

THE STORAGE OF LATENT HEAT AND THERMAL ENERGY FOR INDOOR COMFORT CONTROL:  
AN EXAMINATION OF TECHNO-ECONOMIC FEASIBILITY.

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**ABSTRACT**

It was in the last four seconds of the day before that Homo sapiens first emerged. A lot of people think this was a watershed point in global history. Many people rank this as one of the most pivotal moments in human history. More than two centuries ago, during the period known as the Industrial Revolution, the first fossil fuels were found. A considerable quantity of those fuels were mined from the soil during this era. Global populations' over-reliance on fossil fuels is the direct cause of the two-to-six-degree Celsius rise in Earth's surface temperature that the Intergovernmental Panel on Climate Change, or IPCC, projects will occur by 2100. This is a direct result of the changes in the climate brought about by human activities. Because of this, there is a growing need for treatments that are easier on the environment and the energy grid. With a focus on reducing greenhouse gas emissions, boosting the utilisation of energy from renewable sources, and improving the system's energy efficiency—all without sacrificing quality of life—this study investigates load shifting and peak shaving capabilities of energy storage technology. Achieving these goals does not have to mean sacrificing quality of life. Latent heat (LH) is the primary means by which advanced thermal energy storage (TES) devices store thermal energy. These devices get their power from phase transition materials. Also, in an effort to clean up the environment, the study focused on temporary TES integrated systems to reduce the amount of surplus energy coming from petroleum and coal and other sources. That was the driving force for the creation of renewable energy sources.

**Keywords:** Residual heat, thermal power, indoor settings, technological advancements, economic feasibility.

**INTRODUCTION**

In addition to being referred to as Sapiens, the human population has grown as a result of technological improvements, which have contributed to this overall expansion. There is a direct correlation between ongoing improvements in the level of living and an increase in the amount of energy that is required. Following a period of expansion that lasted for a period of time that was less than forty years, it became the primary source of energy for the entire world in the year 2010. In addition to being responsible for thirty gigatons of carbon dioxide emissions, fissile fuels are responsible for almost half of the annual energy consumption that occurs around the globe. In the event that nothing is done to address the issue, it is anticipated that temperatures

would rise by anywhere from two to six degrees Celsius by the time this century comes to a close. An example of one of the first applications of technology that stores energy is the practice of gathering ice for the purpose of preserving food. The time durations that are covered by these needs range from seconds to hours, and the capacities that are required range from kilowatts to gigawatts. This energy storage will be necessary in order to accommodate the generation of energy (Lakhdari, 2020). Long-term energy storage will be required in addition to long-term energy storage in order to improve the safety and resilience of the electrical system in the face of a rise in the number of natural disasters and intentional threats. TES, which is also known as TES, is a technology that has the potential to help erase the gap that exists between the quantity of renewable resources that are accessible and the amount of energy that is really required. When it comes to storing thermal energy, TES is a technique that includes altering the internal energy of a material in order to do this. The energy that has been stored can then be used at a later time for a variety of purposes, including heating and cooling, among other things. TES offers a lot of benefits to an energy system when it is incorporated into the system. These benefits include an increase in overall efficiency as well as an increase in reliability. As a result of this integration, there is a reduction in the amount of greenhouse gas emissions, as well as there is a reduction in the amount of money spent on investments and operational expenses. Sensible technologies, latent technologies, and thermochemical technologies are the three categories that are typically used to classify TES technologies respectively (Sharma & Rai, 2020).

### **BACKGROUND OF THE STUDY**

A more efficient and dependable energy system may be possible with the help of energy storage. Reason being, energy storage may mitigate the effects of power outages and surges. This would allow for better regulation of peak energy demand and also make it possible to employ renewable energy sources more often, especially those that are "intermittent" in nature. The potential exists for energy storage to help lower emissions of greenhouse gases. The reason for this is because energy storage allows for the efficient generation of electricity from fossil fuels without compromising efficiency. Reducing marginal peak power production "through" energy storage is a distinct possibility. As the idea of a "smart grid" gains traction in the minds of the general population, electric "energy" storage becomes an integral part of power grid management. At the same time, smart grids are becoming more and more significance. Despite heating and cooling being two of the most important energy uses, the Nordic nations depend heavily on both of these uses at the same time (Teamah, 2021). This particular source is responsible for providing more than forty-five percent of the energy that is consumed by households and companies in Sweden. If the heating and cooling loads are managed in an appropriate manner, it is feasible to reduce the marginal production techniques that are dependent on fossil fuels. This is because it is possible to reduce the need for fossil fuels. The practice of load shifting and peak shaving comes with a number of benefits that are valuable to consider. Among these benefits are enhanced operational efficiency due to production units running at nominal power, more utilisation of energy from renewable sources, better environmental conditions, and increased grid capacity at no extra cost. All things considered,

