

Harnessing Phase Changing Materials for Thermal Storage: A Sustainable Solution to Reduce Peak Electricity Demand and Support Decarbonization

Efe Altinkaya

Abstract

The U.S. transition to decarbonization involves replacing fossil fuel-dependent systems with electric alternatives to reduce greenhouse gas emissions. However, this shift significantly stresses power grids, particularly during peak electricity demand periods. To alleviate this burden, this project explores the integration of a Phase Changing Material (PCM) thermal storage system in HVAC heating systems to reduce peak demand by storing heat during off-peak hours. The research question addressed is: *Can a PCM-based thermal storage system effectively reduce electricity demand in HVAC systems while maintaining consistent heat storage to have an impact on facilitating the process of total decarbonization?* To test this, a prototype HVAC system was developed, incorporating a double-walled PCM tank filled with sodium acetate trihydrate, along with PVC connectors, a fan coil, and a pump. The system was tested over four trials, during which temperatures in the PCM and heat tanks were recorded at regular intervals of 30 and 15 seconds to monitor phase change behaviors. The results collected from the prototype show that the PCM consistently underwent phase changes, absorbing and releasing latent heat effectively. Thus, this approach has the potential to be implemented in residential, commercial, and industrial buildings to support the broader goals of decarbonization by spreading out peak electricity demands on power centrals and power lines. While promising, further research is required to address scalability and integration into real-world HVAC systems. Nonetheless, this approach offers significant potential for residential, commercial, and industrial applications, reducing grid strain and advancing decarbonization efforts.

Keywords:

Decarbonization: a method of climate change mitigation and the process of significantly reducing or eliminating carbon dioxide and other greenhouse gas emissions from the atmosphere.

Electrification: the process of replacing technologies that use fossil fuels (coal, oil, and natural gas) with technologies that use electricity as a source of energy.

Powerlines/Powercentrals: powerlines are electrical cables or networks used to transmit electricity from power generation sources to end users, such as buildings. Powercentrals are facilities that convert various forms of energy into electricity.

Phase Changing Material (PCM): substances that absorb and release a significant amount of latent heat when they undergo phase changes. PCMs can be used in thermal storage applications to regulate temperature by storing excess heat and releasing it when needed.

Introduction

The global energy landscape is facing a critical challenge due to the unsustainable consumption and supply of energy. According to the International Energy Agency (IEA), global electricity consumption and production are steadily increasing, necessitating urgent action. In response, the U.S. has committed to decarbonization by transitioning systems reliant on fossil fuels to electric alternatives, including the widespread adoption of all-electric and hybrid vehicles. However, this places a significant burden on power grids, particularly during peak hours when electricity demand is at its highest. This problem will eventually lead to improvement of power centrals, and the power lines that carry the electricity will need to be renewed. However, addressing this issue often requires costly upgrades to power plants and infrastructure, a process that is both time-consuming and resource-intensive.

This project aims to mitigate the load on the electrical grid by storing heat during off-peak hours, thereby spreading the load to a wider time period. Heating and cooling systems, which are major contributors to electricity consumption, offer significant potential for energy savings when optimized for efficiency. In a real-life situation, a PCM Tank would be inserted into every home's heating system, therefore creating the freedom to use electricity whenever.

This would spread the load due to electricity being able to be used at different time periods and solve the grid problem. Management of this system would be controlled by electricity companies or the city to further ensure an effective way of spreading the load.

Scholarly Conversation 'Lit Review'

One change that has been done to decarbonize and convert to the usage of electricity is heat pumps. Heat pumps are known for their efficiency, which is estimated to a range of 300%-400%, meaning they nearly give 3-4 times as much energy in the form of heat as they're using electricity (Crownhart, 2023). A complementary solution involves integrating PCMs, which are usually water-based, organic material based, or are salt hydrates, which is what is used in this experiment. Compared to their size, these materials have surprisingly high capacities as they are able to absorb and release high amounts of latent heat while they undergo phase changes (Avery, 2023). In addition, building systems are a key factor on the heating and cooling loads of a building and present potential to reduce the weight on energy demands. One method to achieve this is to incorporate PCMs into the building's structure. Many projects have been done on incorporating PCMs into different parts of buildings, testing its efficiency (Dardouri, 2023).

