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Storage Of Latent Heat And Thermal Energy For Controlling The Indoor Comfort Level: A Study To Identify Techno-Economic Feasibility

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ABSTRACT
One of the most important historical events was the introduction of Homo sapiens in the last four seconds of the day before. It was during the Industrial that fossil fuels were first discovered two centuries ago and were extracted in large Revolution quantities. Global temperatures are expected to rise by 2 to 6 degrees Celsius by 2100 due to the excessive use of fossil fuels, according to the Intergovernmental Panel on Climate Change (IPCC). As a result, the need for energy-efficient procedures is rising. This study looks at load shifting and peak shaving applications of energy storage technology to reduce greenhouse gas emissions, boost the use of renewable energy sources, and enhance system energy efficiency without sacrificing quality of life. Latent heat (LH) is the primary thermal energy storage medium in a high level of thermal energy storage (TES) technologies powered by phase transition materials. However, applying LHTES in the constructed environment presents challenges, such as inadequate knowledge of system dynamics, unpredictable component design, and unrecorded material properties. To tackle these problems, the research develops precise numerical models of the LHTES element that include shaped-stabilized and free-flowing PCMs. These models are verified by experiments, and promising results were obtained from a study on the possibility of using multistage multi-PCM to enhance thermal power efficiency. The study also concentrated on transient TES integrated systems with the goal of lowering the marginal energy coming from fossil fuels and other sources to provide a cleaner environment.

KEYWORDS: *Heat transmission, Indoor comfort, Phase change material, Thermal energy storage.*

1. Introduction

Humans, sometimes referred to as Sapiens, prosper because of technological breakthroughs. The demand for energy is growing in tandem with the rising level of living. 2010 saw it become the world's primary energy source after expanding in less than 40 years. Approximately half of the world's yearly energy consumption and 30 Gt of CO2 emissions come from fossil fuels. 2. Since the industrial revolution, greenhouse gas (GHG) emissions from human activities have been the main driver of global warming (Nilsson, 2020). If nothing is done, global temperatures are predicted to climb by 2 to 6 degrees Celsius by the end of this century. The maximum amount of CO2 that can be produced under the 450-ppm scenario was be reached "in" 2017. The concept of energy "storage" as a possible weapon in the battle against climate change is gaining popularity. The process of gathering ice to preserve food is among the first applications of energy storage technology. 1 PWh is equivalent to 103 TWh 2 The computation just takes burning into account (Brütting et al., 2019).

2. Background of the Study

Energy storage may improve the dependability and efficiency of today's energy systems by balancing out variations in the energy flow. This would allow for greater use of renewable energy sources, which are "intermittent" in nature, and more efficient management of peak energy demand. Energy storage may contribute to a decrease in greenhouse gas emissions by enabling the efficient production of power from fossil fuels. In order to satisfy the rise in demand during the winter, Sweden imports energy at a rate of 1.5 TWh/month, while the country's marginal energy production using fossil fuels peaked at more than 1 TWh/month. The marginal peak power production may be decreased "through" energy storage (Keskitalo, 2020). Electric "energy" storage is becoming increasingly significant for power grid management as the general people grow more acquainted with the idea of a "smart grid." The Nordic nations rely significantly on heating and cooling, two of the most vital energy sources, at the same time. In Sweden, families and businesses get more than 45% of their energy from this source. With proper management of heating and cooling loads, it is feasible to lower the marginal production techniques that rely on fossil fuels. Benefits of load shifting, and peak shaving include better operating conditions with more favourable environmental circumstances, higher grid capacity without incurring additional costs, increased use of renewable energy sources, and production units operating at nominal power, which results in optimal operational efficiency. The goal of this study is to shed light on the underappreciated area of thermal energy management and storage (TES). This work's primary objective is to enhance TES design beyond traditional hot-and-cold water tanks. via the use of this latent thermal energy (Zahir et al., 2019).

3. Purpose of the Study

A stable and working system is achieved via careful planning when integrating storage technologies into the built environment. Providing that the characteristics and load profiles of the storage unit are sufficiently documented, engineers usually size the unit based on permitted methodologies and experience. Nevertheless, in real-world applications, planned systems can show disparities between expected and achieved outcomes. It is common to blame insufficient design analysis for the reasons. False designs are, in fact, often the result of misinterpreting latent heat-based thermoelectric sensing (LHTES). A deeper understanding of PCM is necessary to continue improving phase change process prediction accuracy via increased modelling methodologies and more accurate material data input. Simple but exacting measurement techniques must enable engineers to get precise PCM properties. Further research is required to determine the best method for developing LHTES components using phase change modelling. "Transient behaviour of a system may be assessed once predesign requirements have been met." At last, an assessment of the system's overall enhancement and mitigation of environmental impacts may be conducted (Cabeza et al., 2020).