these benefits result in maximum efficiency in operations. For the purpose of clarifying thermal energy TES, which is currently underappreciated, the objective of this study is to shed light on the subject. This work is being done with the primary objective of enhancing the design of water storage systems for TES that go beyond the traditional hot-and-cold water tanks. When thermal energy is stored for the purpose of sensible heat storage, the temperature of the medium that is being used for storage is adjusted in order to achieve the desired effect. The ability to store and replenish thermal energy is made possible by this. Every single technology that is utilised for TES comes with its own unique collection of advantages and disadvantages exclusive to that technology. The relatively low energy storage density of sensible TES is a constraint, despite the fact that it is uncomplicated and has been demonstrated in a significant amount of research. The Thermal Energy Storage (TES) system, on the other hand, is capable of obtaining a high energy storage density; but, due to the complexity of the technology, it is still in the process of being developed (Davin et al., 2020).

### **PURPOSE OF THE STUDY**

When it comes to the incorporation of storage technology into the physical environment, careful planning is essential in order to create a system that is not only reliable but also functional. The size of the storage unit is often determined by engineers based on the techniques that are permitted and their own personal experience, provided that the specifications and load profiles of the storage unit are accurately recorded. Despite this, it is possible for planned systems to display inconsistencies between the results that were anticipated and those that were actually obtained in applications that are used in the real world. When attempting to provide an explanation for the consequences, it is common practice to place blame on insufficient design analysis. The crux of the matter is that inaccurate interpretations of LHTES are frequently the cause of false designs. An improved understanding of phase change material (PCM) is absolutely necessary in order to continue improving the accuracy of phase change process prediction through the use of improved modelling methodologies and the input of material data that is more precise. It is necessary for engineers to have measuring methods that are not only straightforward but also accurate in order for them to be able to obtain accurate PCM parameters.

### **LITERATURE REVIEW**

This class includes qualities such as low thermal expansion during storage, high thermal efficiency during energy extraction, suitable operating temperature, low environmental impact, commercial availability, and monetary value. More and more publications have been written in recent years that discuss TES. The study's overarching goal is to summarise the assessments of PCM courses, but it will also provide an overview of the pros and cons of using PCM. Applying TES systems leads to better load control. What benefits does the process of conserving thermal energy provide? To further enhance the system's performance, it may use all of the load capability by raising production and moving high-demand periods from peak to off-peak hours,

when demand is lower. Full preservation, load equalisation, and demand limitation are all aspects of energy system functioning that depend on this being carried out. It is possible that load-shifting during off-peak hours will result in cheaper energy prices. This phenomenon is known as load-shedding (Khattari et al., 2020). Through the application of a number of different management strategies, from peak to off-peak operations, this article shows how entire load and partial load differ. The amount of load that is transported can be controlled in two different ways: load levelling and demand limiting (Xu et al., 2020). Both of these strategies are referred to as load management. For the purpose of maintaining stability, the energy distribution system makes use of a load-balancing strategy. Additionally, the storage facility is able to meet peak demand for the load that is not dispersed effectively and uniformly. The demand limiting mechanism reduces the amount of energy that is available during peak hours, while simultaneously charging the storage at a higher energy rating during off-peak hours. This occurs while the charging of the storage occurs. Despite the fact that they use a relatively small amount of power to transmit a bigger quantity of heat from a heat source, heat pumps are a significant consumer of electricity in residential settings. It is also essential to have heat pumps in order for heat pumps to function properly. The current energy constraints, in addition to inflation, have led to a significant increase in the prices related to the purchase of electricity. Significant shifts can occur in the pricing at which power is traded in different markets. When it comes to energy, there are numerous occasions in which the expenses are really low. This occurs due to the fact that the production of wind electricity has an impact. It is clear from this that the overall costs of trading electricity have increased more than before. Interest has been generated in the utilisation of thermal energy storage (TES) in residential heating systems as a result of its participation in peak load shifting, which is a method for reducing the expenses that are involved with heating (Dauvergne et al., 2021).

