control trial. As expected, the temperature within the sleeping bag is essentially the same as the ambient outdoor temperature at all times. We see that after about 10 hours, all three probe temperatures rose. This was due to the sun rising in the morning. This must be noted, as it affected the other time-course measurements as well.

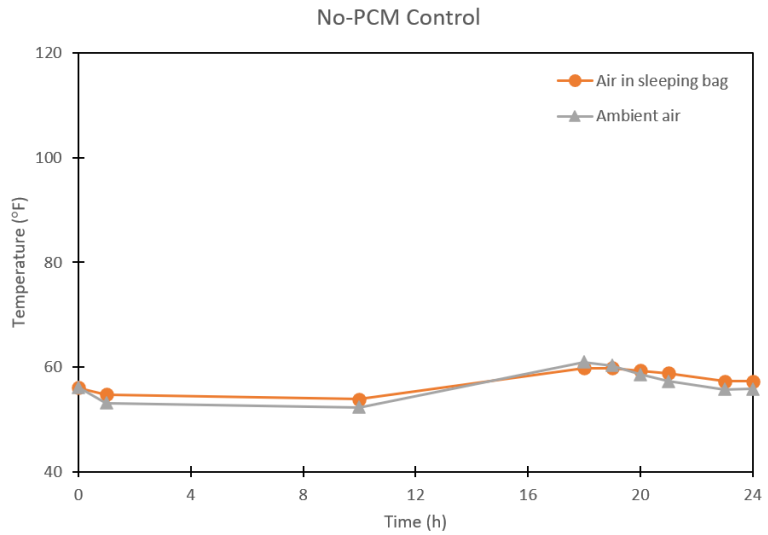


**Figure 2.** No-PCM control trial time course temperature profiles.

Figure 3 is a plot of a water-heated Cryopak trial. Here we see a much higher temperature measured by the probes inside the sleeping bag vs. ambient. From about 2 to 9 hours, the ambient temperature was fairly steady around 54 °F and the temperature of the air within the sleeping bag was about 71 °F, just shy of the Cryopak's transition temperature. After 15 hours, well into the morning and longer than overnight heat is required, the sleeping bag air temperature was 70 °F and the ambient temperature had warmed to 60 °F.

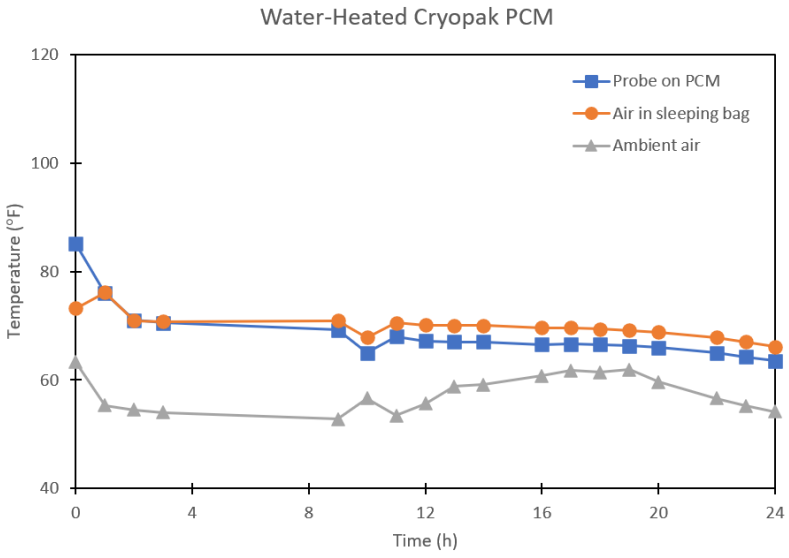


**Figure 3.** Water-heated Cryopak PCM trial time course temperature profiles.

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



For the lamp-heated PCM trial shown in Figure 4, the results are similar to the water heated trial, except we observe a higher initial PCM temperature. At about 4 hours, the sleeping bag air measured 71 °F and the ambient temperature was 54 °F. These temperatures were quite steady until 16 hours, when the ambient temperature reversed its cooling trend due to the sunrise. At 19 hours elapsed time, the inside air measured 63 °F and the ambient temperature was once again 54 °F.