Unlike previous studies that incorporated PCMs into building materials, this research specifically focuses on using PCMs directly within HVAC systems due to them posing a more effective approach towards decarbonization.

A study in Morocco tested PCM integration across diverse climates, confirming their adaptability and effectiveness depending on resource availability and amount (Lounate, 2021). This study seeks to fill the research gap by developing and testing a PCM-based thermal storage system within HVAC heating systems. By storing thermal energy during off-peak hours and releasing it during peak demand, this approach aims to alleviate grid stress and advance decarbonization efforts. While much attention has been given to structural integration, less research exists on using PCMs within HVAC systems for active thermal storage.

Renewable energy is expected to play a significant role in this effort, but its variability and unpredictability pose challenges for grid operators, who must balance supply with fluctuating demand. According to past studies, "The world's renewable energy power generation capacity more than doubled from 1,223 GW in 2010 to 2,532 GW in 2019" (Shen, et al. 2021). From the Lawrence Berkeley National Laboratory, Bo Shen, et al. discuss a study on the usage of DER (Distributed Energy Sources) and business designs to facilitate the electrical load on power grids due to decarbonization. Distributed energy resources (DERs)—such as localized energy generation, demand response systems, and *energy storage solutions*—offer critical flexibility to support the integration of large amounts of renewable energy into the grid (Shen, et al. 2021). By the thorough analysis of the statistics retrieved, the paper ultimately concludes that DERs are able to function effectively with the use of correct business designs (time-of-use rate, critical peak pricing, variable peak pricing, real-time pricing) and reforming existing utility regulatory models to shift the roles, responsibilities, and incentives of electric utilities away from building more traditional generation and grid infrastructure. Energy storage solutions mentioned, such as the usage of PCMs in thermal storage, is supported for real-life usage through the correct design required for it to function.

Another method for cleaning up the grid is the usage of batteries to store electricity. Multiple states are making advancements towards using large batteries to store a communities' electricity needs in order to decrease the load on the grid. The California projects are part of a global trend, including Tesla's 100-megawatt battery array in South Australia, to develop increasingly large lithium-ion storage systems as costs decrease and renewable energy generation expands. "Today's battery storage technology works best in a limited role, as a substitute for "peaking" power plants, according to a 2016 analysis by researchers at MIT and Argonne National Lab. These are smaller facilities, frequently fueled by natural gas today, that can afford to operate infrequently, firing up quickly when prices and demand are high" (Temple, 2018). Lithium-ion technology faces significant challenges in this role due to its high cost and limited lifespan, making it poorly equipped to address prolonged deficits in wind and solar energy production, which can last for days, weeks, or even months. This issue is especially pronounced in California, where wind and solar generation decline sharply during the fall and winter seasons. The

core challenge arises when renewable energy dominates the grid: an enormous surplus of wind and solar capacity is required during peak production periods to compensate for the extended seasonal drops and ensure reliable grid operation (Temple, 2018). It is known that a lithium battery's lifespan is from 300-500 charges or about 2.5 years. However, a PCMs life span, if used right, is infinite. This is because a PCM is able to phase change as many times as it is possible to. As long as it is contained in a regulated and a well-built tank, it will be used forever and certainly more than batteries. It should also be kept in mind that studies or any relevant findings on energy-saving technologies are not solutions for the grid load but rather a factor in determining what type of energy will be used in order to electrify. This study contributes to the field by directly addressing the operational aspects of HVAC systems, offering a novel perspective on their application in energy-efficient building design. Future studies should explore comparisons with alternative energy-saving technologies to better contextualize the benefits and challenges of PCM systems.