### RESEARCH QUESTION

What is the impact of thermal energy storage on indoor comfort regulation?

What is the effect of thermal energy storage on techno-economic feasibility?

### RESEARCH METHODOLOGY

**Research Design:** The quantitative data analysis utilised SPSS version 25. The odds ratio and 95% confidence interval were employed to assess the magnitude and direction of the statistical link. The researchers determined a statistically significant criterion of  $p < 0.05$ . A descriptive analysis was performed to identify the key characteristics of the data. Quantitative methods are frequently employed to assess data derived from surveys, polls, and enquiries, as well as information evaluated by statistical software.

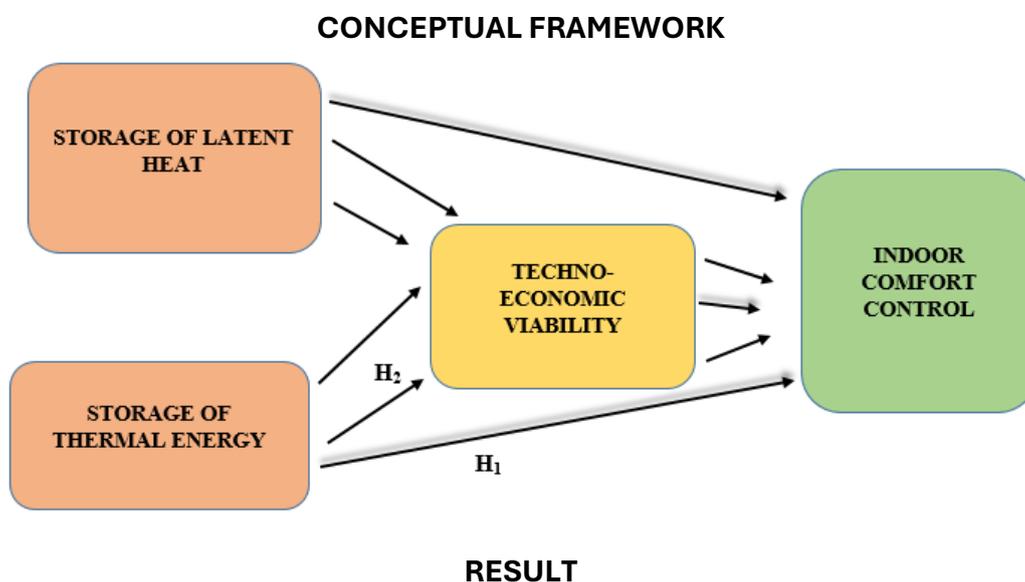
**Sampling** Study participants completed questionnaires to supply data for the investigation. Utilising the Rao-soft algorithm, researchers identified a study population of 1,386 individuals,

resulting in the distribution of 1,512 questionnaires. The researchers received 1456 responses, excluding 47 for inadequate participation, resulting in a final sample size of 1409.

**Data and measurement:** A questionnaire functioned as the principal tool for data collection in this study. Part A of the survey requested essential demographic information, whereas Part B employed a 5-point Likert scale to collect responses regarding characteristics related to online and offline channels. A plethora of sources, especially online databases, provided supplementary information.

**Statistical Software:** The statistical study was performed utilising SPSS 25 and Microsoft Excel.

**Statistical Tools:** In order to understand the key features of the data, the descriptive analysis approach was used. Using ANOVA, the researcher must examine the data.



**Factor Analysis:** A prevalent application of Factor Analysis (FA) is to reveal latent variables within observable data. Standard procedure requires the utilisation of correlation coefficients for assessment in the absence of diagnostic or visually observable signs. Models are crucial for success in FA. Modelling inherently entails errors, intrusions, and discernible connections. The Kaiser-Meyer-Olkin (KMO) Test is a technique for assessing datasets produced by multiple regression studies. This indicates that the variables in the model and the sample are genuinely representative. The figures reveal data duplication. Data is rendered more intelligible when proportions are reduced. The execution of KMO produces a result between 0 and 1. An appropriate sample size is indicated by a KMO value between 0.8 and 1. Kaiser specifies the permissible parameters: Kaiser has instituted the following additional admission requirements:

Unsatisfactory: 0.60 to 0.69; insufficient: 0.050 to 0.059.

The range of 0.70 to 0.79 is prevalent in middle grades.

Exhibiting a quality point score between 0.80 and 0.89.

The range from 0.90 to 1.00 astonishes them.