4. Literature Review

"These consist of low heat loss during storage, high energy extraction efficiency, suitable operating temperature, eco-friendliness, commercial availability, and economical value. A number of TES-related articles have been published in recent years. This research overviews evaluations of PCM classes and provides an overview of the benefits and drawbacks of PCM use. When TES systems are deployed, load management is improved. Benefits of Thermal Energy Storage: It may use all of the load capacity by increasing production and shifting high demand periods during peak periods to off-peak periods when demand is lower in operating energy systems, complete storage, load levelling, and demand limitation to enhance overall system performance (Ali et al., 2021). Energy costs may be reduced via load-shifting during off-peak hours. demonstrates the distinction between total and partial load fluctuations from peak to off-peak hours using various management tactics. There are two ways to control how much load is moved: load levelling and demand limitation. A load-balancing strategy is used by the energy distribution system to maintain stability, and the storage can meet peak demand for the unbalanced load. The demand restriction mechanism charges the storage at a higher energy rating during off-peak hours and reduces the energy supply during peak hours. This regulatory approach's goal is to reduce peak energy use and, therefore, prices under an uneven "tariffing" system. TES may provide benefits to the economy and environment via the reduction of thermal and electricity-producing resources, the operation of power plants and thermal machinery at minimum capacity, the use of less costly energy during off-peak hours, and the reduction of marginal production based on fossil fuels (Yang et al., 2021).

5. Research Question

- To what extent might TES support mitigation of the effects of climate change and sustainable development?
- What technical and financial gains are made in terms of power management, reducing infrastructure, and energy consumption?
- What methods and resources can they use to make this vision a reality?

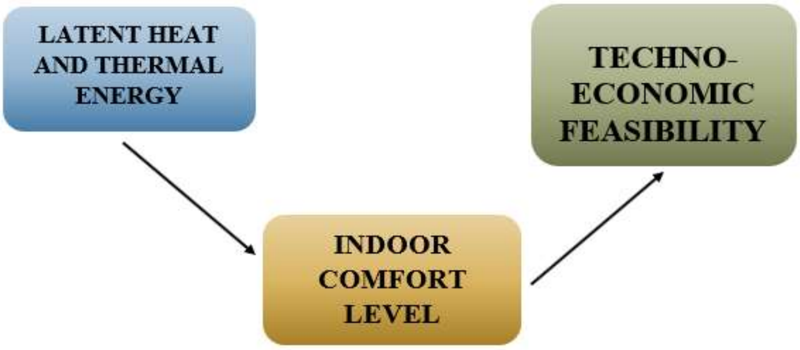
6. Methodology

Precise understanding of the thermo-physical characteristics of PCMs is necessary for the design of LHTES. The quantity of heat that may be stored in a change in temperature interval also referred to as a particular heat capacity or energy change is one of the most important thermal qualities. “Differential scanning calorimetry” (DSC) and “differential thermal analysis” (DTA) are two widely used measurement methods for homogeneous materials with small sample sizes. The temperature history approach, or T-History methodology, has garnered a lot of interest since it demonstrates the limitations of DSC measurement in evaluating nonhomogeneous PCM characteristics.

Rather, it was demonstrated that the T-History is a reliable approach to characterising thermophysical properties. Since then, many modifications to the procedure have been suggested.

This part is the outcome of the researcher's work, which has been released in IEA Annex 24 Task 42 subsection A2. This section provides an overview of the T-History technique's guiding principles. This chapter emphasises the dissertation's contributions to enhanced T-History test protocols and looks more closely at the possibility of representing specific heat capacity mathematically. The methodology's fundamental Lumped Capacitance model regards the observed sample's internal temperature gradient as negligible. Put otherwise, the proportion of the internal thermal efficiency to the total exterior thermal resistance should be expressed using a moderate, non-dimensional Biot number.

6.1 Conceptual Framework



7. Results

7.1 Convection-Based PCM Based on Paraffin
A non-gelled PCM-based thermoelectric sensor's thermal power charge/discharge rate is increased by natural convection brought on by buoyancy. This study aims to investigate the effects of natural convection by comparing a conduction-only model.