Methods

A prototype mimicking a simple HVAC system was developed to test the efficiency of a PCM tank in a heating system. To mimic the heat resistance, a heat tank was used. The prototype comprised a heat tank, a double-walled PCM tank, PVC connectors, valves, a fan coil, thermometers inside each tank and the fan coil, and a pump. A salt hydrate, sodium acetate trihydrate ($\text{NaC}_2\text{H}_3\text{O}_2 \cdot 3\text{H}_2\text{O}$) was used as the PCM, placed inside the inner wall of the tank. 219 grams of the PCM was used during testing. During the testing of the prototype, data of the temperatures was collected every 30 seconds and every 15 seconds during phase changes of the PCM. The temperature difference between the tanks was kept more than 50°F and the temperature of the heat tank was kept under 185°F to maximize accuracy and to keep the prototype at the best condition. Standard thermometers that are used in fish tanks were used with 0.1 data display. There were a total of 4 trials and a data set averaging of those 4 trials was created. The graphs and tables in this paper are the result of that data table. In a real-world setting, as discussed above, the effectiveness of a PCM tank in a heating system is theoretically possible if the right actions are taken. A real life PCM tank would be a double-walled tank with water flowing in the first layer and the PCM inside the second layer. Quality insulators would be used to minimize heat loss during phase changing and maximizing heat storage. The design of the tank would be really similar to a simple water and a heat tank. However, because this has not been tested yet, the design is likely to be changed in the future. But for now, the following designs in the bottom of this section show to be efficient due to them being so similar to what is already built. Because of this, the production of these tanks, as well as the PCM (which are easily manufactured, and some of them are even natural), will likely be cheaper and easier than improving the grid which will take billions of dollars.

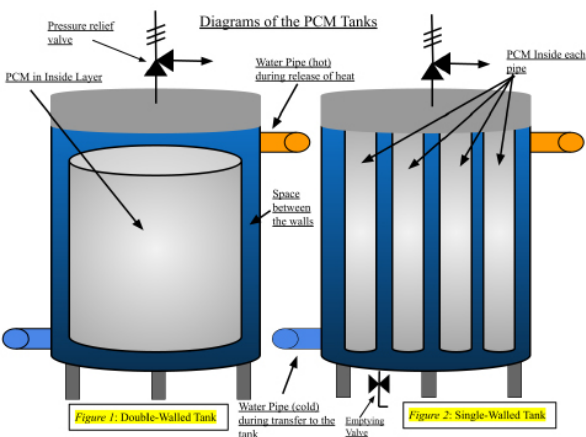


Image 1: Designs of two possible PCM Tanks with pressure valves and cold and hot water flow directed in the diagram. Emptying valve also included in the first model (model on the right, aka the model that was used in this experiment).

Procedures

- 1. Prototype Assembly:** Constructed a basic HVAC system prototype with a heat tank, PCM tank, PVC connectors, valves for system control, a fan coil, and a 12V DC pump. Thermometers were placed inside each tank and the fan coil.
- 2. PCM Tank Preparation:** Assembled the double-walled PCM tank, filling the inner layer with sodium acetate trihydrate. The system was designed so that water could flow between the tank's inner and outer walls.
- 3. System Integration:** Integrated the PCM tank into the HVAC system. Dealt with any design errors and fixed them.
- 4. Initial Circulation:** Activated the system, circulating water through the heat tank and PCM tank, controlling water flow using the valves.
- 5. Temperature Monitoring:** Maintained the heat tank temperature below 185°F. The temperature difference between the heat and PCM tanks was kept above 50°F to have efficient transfer of heat.
- 6. Phase Change Observation:** As the PCM tank temperature neared 137°F, data was collected every 15 seconds to monitor the phase change. The system was continuously heated to observe the phase change behavior.
- 7. Heat Transfer to Fan Coil:** Once the PCM tank temperature reached 140-145°F, water was redirected from the PCM tank to the fan coil. Temperature data from both the PCM tank and fan coil was recorded every 30 seconds until the fan coil's temperature approached room temperature (75-80°F).
- 8. Testing:** The prototype was tested a total of 4 times. The average of that data was taken and put into one data set.

Temperature trends were analyzed to confirm phase changes. Statistical methods, including two-way ANOVA, were employed to validate the reliability and consistency of the results.

Data Graphs

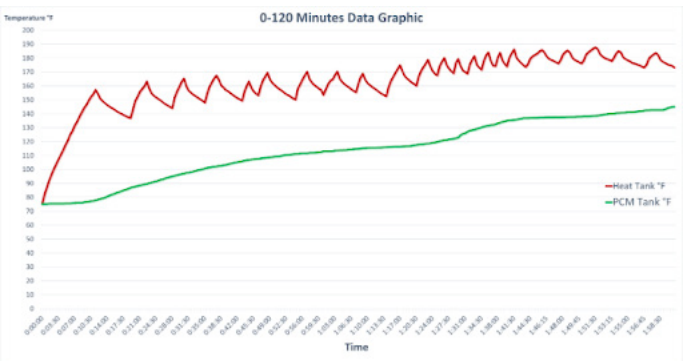


Fig. 1. Temperature of Heat and PCM tanks vs. time- Collected from prototype testing