Kaiser-Meyer-Olkin Statistic: 0.865; Bartlett's test of sphericity yielded the subsequent results:

The chi-square test possesses around 190 degrees of freedom, with a significance level of 0.000.

This corroborates the veracity of the claims regarding sampling. Researchers evaluated the importance of the correlation matrices by Bartlett's Test of Sphericity. The Kaiser-Meyer-Olkin measure signifies a satisfactory sample with a value of 0.865. The p-value obtained from Bartlett's sphericity test is 0.00. The association matrices may be indistinguishable if Bartlett's test of sphericity produces favourable results.

**Table 1.** Assessment of Sampling Adequacy by KMO and Bartlett's Test.

<b>KMO and Bartlett's Test</b>		
<b>Kaiser-Meyer-Olkin Measure of Sampling Adequacy.</b>		.865
<b>Bartlett's Test of Sphericity</b>	<b>Approx. Chi-Square</b>	3252.968
	<b>df</b>	190
	<b>Sig.</b>	.000

The correlation matrix was shown to be statistically significant using the Bartlett Test of Sphericity. As a measure of sample adequacy, the Kaiser-Meyer-Olkin statistic is 0.865. Using the Bartlett circularity test, the researchers arrived at a p-value of 0.00. Due to the substantial result of Bartlett's test of sphericity, the researcher admits that the correlation matrix is erroneous.

### INDEPENDENT VARIABLE

**Storage Of Thermal Energy:** Energy may be transferred and stored from hot or cold sources, such as ice, water, or air, using thermal energy storage technology. Heat energy can be transferred and stored in this way. This technique is used into emerging technologies that are designed to supplement sources of energy such as solar and hydropower. Thermal energy, which can be either chilled or hot water, is generated during times of off-peak electrical demand or utilisation. This energy is then stored in a thermal energy storage tank, from which it is subsequently taken and distributed to the facility at times of peak demand at the facility. The diffusers that are situated at the top and bottom of the tank are responsible for allowing the heated or cooled water to enter and depart the tank. By eliminating turbulence and allowing the water in the tank to stratify, with colder water at the bottom and hot water at the top, the

diffusers are supposed to improve the water's quality. There is a transition layer of water that is both narrow and sharp, and it forms between the regions of warm water and cold water. Let's say there is a gathering with the expectation that Researcher won't be able to break the ice when guests arrive. The ice would be purchased, placed in a freezer, and then utilised whenever it was necessary. The process of thermal energy is quite comparable to mechanical energy. At night, the cost of the electricity that Researcher use to manufacture that ice is lower than it is during the daytime during when Researcher use it (Beust et al., 2021).

### DEPENDENT VARIABLE

**Indoor Comfort Control:** The term "indoor comfort" refers to a broad category that includes not just air quality but also thermal, visual, and auditory comfort. Researchers have overcome each and every one of these obstacles. What Researchers mean when Researchers talk about comfort is "a pleasant feeling of being relaxed and free from pain." For some, this is the pinnacle of ease. Comfort is a mental condition, according the Cambridge English Dictionary. The dictionary provided this definition. Under normal conditions (i.e., suitable humidity and proper attire), most people find that a room temperature between 20 and 25 degrees Celsius (68- and 77-degrees Fahrenheit) is just right. Contrarily, this range might vary to a certain extent depending on factors like activity level, personal taste, and specific groups like infants and the elderly. It is generally believed that a temperature range of 18–20 degrees Celsius (65–68 degrees Fahrenheit) provides the best circumstances for a good night's sleep. Several factors, including as airflow, human metabolism, and environmental humidity, contribute substantially to an individual's overall perception of comfort. When it comes to air quality, lighting, and acoustics, indoor comfort solutions are what people need to keep their homes and workplaces safe and comfortable. Researchers have a broad choice of alternatives accessible to adapt to individuals' needs. Soundproofing panels, HVAC systems, heaters, humidification systems, and smart thermostats are just a few of the many home appliance kinds shown here. 9Researcher's rooms are kept cool in the summer, pleasant in the winter, and free of dust and excess water thanks to these options. There are a lot of us that do this. It is possible to use curtains or smart lighting to decrease glare and enhance mood in addition to temperature when thinking about the ease of the interior space. Researchers may now adjust the degree of comfort in their home with the push of a button or the sound of their voice, thanks to smart systems that are loaded with the latest technical breakthroughs. Learn about the main types, find ways to make it more comfortable, and figure out how to choose the right one for researchers requirements from the information provided here (Nie et al., 2020).