7.1.1 Modelling Outcomes
The numerical model's foundation is made up of the governing equations for momentum, energy conservation, and continuity (Eq. 4.1, 4.2, and 4.3). "The gravitational component of the momentum equation, often known as the Navier Stokes equation," is included under the Boussinesq approximation. During the discharging process, PCM melts, as shown in Figure 1. I'll end with a qualitative remark. Natural convection caused by buoyancy is what led to the non-symmetric melt. The arrows indicate how much PCM is melting and flowing through it. This illustrates how natural convection is highlighted above the bottom fin and along the heat exchanger pipe.

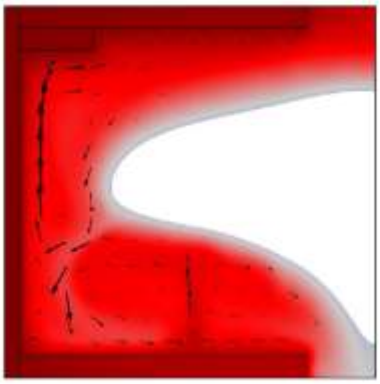
Eq. 4.1, 4.2, and 4.3

$$\frac{\partial \rho}{\partial t} + \nabla \rho u = 0 \qquad \textit{Eq. 4-1}$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla \mathbf{p} + \nabla \left\{ \mu [\nabla \mathbf{u} + (\nabla \mathbf{u})^{T}] - \frac{2}{3} \mu (\nabla \mathbf{u}) \mathbf{I} \right\} + \mathbf{F} \qquad \textit{Eq. 4-2}$$

$$\rho \cdot c_p \left[\frac{\partial T}{\partial t} + (u \cdot \nabla) T \right] = -(\nabla \cdot \dot{q}) + \tau S - \frac{T}{\rho} \frac{\partial \rho}{\partial T} \Big|_p \left[\frac{\partial p}{\partial t} + (u \cdot \nabla) p \right] + \dot{Q} \qquad \textit{Eq. 4-3}$$

Figure 1: Melting of Polycrystalline Mica in a Single Finned Compartment (Flow Intensities Indicated by Arrows)



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7.1.2 The Verification of Experiments

"The RT9 paraffin based PCM within the TES unit was found to be frozen by visual inspection." Just for the sake of filming, insulation was removed. Charging progress at the beginning, one hour, and three hours are shown in Figure 2.

Figure 2: Immobilisation of PCM Throughout Charging

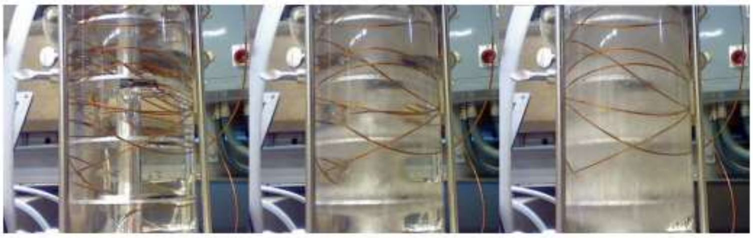
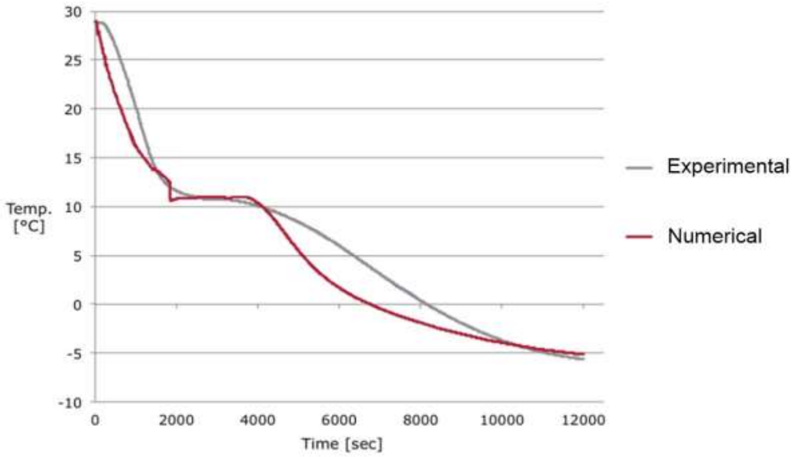


Figure 3 displays the experimental data and CFD findings. Both the predicted and actual temperatures are located exactly where they are shown. When the solid phase is stored at a lower temperature, the biggest difference is seen. The disparity in the predicted heat gain from the surrounding environment is probably to blame. Within a 15% variation in the time needed to achieve the same temperature level, the suggested model properly depicts the physical behaviour of the nongelled PCM storage.