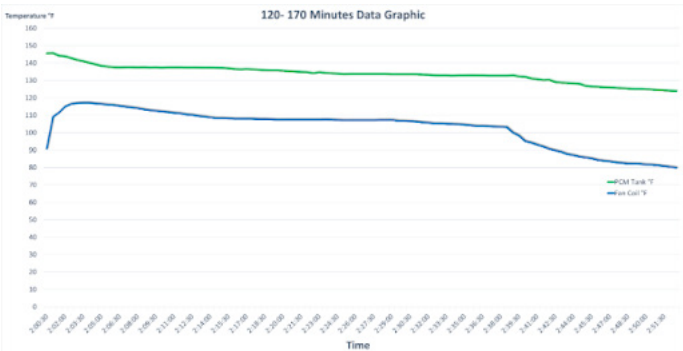


Fig. 2. Temperature of Heat and Fan Coil vs. time- Collected from prototype testing

Tables

The following tables are averages for the 4 trials for each time period.

Time	Heat Tank	PCM Tank	Heater	Fan Coil	Time	Heat Tank	PCM Tank	Heater	Fan Coil
0s	75.3	75.3	ON	75.3	15m 30s	143.2	82.5		
30s	82	75.3		75.3	16m	141.9	83.3		
1m	87	75.3		15.3	16m 30s	141	83.8		
1m 30s	92.3	75.5		75.3	17m	140.1	84.5		
2m	96.4	75.5		75.3	17m 30s	139.2	85.1		
2m 30s	100.2	75.5			18m	138.3	85.6		
3m	103.6	75.5			18m 30s	137.6	86.1		
3m 30s	107.2	75.5			19m	136.9	86.9	ON	
4m	110.4	75.5			19m 30s	142.3	87.3		
4m 30s	113.9	75.5			20m	149.1	87.6		
5m	117.5	75.7			20m 30s	152	88.1		
5m 30s	120.7	75.7			21m	155.8	88.7		
6m	125	75.7			21m 30s	157.8	88.9		
6m 30s	127.5	75.9			22m	159.9	89.4		
7m	131.5	75.9			22m 30s	163.2	89.7	OFF	
7m 30s	134.2	76.1			23m	158.5	90.3		
8m	137.8	76.2			23m 30s	154.9	90.6		
8m 30s	141	76.2			24m	153.1	91.2		
9m	144.1	76.6			24 30s	151.8	91.5		
9m 30s	146.4	76.8			25m	150.6	92.1		
10m	149.5	77			25m 30s	149.5	92.6		
10m 30s	152.2	77.3			26m	148.2	93		
11m	154.2	77.5			26m 30s	147	93.7		
11m 30	157.1	78	HEAT OFF		27m	146.1	94.1		
12m	154.4	78.4			27m 30s	145	94.6		
12m 30	150.8	78.9			28m	144.1	95.1	ON	
13m	149.1	79.3			28m 30s	151.7	95.5		
13m 30s	147.7	79.8			29m	156	96		
14m	146.3	80.6			29m 30s	159.4	96.4		
14m 30s	145.2	81.3			30m	163	96.8		
15m	144.1	82							

Table 1. 0 minutes-15 minutes

Table 2. 15 minutes 30s-30 minutes

Time	Heat Tank	PCM Tank	Heater	Fan Coil
30m 30s	165.3	97.1	OFF	
31m	159.9	97.7		
31m 30s	156.7	97.8		
32m	155.3	98.2		
32m 30s	153.8	98.6		
33m	152.7	99.1		
33m 30s	151.5	99.5		
34m	150.4	99.8		
34m 30s	149.3	100.2		
35m	148.1	100.7	ON	
35m 30s	154.5	101.1		
36m	159.4	101.4		
36m 30s	162.5	101.8		
37m	165.5	102		
37m 30s	167.5	102.3	OFF	
38m	164.4	102.5		
38m 30s	160.5	102.7		
39m	158.9	103.1		
39m 30s	157	103.4		
40m	156.3	103.8		
40m 30s	154.9	104.3		
41m	153.6	104.7		
41m 30s	152.4	105		
42m	151.3	105.4		
42m 30s	150.4	105.6		
43m	149.3	105.9	ON	
43m 30s	155.8	106.3		
44m	159.9	106.7		
44m 30s	163.2	106.8	OFF	
45m	158.5	107.2		