### MEDIATING VARIBALE

**Techno economic Feasibility:** Within the context of a comprehensive review that is referred to as a Techno-Economic Feasibility Study (TEFS), both the technical and financial feasibility of a project are investigated thoroughly. It is an important decision-making tool that must be utilised in order to guarantee that the project is technically possible, financially sound, and economically environmentally sustainable. Through a combination of engineering analysis,

economic modelling, and risk assessment methodologies, this research provides a data-driven evaluation of the feasibility of the project. A Techno-Economic Feasibility Study, often known as a TEFS, is required for any business or organisation that is contemplating making an investment in a project or beginning a new enterprise. In order to determine whether or not a project is feasible, it is a process that takes into account the technical and economic aspects of the project and calculates the likelihood of the project in fact being successful. Within the context of a comprehensive review that is referred to as a TEFS, both the technical and financial feasibility of a project are investigated thoroughly. It is an important decision-making tool that must be utilised in order to guarantee that the project is technically possible, financially sound, and economically environmentally sustainable. In order to carry out assessments of this nature, the most common instrument that is utilised is a techno-economic model. You may utilise a techno-economic model to have a better understanding of the processes and the expenses that are connected with them. For example, it takes into account the size of equipment, the modelling of processes, the design of processes, as well as the assessment of operating costs and capital costs (Teamah, 2021).

**Relationship between Storage of Thermal Energy and Indoor Comfort Control:** The storage of thermal energy is intimately related to the management of the comfort of the interior of a building because it contributes to the maintenance of a temperature that is consistent and desirable within the structure. Because heat contributes to maintaining temperatures at a consistent level. It is possible for thermal energy storage devices to capture and store heat when there is an excessive amount of heat, such as during the day. After that, the heat is released exactly when it is required, such as during the night when the temperature is lower or when there is not a great deal of demand for heat. The flow of heat is regulated by these systems, which ensures that the temperature of the building remains consistent. People who reside there will experience increased comfort as a result of this. As a consequence of this, the fluctuations in temperature are less severe, which results in the guests experiencing a higher level of comfort. Because of this, heating, ventilation, and air conditioning (HVAC) systems do not have to exert as much effort, which results in a reduction in the amount of energy they use and the amount of money they cost to operate. The heating, ventilation, and air conditioning (HVAC) systems experience reduced strain as a result of this adjustment. The storage of thermal energy also contributes to the development of building designs that are more environmentally friendly. One way to do this is by assisting individuals in making more efficient use of renewable energy sources and by making it feasible for them to depend less on fossil fuels. However, in order to make a building as pleasant as possible while simultaneously making it more energy-efficient and cost-effective, it is essential to have a thermal energy storage system that is sufficient (Mhiri et al., 2020). In order to assess the connection between thermal energy storage and indoor comfort control, the researcher formulated the following hypothesis based on the subsequent discussion.

“H<sub>01</sub>: There is no significant relationship between Storage of Thermal Energy and Indoor Comfort Control”

“H<sub>1</sub>: There is a significant relationship between Storage of Thermal Energy and Indoor Comfort Control”

**Table 2.** H1 ANOVA Test.

ANOVA					
Sum					
	Sum of Squares	df	Mean Square	F	Sig.
<b>Between Groups</b>	39588.620	643	5465.517	1018.545	.000
<b>Within Groups</b>	492.770	765	5.366		
<b>Total</b>	40081.390	1408			

This inquiry will provide significant outcomes. The F statistic is 1018.545, attaining significance with a p-value of .000, which is below the .05 alpha level. The hypothesis asserts that “H<sub>1</sub>: There is a significant relationship between Storage of Thermal Energy and Indoor Comfort Control” The alternative hypothesis is confirmed, while the null hypothesis is dismissed.

**Relationship Between Storage of Thermal Energy and Techno Economic Feasibility:**

Thermal energy storage is very important for energy systems to work well and be cost-effective. This is especially true for things like solar power, heating buildings, and managing energy use in buildings. This is especially true for solar energy. TES devices can make energy consumption more efficient, make the balance between supply and demand better, and make us less dependent on fossil fuels by collecting and storing heat for later use. When it comes to technology, good thermal storage systems accomplish two things: they make the system more efficient and reliable, and they make it simpler to use renewable energy sources like solar thermal, which only give energy sometimes. Energy prices and the necessity for backup power systems are big financial challenges. TES can help lower both of these expenses. The project's economic sustainability depends on a number of things, such as the original investment, the choice of materials, and the cost of upkeep. People think that all of these things are very important. To get the best results, both the technical performance (which includes heat loss and storage time) and the cost-effectiveness (which depends on the technological-economic feasibility of distributed energy systems (TES)) need to be enhanced. This is necessary for the creation of energy solutions that are both cheap and good for the environment (Davin et al., 2020).