We also tested Vaseline as a potential PCM while waiting for the Cryopak to arrive. Vaseline is petroleum jelly, which shares chemical similarities with paraffin wax, and is less expensive than PCMs. Figure 5 shows the temperature data for a trial with lamp-heated Vaseline. We see it did not supply heat as long as the Cryopak PCM under similar conditions. Compared with the results for the lamp-heated Cryopak in Figure 4, which supplied heat for the entire 24 hours, the lamp-heated Vaseline supplied heat for only about 8 hours, after which the air temperature within the sleeping bag had cooled to about the same as ambient. At 5 hours elapsed time, the sleeping bag air was only 5 °F warmer than ambient.

As discussed earlier, the prewarmed PCM trial data were obtained with a scaled-down experimental setup (Figure 1). To determine how large a PCM pack should be for a full-size human sleeping in a sleeping bag, scaleup calculations are required. There are several possible scaling principles that could be applied. We considered the most applicable approach was to scale by air volume. For our trials, the volume of air inside the sleeping bag footbed is approximately equal to that of the box: 8.6 L. Considering a full-size human in a sleeping bag, the total body volume of an average person is about 60 L [13]. Sleeping bags are not rigid and touch the occupant's body on the top and bottom surfaces. We estimate that the air volume between the occupant's body and the inside surface of the sleeping bag to be about 20% of the body's volume, or 12 L.

Scaling by air volume means that the scaling factor for full size / model size is 12 L / 8.6 L or 1.4. We observed more than acceptable performance with a single Cryopak-22 with a mass of 167 g. Therefore, at full size, we expect to observe equivalent performance from 1.4 · 167 g = 240 g of Cryopak-22 material, ideally with the same thickness of 2 cm. We paid a retail price of US$6.25 for each Cryopak-22 PCM pack. Assuming a bulk price for that PCM material of 30% of retail gives a material price of less than $3 for 240 g.