Table 3. 30 minutes 30s- 45 minutes

Time	Heat Tank	PCM Tank	Heater	Fan Coil
45m 30s	156	107.4		
46m	154.5	107.6		
46m 30s	153.3	107.7	ON	
47m	159.8	107.9		
47m 30s	164.1	108.1		
48m	166.8	108.5		
48m 30s	169.5	108.6	OFF	
49m	164.4	108.8		
49m 30s	162.1	109		
50m	160.7	109.2		
50m 30s	159	109.4		
51m	157.8	109.5		
51m 30s	156.7	109.9		
52m	155.4	110.3		
52m 30s	154.2	110.4		
53m	153.3	110.6		
53m 30s	152.2	110.8		
54m	150.9	111		
54m 30s	150.2	111.2	ON	
55m	158.1	111.3		
55m 30s	161.2	111.5		
56m	164.6	111.7		
56m 30s	167.5	111.7		
57m	170.2	111.7	OFF	
57m 30s	164.8	112.1		
58m	162.5	112.1		
58m 30s	160.8	112.1		
59m	159.6	112.2		
59m 30s	158.1	112.4		
1hr	157.1	112.6		

Table 4. 45 minutes 30s- 1 hour

Time	Heat Tank	PCM Tank	Heater	Fan Coil
1hr 30m 30s	171	125.7		
1hr 31m	170	126.1		
1hr 31m 30s	168.8	127.2	ON	
1hr 32m	175.4	127.9		
1hr 32m 30s	178.8	128.3		
1hr 33m	181.5	128.6	OFF	
1hr 33m 30s	175.2	129.2		
1hr 34m	173.3	129.7		
1hr 34m 30s	171.6	130.2	ON	
1hr 35m	178.1	130.8		
1hr 35m 30s	181.9	131.3		
1hr 36m	184.1	131.5	OFF	
1hr 36m 30s	178.1	131.9		
1hr 37m	174.6	132	ON	
1hr 37m 30s	174.3	132.6		
1hr 38m	180.3	133.1		
1hr 38m 30s	183.9	133.7	OFF	
1hr 39m	178.3	134.2		
1hr 39m 30s	175.8	134.6		
1hr 40m	174	135.1	ON	
1hr 40m 30s	180.1	135.3		
1hr 41m	183.5	135.5		
1hr 41m 30s	186.2	135.6	OFF	
1hr 42m	180.5	135.8		
1hr 42m 30s	178.3	136.2		
1hr 43m	176.5	136.5		
1hr 43m 30s	175.1	136.9		
1hr 44m	173.6	136.9	ON	
1hr 44m 15s	175.6	136.9		
1hr 44m 30s	179.6	137.1		
1hr 44m 45s	181.2	137.1		
1hr 45m	182.4	137.1		

Table 7. 1 hour 30 minutes- 1 hour 45 minutes

Time	Heat Tank	PCM Tank	Heater	Fan Coil
1hr 45m 15s	183.3	137.1		
1hr 45m 30s	184.8	137.3		
1hr 45m 45s	185.9	137.3	OFF	
1hr 46m	184.2	137.3		
1hr 46m 15s	181.5	137.4		
1hr 46m 30s	179.6	137.4		
1hr 46m 45s	178.7	137.4		
1hr 47m	177.9	137.4		
1hr 47m 15s	177	137.6		
1hr 47m 30s	176.1	137.4	ON	
1hr 47m 45s	178.5	137.6		
1hr 48m	182.4	137.6		
1hr 48m 15s	184.1	137.6		
1hr 48m 30s	185.5	137.8	OFF	
1hr 48m 45s	184.1	137.8		
1hr 49m	180.5	137.8		
1hr 49m 15s	178.8	137.8		
1hr 49m 30s	177.9	138		
1hr 49m 45s	177	138		
1hr 50m	176.1	138	ON	
1hr 50m 15s	178.3	138.2		
1hr 50m 30s	182.4	138.2		
1hr 50m 45s	184.1	138.2		
1hr 51m	185.5	138.3		
1hr 51m 15s	186.8	138.5		
1hr 51m 30s	187.8	138.5	OFF	
1hr 51m 45s	186.4	138.7		
1hr 52m	182.8	139.1		
1hr 52m 15s	181.2	139.2		
1hr 52m 30s	180.1	139.6		
1hr 52m 45s	179.4	139.8		
1hr 53m	178.7	140		
1hr 53m 15s	177.8	140.1	ON	
1hr 53m 30s	180.3	140.1		
1hr 53m 45s	183.5	140.5		