To evaluate the relationship between Thermal Energy and Techno Economic Feasibility, the researcher established the following hypothesis based on the ensuing discourse.

“H<sub>02</sub>: There is no significant relationship between Storage of Thermal Energy and Techno Economic Feasibility”

“H<sub>2</sub>: There is a significant relationship between Storage of Thermal Energy and Techno Economic Feasibility”

**Table 3.** H2 ANOVA Test.

ANOVA					
Sum					
	Sum of Squares	df	Mean Square	F	Sig.
<b>Between Groups</b>	39588.620	689	5635.417	611.212	.000
<b>Within Groups</b>	492.770	719	5.346		
<b>Total</b>	40081.390	1408			

This inquiry will provide significant outcomes. The F statistic is 1054.137, attaining significance with a p-value of .000, which is below the .05 alpha level. The hypothesis asserts that “H<sub>2</sub>: There is a significant relationship between Storage of Thermal Energy and Techno Economic Feasibility” The alternative hypothesis is confirmed, while the null hypothesis is dismissed.

### DISCUSSION

Some technologies may help bring about improvements in energy conservation; one such example is the storage of thermal energy. Solar and wind power are two more examples. Utilising waste heat or free cooling is only one of the many benefits of this technology; it also allows shifting energy consumption and lowering the system's peak load practicable. To keep heat within the thermally permissible range, one option is to use a multi-layer hot water storage tank. One of the ways heat may be stored is in this manner. Nevertheless, a larger storage capacity is required for practical thermal energy storage methods (such as layered chilled water). The need for larger storage capabilities is the main reason for this. This is because cold storage activities can only withstand a narrower temperature range. This is the rationale for the situation. The usage of PCMs as a storage medium in LHTES has the potential to bring about a number of benefits. One benefit of PCMs is their considerable thermal energy storage capacity with little temperature swings. Although ice and water are two of the most popular PCMs, their low phase change temperatures render them unsuitable for creating an effective interior cooling environment. Researchers and scientists have been studying and testing a diverse array of phase-change materials with "various phase change energies" over the last several years. A great deal of research and investigation has focused on the materials in issue.

### CONCLUSION

Regarding the technology-enabled systems (TES) that are being spoken about, the personal computing materials (PCMs) that fall into the organic or inorganic categories provide a lot of advantages. Among their many advantages are the fact that they are not phase segregating, that sub cooling is not as problematic, and that they work well in containers made of metallic materials. The high price tag, low heat conductivity, and lack of trustworthy data on the thermal characteristics of these materials are just a few of the few drawbacks of these materials. These materials are quite expensive, which is one of the major reasons. One innovative approach to assessing material properties is the T-History method, which may be used to determine the enthalpy change of an unknown material by comparing it to a known reference sample from the

past. To ensure the accuracy of this technique, many critical components must be met. Among these factors are familiarity with the reference material, a high temperature sensor sensitivity, a repeatable heat flow, and a low Biot number. Contributing to the creation of a sophisticated calculating approach, this study measures thermophysical parameters of various materials and analyses the orientation of the T-History setup. In this research, Researchers look at both of those things. A simple modified Dirac delta function will be used to illustrate the specific heat capacity of PCMs. The goal is to demonstrate the function, thus this is being done. The results of the experiments will be closely mirrored by this function. On the other hand, there are boundaries that, no matter what, must be respected. In the instance of the charge/discharge performance assessment, this was the case. Researcher may see this by comparing the model with the data that was acquired during testing. To achieve the goal of evaluating the efficacy of non-gelled storage, a conduction/convection model using differences in "material viscosity above and below the phase change temperature" has to be designed. In order to complete the task, this was essential. The results of the study, including experimental and numerical studies, indicate that when PCM is present in both the liquid and solid phases, a "15% time difference in the mushy" zone occurs. This is supported by the results of the study that was conducted. The lack of consensus on when exactly the convective heat transfer mechanism begins to terminate is a major contributor to the current state of debate.

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