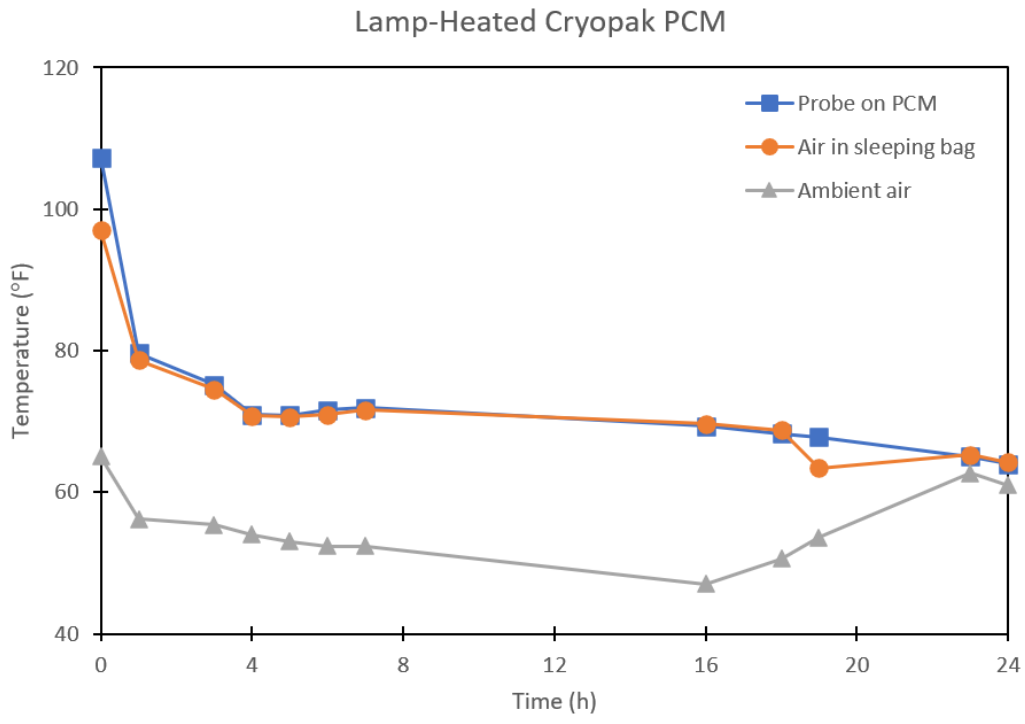


**Figure 4.** Lamp-heated Cryopak PCM trial time course temperature profiles.

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



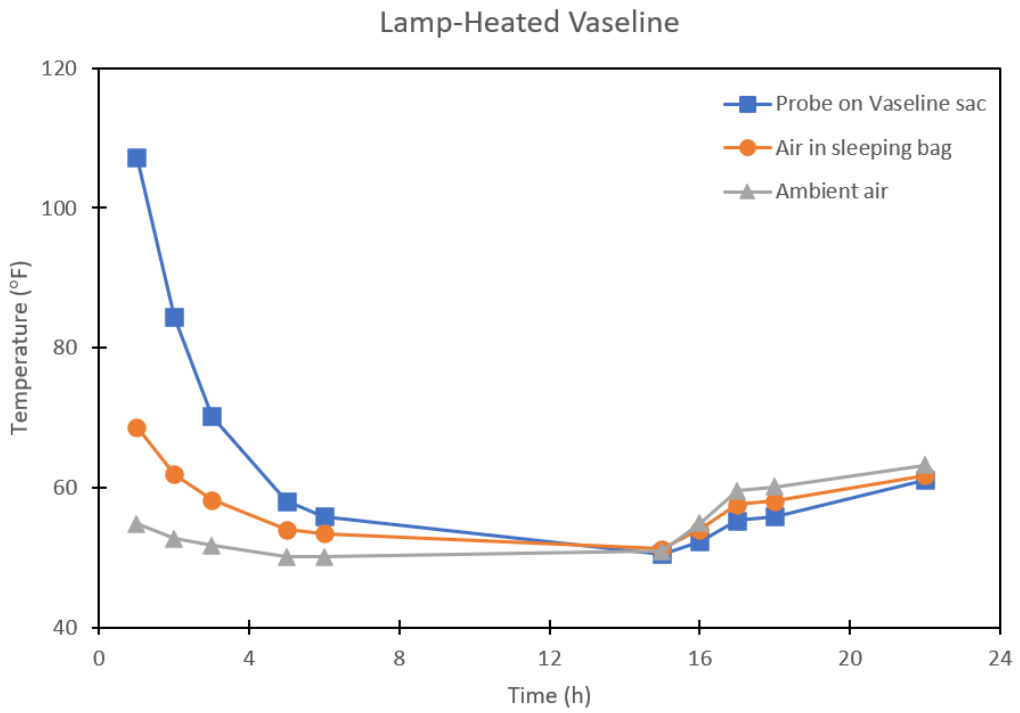


**Figure 5.** Lamp-heated Vaseline trial time course temperature profiles.

## 4. Discussion

In the warmed PCM trials, the air temperature within the sleeping bag was 15–20 °F higher than the ambient air for the first ~12 hours (Figures 3 and 4). This is a full overnight period and means that, if the size of the PCM pad is properly scaled to a full-size sleeping bag occupied by a person, the occupant should experience a comfortable temperature. Without a PCM pack, the sleeping bag's occupant's body would still emit heat. This was not included in our experiments or calculations. Some high-end sleeping bags can be sufficient under certain conditions, such as dry environments, for the occupant to be comfortably warm without an additional heat source, even in freezing outdoor weather. However, many people sleep outdoors due to poverty and lack access to high-end sleeping bags and dry conditions. These individuals can use all the help they can get to stay warm at night.

The scaling calculations indicate that each full-sized PCM pack would cost as little as $3 for materials. Furthermore, temperature cycling of paraffin wax PCMs has been studied with very encouraging results. These materials can undergo 10,000 thermal cycles with only a 9% reduction in latent heat capacity [12].

Our test of Vaseline was enlightening. Despite its chemical similarities with paraffin wax, it provided heat for a much shorter time than the Cryopak-22. We also observe no steady temperature period for Vaseline in Figure 5. Although the Vaseline had melted or at least become less viscous from the heat lamp, it probably doesn't undergo as abrupt a phase change as paraffin wax. Also, to our understanding, Vaseline is a mixture of molecules of varying size, while a paraffin wax PCM is much more uniform in molecular mass. The lack of a uniform transition temperature for Vaseline is likely the reason why a period of steady temperature was not seen in its cooling profile. Although Vaseline is not technically a PCM, it may be useful as a lower-cost alternative to PCMs for short time periods, e.g., for hot packs in winter sports apparel. On the other hand, since paraffin wax PCMs can already be quite inexpensive and eminently reusable, they are also a sound choice for short-term applications.

In terms of PCM heating methods, our heat lamp setup was not a realistic model for solar heating. Placing a material 3 inches from a 75-watt lamp indoors is much more intense than heating from the sun. We had planned to build a model solar greenhouse for these experiments but lacked time to complete the task. Literature research on solar greenhouses shows that they can easily

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



maintain daytime temperatures above the 72 °F melting temperature of Cryopak-22, and can top 120 °F for extended periods [14]. Solar greenhouses therefore appear to be a realistic source of daytime heat for this application.