Table 8. 1 hour 45 minutes- 1 hour 53m 45s

Time	Heat Tank	PCM Tank	Heater	Fan Coil
1hr 30s	153.6	113.1	ON	
1hr 1m	156.4	113.1		
1hr 1m 30s	162.2	113.2		
1hr 2m	163.8	113.2		
1hr 2m 30s	164.8	113.2		
1hr 3m	167.9	113.5		
1hr 3m 30s	170.4	113.7	OFF	
1hr 4m	165.2	113.9		
1hr 4m 30s	163	113.9		
1hr 5m	161.4	114		
1hr 5m 30s	160.1	114		
1hr 6m	158.9	114.4		
1hr 6m 30s	157.6	114.4		
1hr 7m	156.5	114.6		
1hr 7m 30s	155.4	114.8	ON	
1hr 8m	161.6	114.8		
1hr 8m 30s	166.1	115.1		
1hr 9m	168.9	115.3	OFF	
1hr 9m 30s	164.3	115.3		
1hr 10m	161.9	115.5		
1hr 10m 30s	160.7	115.7		
1hr 11m	159.2	115.7		
1hr 11m 30s	158.1	115.7		
1hr 12m	156.9	115.8		
1hr 12m 30s	155.6	115.8		
1hr 13m	154.5	115.8		
1hr 13m 30s	153.6	116		
1hr 14m	152.6	116	ON	
1hr 14m 30s	159	116.2		
1hr 15m	163.4	116.2		

Table 5. 1 hour 30s- 1 hour 15 minutes

Time	Heat Tank	PCM Tank	Heater	Fan Coil
1hr 15m 30s	166.4	116.4		
1hr 16m	169.5	116.4		
1hr 16m 30s	172.2	116.4		
1hr 17m	174.9	116.4	OFF	
1hr 17m 30s	170.45	116.5		
1hr 18m	167	116.6		
1hr 18m 30s	165.3	116.7		
1hr 19m	163.9	116.9		
1hr 19m 30s	162.5	117.1		
1hr 20m	161.4	117.5		
1hr 20m 30s	160.1	117.6	ON	
1hr 21m	166.8	118		
1hr 21m 30s	170.7	118.2		
1hr 22m	173.6	118.2		
1hr 22m 30s	176.1	118.5		
1hr 23m	178.8	118.7	OFF	
1hr 23m 30s	174.2	118.9		
1hr 24m	170.6	119.3		
1hr 24m 30s	168.8	119.4		
1hr 25m	167.5	119.8	ON	
1hr 25m 30s	174.3	120.3		
1hr 26m	177.4	120.7		
1hr 26m 30s	180.1	121.1	OFF	
1hr 27m	175.1	121.2		
1hr 27m 30s	172.5	121.6		
1hr 28m	170.6	121.8		
1hr 28m 30s	169.1	122.1	ON	
1hr 29m	176.5	122.5		
1hr 29m 30s	179.4	122.9	OFF	
1hr 30m	174.3	124.7		

Table 6. 1 hour 15m 30s- 1 hour 30 minutes

Time	Heat Tank	PCM Tank	Heater	Fan Coil
1hr 54m	185	140.5	OFF	
1hr 54m 15s	184.1	140.9		
1hr 54m 30s	180.6	140.9		
1hr 54m 45s	179.4	141		
1hr 55m	178.3	141.2		
1hr 55m 15s	177.6	141.2		
1hr 55m 30s	176.3	141.2		
1hr 55m 45s	176	141.4		
1hr 56m	175.4	141.6		
1hr 56m 15s	174.9	141.9		
1hr 56m 30s	174	141.9		
1hr 56m 45s	173.3	142.3	ON	
1hr 57m	175.4	142.5		
1hr 57m 15s	179.6	142.5		
1hr 57m 30s	181.4	142.7		
1hr 57m 45s	182.6	142.7		
1hr 58m	183.7	142.7	OFF	
1hr 58m 15s	182.3	142.8		
1hr 58m 30s	178.8	142.8		
1hr 58m 45s	177.4	142.8		
1hr 59m	176.5	143		
1hr 59m 15s	175.5	144.1		
1hr 59m 30s	175.1	144.5		
1hr 59m 45s	174.5	145		
2hr	173.3	145.2	SWITCH VALVE	
2hr 30s		145.5		90.8
2hr 1m		145.6		109
2hr 1m 30s		144.1		111.5
2hr 2m		143.7		114.8
2hr 2m 30s		142.7		116.4
2hr 3m		141.6		116.9
2hr 3m 30s		140.9		117.1
2hr 4m		140		117.1
2hr 4m 30s		139.1		116.7
2hr 5m		138.3		116.4