Figure 3: Experimental Validation of Numerical Modelling



7.1.3 Fin Spacing's Effect on Convection

Fin spacing affects the heat transfer area of the surface per storage volume. Higher heat exchange rates are associated with bigger heat transfer surface areas; however, natural convection is inhibited by fin configurations that are arranged too finely. Here, the relationship between natural convection's effects on finned LHTES is investigated. To do this, modelling outcomes on various fin configurations from both the conductive/convective and pure conductive models are compared. In this experiment, the system was started at -2 °C, and a constant 30 °C inner pipe heat was considered. Four geometric designs with "fin spacings of thirty mm, 22.5 mm, 18 mm, and 15 mm" were examined (Figure 4). The outcomes of the simulation at minute fifty are shown, with the red zone indicating melt, the white hue indicating solid, and the blue region representing the mushy zone.

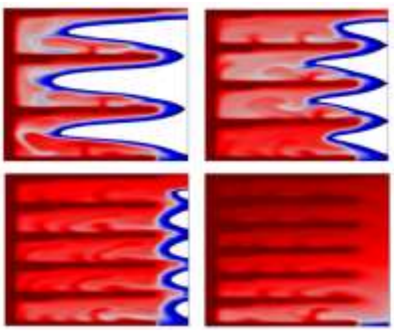


Figure 4: Impact of Fin Spacings on Melting Rate (Meaning at Minute 50)

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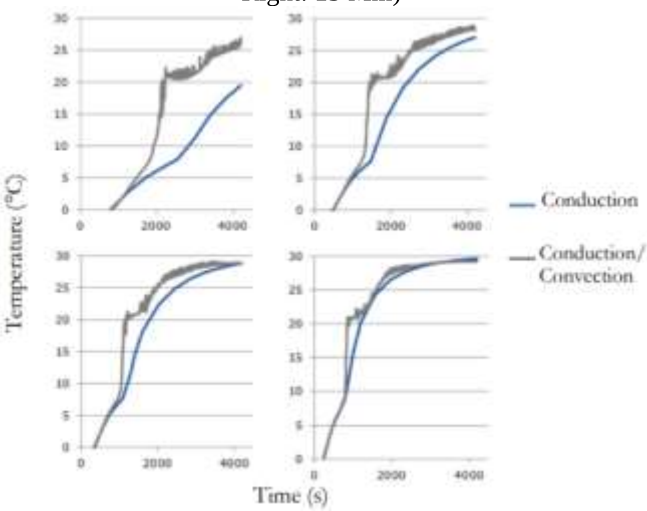
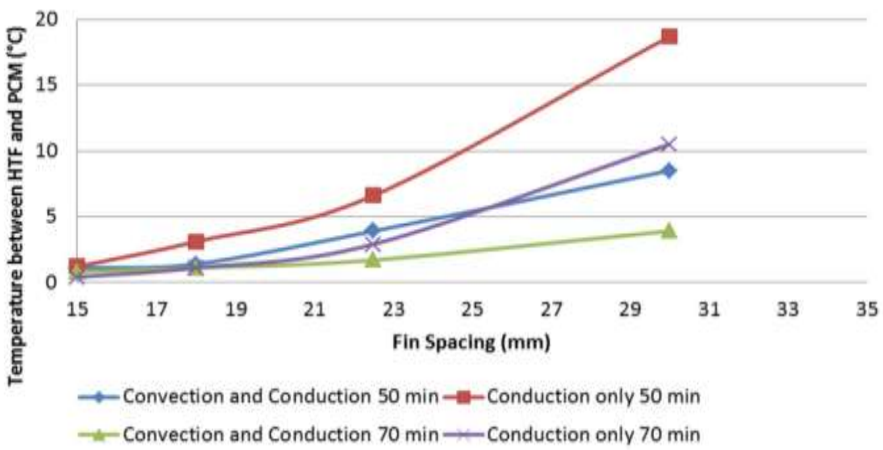
A heat exchanger with finer spacing fins performs better because it causes a speedier phase transition. By contrasting the gelled model with the nongelled model, the following shows how much the convective transmission of heat mechanism contributes to "temperature transfer in the finned" form. Figure 5 displays the temperature profiles of the PCM based on numerical calculations. Here, it is seen that convection has no influence on heat transfer increase when fins are positioned fewer than 15 mm apart. Natural convection, however, shortens the time required to achieve 20 °C by around 5 minutes for fin spacing of 18 mm. One must allow an additional fifteen minutes if fins are spaced 22.5 mm apart. The amount of time required is reduced by about half for fins positioned 30 mm apart.