We consider our warm water trials a realistic simulation of using return water from an industrial or other facility's cooling loop to heat PCMs. In particular, large data centers have attracted substantial media attention because many have been built or are scheduled for construction to satisfy increasing demand for cloud computing, data storage, and artificial intelligence [11]. These data centers generate tremendous quantities of waste heat that is almost never put to productive use. In some cases, data centers have been observed discharging warm water into local waterways, resulting in environmental degradation [11]. Local data centers thus appear to be an ideal source of daytime heat for PCM-based thermal batteries distributed to nearby unhoused populations to allow them to sleep at a safe, comfortable temperature.

The question arises of whether other applications for so much waste heat could be more advantageous. Carnot's 200-year-old thermal efficiency Equation (1) for a heat engine operating between two thermal reservoirs provides elegant insight:

$$\eta = 1 - \frac{T_C}{T_H} \quad (1)$$

where $\eta$ is the maximum possible efficiency, $T_C$ is the temperature of the cold reservoir, and $T_H$ is the temperature of the hot reservoir, both in absolute units [15]. Because the absolute temperature of the warm cooling water is only about 10 or 20% higher than the ambient temperature in a typical data center cooling loop, the maximum possible efficiency of converting this temperature difference into mechanical work would be on the order of 10%. Industrial processes running at much higher temperatures would be a different story. However, it is likely that the excess heat energy from such operations is already being used elsewhere in the facility. The massive loss of efficiency inherent in converting heat from warm cooling water from data centers or similar facilities into other forms of energy makes it generally advisable to use the harvested heat energy directly as heat itself, or for melting a PCM that is later frozen by releasing the stored latent heat, which has an estimated "round trip" efficiency of 75 to 90% [16].

We performed a calculation for a 10 MW data center, which corresponds to a moderate size (large ones can be over 100 MW). A 10 MW data center produces 360 million kJ of waste heat in 10 hours. A single Cryopak-22 mat weighing 240 g has a latent heat of fusion of about 200 kJ/kg · 0.240 kg = 48 kJ. Dividing 360 million kJ by 48 kJ gives 7.5 million. This means that a 10 MW data center produces enough waste heat every day to melt >7 million full-size PCM mats. There is clearly ample heat; the main problem would become the logistics of gathering and arraying PCM packs to be warmed by the return water. There is surely a space limitation that is much lower than 7 million mats for one data center.

## 5. Conclusions

For this project, we explored and technically evaluated the concept of using phase-change materials to provide overnight heat to people without heated shelter. Our technical results on how much heat can be supplied and for how long by Cryopak-22, a paraffin wax PCM, exceeded our expectations. Sleeping bags left outdoors that began the night with a melted PCM pack maintained 15–20 °F warmer air inside than the ambient temperature for the entire night (>12 hours). Volumetric scaling of the results indicates that each full-size mat would cost less than $3 in materials and a calculation of the waste heat produced by a single 10-MW data center shows it wastes enough heat for millions of full-size PCM packs. Solar greenhouses also appear to be a viable option for daytime heating. Therefore, our results and calculations are extremely encouraging for the feasibility of this concept.

This project has demonstrated the technical feasibility and partial economic feasibility of using thermal batteries made from a paraffin wax PCM like Cryopak-22 to absorb waste or solar heat during the daytime and provide needed heat to vulnerable populations at night. By partial economic

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



feasibility, we mean that the material costs for the PCM packs are very inexpensive, but the logistical costs of collecting, heating, and distributing them remain the subject for a future investigation. We believe our society can and should do better by our least fortunate and are determined to discover and secure resources to study the economics and logistics of implementing a program based on this promising research.

**Author Contributions:** Conceptualization, O.M.A. and A.V.T.; methodology, O.M.A. and A.V.T.; data collection, O.M.A.; data analysis and visualization, O.M.A. and A.V.T.; writing—original draft preparation, O.M.A. and A.V.T.; writing—review and editing, O.M.A. and A.V.T.; supervision, A.V.T. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** The raw data used to generate the figures in this article will be made available by the corresponding author on request.