Table 9. 1 hour 54m- 2 hours 5m

Time	Heat Tank	PCM Tank	Heater	Fan Coil
2hr 5m 30s		137.8		116
2hr 6m		137.3		115.8
2hr 6m 30s		136.5		115.3
2hr 7m		136		114.8
2hr 7m 30s		135.6		114.4
2hr 8m		135.1		113.9
2hr 8m 30s		134.7		113.3
2hr 9m		134.2		112.8
2hr 9m 30s		133.8		112.4
2hr 10m		133.3		112.1
2hr 10m 30s		133.1		111.7
2hr 11m		132.8		111.3
2hr 11m 30s		132.4		111
2hr 12m		132		110.4
2hr 12m 30s		131.9		110.1
2hr 13m		131.5		109.5
2hr 13m 30s		131.3		109.2
2hr 14m		131.1		108.6
2hr 14m 30s.		130.8		108.3
2hr 15m		130.8		108.3
2hr 15m 30s		130.8		108.1
2hr 16m		130.6		107.9
2hr 16m 30s		130.6		107.9
2hr 17m		130.8		107.9
2hr 17m 30s		130.8		107.9
2hr 18m		131.1		107.7
2hr 18m 30s		131.5		107.7
2hr 19m		131.9		107.6
2hr 19m 30s		132.2		107.4
2hr 20m		132.4		107.4
2hr 20m 30s		132.6		107.3

Table 10. 2 hours 5m 30s- 2 hours 20m 30s

Time	Heat Tank	PCM Tank	Heater	Fan Coil	Time	Heat Tank	PCM Tank	Heater	Fan Coil
2hr 21m		132.9		107.4	2hr 36m 30s		132.8		103.8
2hr 21m 30s		133.1		110.2	2hr 37m		132.6		103.6
2hr 22m		133.3		111.2	2hr 37m 30s		132.6		103.4
2hr 22m 30s		133.5		111	2hr 38m		132.6		103.2
2hr 23m		133.5		110.6	2hr 38m 30s		132.6		103.1
2hr 23m 30s		133.5		109.5	2hr 39m		132.9		100
2hr 24m		133.5		109.5	2hr 39m 30s		132.9		98.2
2hr 24m 30s		133.7		109.5	2hr 40m		133.5		95.1
2hr 25m		133.7		109.5	2hr 40m 30s		133.5		94.2
2hr 25m 30s		133.7		109.2	2hr 41m		133.3		93
2hr 26m		133.7		109	2hr 41m 30s		132.9		91.9
2hr 26m 30s		133.7		108.6	2hr 42m		132.6		90.6
2hr 27m		133.7		108.3	2hr 42m 30s		132.4		89.7
2hr 27m 30s		133.7		108.1	2hr 43m		131.9		88.8
2hr 28m		133.7		107.9	2hr 43m 30s		131.3		87.6
2hr 28m 30s		133.7		107.6	2hr 44m		131.1		87
2hr 29m		133.5		107.2	2hr 44m 30s		131		86.1
2hr 29m 30s		133.5		106.8	2hr 45m		130.6		85.6
2hr 30m		133.5		106.7	2hr 45m 30s		130.6		85.1
2hr 30m 30s		133.5		106.5	2hr 46m		130.2		84.2
2hr 31m		133.5		106.3	2hr 46m 30s		130.2		83.8
2hr 31m 30s		133.3		105.9	2hr 47m		130.1		83.4
2hr 32m		133.1		105.6	2hr 47m 30s		129.9		82.9
2hr 32m 30s		132.9		105.2	2hr 48m		129.7		82.5
2hr 33m		132.8		105.2	2hr 48m 30s		129.5		82.2
2hr 33m 30s		132.8		105	2hr 49m		129.5		82.1
2hr 34m		132.6		104.9	2hr 49m 30s		129.3		82
2hr 34m 30s		132.8		104.7	2hr 50m		129.2		81.6
2hr 35m		132.8		104.5	2hr 50m 30s		129		81.5
2hr 35m 30s		132.9		104.1	2hr 51m		128.8		81.1
2hr 36m		132.8		103.8	2hr 51m 30s		127.9		80.7
					2hr 52m		127.6		80.2
					2hr 52m 30s		127.4		79.8