Figure 5: Fin Spacing's Effect on Convection (Top Left: 30 Mm, Top Right: 22.5 Mm, Bottom Left: 18 Mm, Bottom Right: 15 Mm)



Both non-gelled PCM methods based on conducting/convective heat transfer and gelled PCM systems based on heat transfer that is conductive have been the subject of more research. After fifty to seventy minutes of cold discharge, Figure 6 displays “the temperature difference between the HTF and the PCM at 15 mm from the pipe.” A lower temperature difference indicates more thermal energy extraction or storage. This suggests that there has also been an increase in the thermal power rate. As a result, the graph shows that fins with tighter spacing produce higher heat rates. This study indicates that convection contributes significantly to heat transmission in systems with wider fin spacing, as shown by the bigger difference between "the gelled and non-gelled heat curves" in these systems. When the temperature variations are identical, "the thermal power rate in gelled and non-gelled LHTESs" is the same. The heating rate of non-gelled PCM with fins spaced 30 mm apart is comparable to that of gelled PCM with fins set 22.5 mm apart when comparing "free convective PCM storage with conductive only PCM" storage. For "gelled and non-gelled PCM" with fin widths less than 18 mm after 70 minutes and less than 15 mm after 50 minutes, the thermal power rates are the same.

Figure 6: Temperature Difference Measured at Half the Radial Distance Between HTF and PCM



This research demonstrates that convective heat transfer plays a major role in improving performance for widely dispersed fins and that narrower fin spacing results in improved thermal performance. Conversely, a narrow fin spacing results in a lower convection contribution. This factor must be considered when designing heat exchangers to have the best configuration possible for affordable heat exchanger materials and sufficient performance.

8. Discussion

One technology that might help save energy is thermal energy storage, which can be used for waste heat or free cooling, as well as to shift energy demand and minimise peak energy load. A layered hot water storage unit may be used to store heat within the thermal comfort temperature range. However, if sensible storage of thermal energy is employed (such layered chilled water), a larger storage capacity is required since the allowed operational temperature range for frigid storage is smaller. The benefit of using "phase change materials" (PCMs) as storage mediums in LHTES is their ability to store large amounts of thermal energy with little temperature variations. Although ice and water are two of the most often used PCMs, their low phase change temperatures make them less ideal for pleasant indoor cooling. In the last several years, a great deal of phase-change materials with "various phase change energies" have been investigated and tested (Thölix, 2021). The following are some ways that the study given here has advanced our understanding of LHTES:

- Assessment and confirmation of the updated data outlining the T-history methodology.
- Developing numerical models and theorising on storage component design.
- Enhancing evaluation and system integration for climate change mitigation strategies.

9. Conclusion

Because they don't phase segregate, have less subcooling problems, and work well in metallic containers, PCMs which are classified as organics or inorganics offer several benefits in thermal energy storage systems (TES). Their poor heat conductivity, high material cost, and lack of repeatable thermal property data are some of their drawbacks. An unknown material's enthalpy change may be determined by comparing it to a known reference sample using the T-History method, a revolutionary material property testing technique. A low Biot number, repeatable heat flux, high temperature sensor sensitivity, and familiarity with the reference material are all necessary for this method's accuracy. By analysing the orientation of the T-History setup and establishing the thermophysical properties of materials, this study advances a sophisticated computation technique (Schüppler et al., 2019). Subject to certain restrictions, the specific heat capacity of PCMs is represented by a simplified modified Dirac delta function that closely matches experimental data. For the charge/discharge performance evaluation of gelled salt-hydrate PCM based LHTES, when compared to experimentally obtained data, it was shown that a conductivity model based on finite-difference enthalpy was within a 5%-time difference. A conduction/convection model was created utilising variations in "material viscosity above and below the phase change temperature" to evaluate the efficacy of non-gelled storage. When PCM present in both the liquid and solid phases, there is a "15% time difference in the mushy" zone, according to experimental and numerical studies. This disagreement is mostly caused by uncertainty surrounding the convective heat transfer mechanism's cutoff point (Xu et al., 2020).

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