**Acknowledgments:** O.M.A. is grateful to her parents for emphasizing education and providing her with so many opportunities. A.V.T. thanks his family for their unwavering support.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| PCM | phase change material |
| MW | megawatt |
| kJ | kilojoule |

## References

1. Cahn, R.W. Phases and Crystal Structures. In *Pergamon Materials Series*; Pergamon Press: Oxford, UK, 2007; pp. 1–86. (https://doi.org/10.1016/S1470-1804(07)80054-X)
2. Cartagenas, I. Phase Change Material (PCM). Thermtest Inc., 2024. Available online: https://thermtest.com/phase-change-material-pcm (accessed on 31 December 2025).
3. Rinde, M. The Sun Queen and the Skeptic: Building the World's First Solar Houses. *Distillations Magazine*, 2020. Available online: https://www.sciencehistory.org/stories/magazine/the-sun-queen-and-the-skeptic-building-the-worlds-first-solar-houses (accessed on 13 November 2025).
4. Cui, Y.; Xie, J.; Liu, J.; Wang, J.; Chen, S. A review on phase change material application in building. *Adv. Mech. Eng.* **2017**, *9(6)*, 1–15. (https://doi.org/10.1177/1687814017700828)
5. Nicolalde, J.F.; Cabrera, M.; Martínez-Gómez, J.; Salazar, R.B.; Reyes, E. Selection of a PCM for a Vehicle's Rooftop by Multicriteria Decision Methods and Simulation. *Appl. Sci.* **2021**, *11(14)*, 6359. (https://doi.org/10.3390/app11146359)
6. Embrace Global: Creating a world in which all premature babies have access to warmth. Available online: https://www.embraceglobal.org (accessed on 13 November 2025).
7. Upbin, B. The Sleeping Bag That Will Save Thousands of Babies. *Forbes*, 21 December 2010. Available online: https://www.forbes.com/sites/bruceupbin/2010/12/21/the-sleeping-bag-that-will-save-thousands-of-babies (accessed on 13 November 2025).
8. Loibl, W.; Stollnberger, R.; Österreicher, D. Residential Heat Supply by Waste-Heat Re-Use: Sources, Supply Potential and Demand Coverage—A Case Study. *Sustainability* **2017**, *9*, 250. (https://doi.org/10.3390/su9020250)
9. Wehbi, Z.; Taher, R.; Faraj, J.; Ramadan, M.; Castelain, C.; Khaled, M. A short review of recent studies on wastewater heat recovery systems: Types and applications. *Energy Rep.* **2022**, *8*, 896–907. (https://doi.org/10.1016/j.egyr.2022.07.104)

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 15 June 2026 doi:10.20944/preprints202606.1093.v1



10. Yuan, M.; Vad Mathiesen, B.; Schneider, N.; Xia, J.; Zheng, W.; Sorknæs, P.; Lund, H.; Zhang, L. Renewable energy and waste heat recovery in district heating systems in China: A systematic review. *Energy* **2024**, *294*, 130788. (https://doi.org/10.1016/j.energy.2024.130788)
11. Yañez-Barnuevo, M. Data Centers and Water Consumption. Environmental and Energy Study Institute, Washington, DC, USA, 2025. Available online: https://www.eesi.org/articles/view/data-centers-and-water-consumption (accessed on 6 February 2026).
12. Zhang, L.; Dong, J. Experimental study on the thermal stability of a paraffin mixture with up to 10,000 thermal cycles. *Therm. Sci. Eng. Prog.* **2017**, *1*, 78–87. (https://doi.org/10.1016/j.tsep.2017.02.005)
13. Bianconi, E.; Piovesan, A.; Facchin, F.; Beraudi, A.; Casadei, R.; Frabetti, F.; Vitale, L.; Pelleri, M.C.; Tassani, S.; Piva, F.; et al. An estimation of the number of cells in the human body. *Ann. Hum. Biol.* **2013**, *40*, 463–471. (https://doi.org/10.3109/03014460.2013.807878)
14. García-Vázquez F.; Ponce-González, J.R.; Guerrero-Osuna, H.A.; Carrasco-Navarro, R.; Luque-Vega, L.F.; Mata-Romero, M.E.; Martínez-Blanco, M.R.; Castañeda-Miranda, C.L.; Díaz-Flórez, G. Prediction of Internal Temperature in Greenhouses Using the Supervised Learning Techniques: Linear and Support Vector Regressions. *Appl. Sci.* **2023**, *13*, 8531. (https://doi.org/10.3390/app13148531)
15. Carnot S. Réflexions sur la Puissance Motrice du Feu et sur les Machines propres à Dévelopeer cette Puissance. Bachelier: Paris, France, 1824.
16. Pompei, L.; Nardecchia, F.; Miliozzi, A. Current, Projected Performance and Costs of Thermal Energy Storage. *Processes* **2023**, *11*, 729. (https://doi.org/10.3390/pr11030729)

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© 2026 by the author(s). Distributed under a Creative Commons CC BY license.