Table 11. 2 hours 21m- 2 hours 36m

Table 12. 2 hours 36m 30s- 2 hours 52m 30s

Results

The results from four trials confirmed that a PCM tank integrated into a heating system consistently undergoes multiple phase changes (solid to liquid and liquid to solid) without affecting system performance. If applied in real life, because the tank absorbs and releases the same amount of latent heat, the engineering goal, which is to spread the peak hours to a wider range, is able to be met. In Figure 2, the phase changes are clearly visible in the temperature graphs, where temperatures remain constant during the phase changes, demonstrating effective thermal energy storage and release. In Figure 1, during testing, the system maintained a temperature difference of 50-60°F between the heat tank and the PCM tank, ensuring accurate results. In Figure 2, when the water was redirected from the PCM tank to the fan coil, the temperature decreased steadily, validating the PCM’s ability to store and gradually release heat. These findings suggest that a PCM tank can effectively spread peak electricity demand and support decarbonization efforts in real-world applications. The data can be seen in each data set accurately showing phase changes and how the prototype was regulated.

Discussion

The data collected from the prototype indicates that integrating a PCM tank into heating systems can effectively reduce electrical demand during peak hours. If scaled to real-life applications with proper equipment and installation, the PCM tank would function efficiently, helping to spread peak electricity usage over a broader time range. While this prototype introduces a novel approach rather than enhancing existing systems, it demonstrates that adding a PCM tank to a standard heating system can address the challenge

of increased electrical demand caused by decarbonization efforts. Providing a consistent and reliable method for thermal storage, PCM tanks help alleviate the strain on power grids, making it a valuable tool in the transition toward electrification and decarbonization. However, challenges remain for real-world implementation. Barriers such as upfront costs, retrofitting compatibility, and long-term reliability need to be addressed. Future research should focus on: 1: Testing PCM integration in diverse building types, 2: Conducting cost-benefit analyses, 3: Exploring PCM systems in smart grid frameworks for energy distribution. As discussed in the Introduction, in a real-life situation, a PCM Tank would be inserted into every home’s heating system, therefore creating the freedom to use electricity at any given time period. Management of this system in urban areas would be controlled by electricity companies or the city to further ensure an effective way of spreading the load. A possible design is the grouping of neighborhoods in a city in which every group will use electricity at different times to ensure the spread of demand on the grid. As stated before, this usage would be controlled by companies and even smart devices or apps in our thermostats to be more accurate.

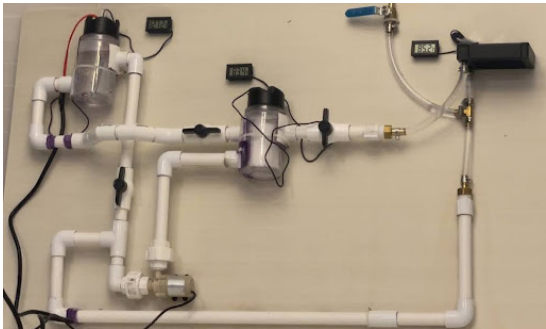


Fig. 3. Picture of the Prototype

Conclusion

This project confirmed that a PCM tank consistently allows for ongoing phase changes within heating systems, effectively storing and releasing thermal energy. Sodium acetate trihydrate proved effective in storing and releasing thermal energy through consistent phase changes. While the prototype establishes proof-of-concept, further research is needed to address scalability, long-term performance, and integration into existing systems. As cities strive for decarbonization, PCM tanks present a sustainable, reusable, and efficient solution to support the transition toward electrification while mitigating grid strain. By investing in PCM technology, policymakers and engineers can drive meaningful progress toward a sustainable energy future.

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