

STORAGE OF LATENT HEAT AND THERMAL ENERGY FOR INDOOR COMFORT CONTROL: A STUDY TO DETERMINE TECHNO-ECONOMIC FEASIBILITY

1st ZHU DONGMEI, 2nd Mohammad Nizamuddin Inamdar

ABSTRACT

The feasibility of using phase change materials as a medium for the storage of cold thermal energy for district cooling was evaluated from both a scientific and a financial point of view. Mixed-integer quadratic programming was used in order to accomplish this goal. This allowed for the best management of a cooling bus network to be found. The substances eutectic salt, paraffin, and polyethylene glycol are examples of substances that are capable of undergoing phase shifts. This research also investigated the ways in which district cooling cold thermal energy storage systems may be enhanced by the use of a storage medium that does not need a lot of space and has a high density. One of the potential solutions for enhancing the comfort of a building while simultaneously reducing its energy consumption is the storage of thermal energy and latent heat. The evidence that is currently available bears this out. The primary purpose of this research is to determine, via the application of a mix of technical and economic criteria, whether or not heating, ventilation, and air conditioning (HVAC) systems are capable of utilising phase change materials (PCMs) and thermal energy storage (TES) devices. This is made possible by the presence of materials that go through phase transitions. This makes it easier to maintain a consistent temperature throughout the building and decreases the amount of work that the HVAC system has to do. This study will examine several storage technologies and the most effective PCMs, as well as diverse approaches to system integration. The study's main focus is on how thermal capacity, cost, and the environment are all related to each other. It also looks at how the weather and other types of buildings affect the economy. The payback time, the amount of money saved on operational costs, and the initial cost of using the product are all examples of things that fit into this group.

Keywords: Latent Heat, Thermal Energy, Indoor, Economic Feasibility, Techno-Economic

1. INTRODUCTION

In addition to the fact that researchers are now more often known as sapiens, technological advancements have had a role in the general increase in the human population. Continuously raising the standard of life is directly associated with a corresponding rise in the quantity of energy needed. In 2010, after a growth phase of less than forty years, it replaced all other energy sources as the major one on Earth. In addition to thirty gigatonnes of CO₂ emissions, over half of the world's yearly energy consumption is attributed to fissile fuels. If this problem is left unchecked, global temperatures are projected to increase by two to six degrees Celsius by the end of this century. The collection of ice for the preservation of food is an example of a technology that stores energy that had an early use. These demands span time intervals ranging from milliseconds to gigawatts, and the capabilities needed are similarly diverse. To make room for energy creation, this energy storage is essential. In order to make the electrical system

more secure and resistant to an increase in both natural catastrophes and man-made threats, long-term energy storage is going to be necessary. One technology that might assist bridge the gap between the amount of renewable resources available and the amount of energy really needed is TES, or technology for energy storage and conversion. Altering a material's internal energy is a part of TES, a method for doing just that. Energy storage allows for a wide range of potential future uses, including, but not limited to, heating and cooling. The integration of TES into an energy system has several advantages. Improved overall efficiency and dependability are two of these advantages. Reducing capital and operating expenditures and emissions of greenhouse gases are two outcomes of this integration. Three common ways that TES technologies are categorised are as follows: sensible, latent, and thermochemical (Thakar et al., 2021).

2. BACKGROUND OF THE STUDY

Energy storage has the potential to make researcher's energy system more efficient and reliable. Power surges and outages may be lessened by energy storage. This would make it easier to control energy use during peak hours and open the door to using renewable power sources more often, particularly those with a "intermittent" characteristic. Energy storage has the ability to reduce emissions of greenhouse gases. Reason being, with the help of energy storage, researchers can generate power from fossil fuels in an effective manner, without sacrificing efficiency. It is very possible to decrease the output of marginal peak power "through" energy storage. When people start to think about a "smart grid" more and more, electric "energy" storage is a crucial component in managing the power grid. Also, smart grids are starting to make a big impact. Both heating and cooling are major energy consumers, but the Nordic countries rely disproportionately on both. More than 45 percent of Sweden's residential and commercial energy use comes from this one source. It is possible to lessen the reliance on fossil fuels in marginal production methods with proper management of heating and cooling loads (Tran et al., 2021). This is due to the fact that less reliance on fossil fuels is within reach. Researcher should give serious thought to the many advantages that load shifting and peak shaving provide. Some of these advantages include better environmental conditions, higher grid capacity at no additional cost, improved operational efficiency owing to industrial units working at minimal power, and more utilisation of energy from renewable sources. Taken together, these advantages lead to operational efficiency at its peak. The goal of this work is to provide more clarity on thermal energy TES, a topic that is presently undervalued. Beyond the conventional hot-and-cold water tanks, the fundamental goal of this effort is to improve the design of water storage systems for TES. Changing the temperature of the material used to store thermal energy allows for sensible heat storage to accomplish the intended result. This allows for the possibility of storing and recharging thermal energy. The use of any given technology for TES is not without its own set of pros and cons connected to that technology alone. The low energy storage density of practical TES is a limitation, even though it is simple and has been shown in a lot of studies. However, a system for TES is still in its early stages of development despite its potential to achieve a high energy storage density; this is mainly because to the technological complexity involved (Gao et al., 2023).

3. PURPOSE OF THE STUDY

A comprehensive preparation is necessary in order to construct a system that is both reliable and practical for the purpose of integrating storage technologies into the physical environment. In order to determine the size of the storage unit, engineers often make use of the approaches that are permitted as well as their own personal experience, provided that the dimensions and

load profiles of the unit are adequately recorded. Despite this, it is possible that planned systems may still exhibit inconsistencies between the results that were intended and those that were actually achieved in real-world applications. In the process of attempting to understand the impacts, it is occasionally suggested that the phenomenon might be attributed to insufficient design analysis. The most important thing to keep in mind is that inaccurate interpretations of LHTES are often the root cause of flawed designs. Researchers need to have a much better understanding of phase change material (PCM) if researchers wish to continue improving researcher's ability to forecast phase change processes by using improved modelling methodologies and more precise material data. To get accurate PCM parameters, engineers want measuring equipment that are both straightforward and dependable.

4. LITERATURE REVIEW

Features such as appropriate operating temperature, minimal environmental effect, commercial availability, monetary worth, and low thermal expansion during storage are all part of this class. So is good thermal efficiency during energy extraction. In recent years, TES has been the subject of an increasing number of articles. Overall, the research will aim to summarise PCM course evaluations, but it will also provide a rundown of PCM's benefits and drawbacks. Improved load control is the result of implementing TES systems. In what ways does the act of reducing heat energy use help? In order to maximise the system's performance, it may increase output during peak hours and shift high-demand times to off-peak hours, when demand is lower, thereby using all of the load capabilities (Li et al., 2024). This is essential for the proper operation of the energy system as a whole, including full preservation, load equalisation, and demand restriction. Energy costs may go down if more people shifted their loads during off-peak hours. The term for this occurrence is load-shedding. This article compares and contrasts total load versus partial load using a variety of management techniques, spanning peak to off-peak activities. Load levelling and demand limitation are two methods for controlling the quantity of cargo that is carried. The term "load management" applies to both approaches. A load-balancing approach is used by the energy distribution system to ensure stability. Also, even when the load isn't distributed evenly, the storage facility can handle the peak demand. During off-peak hours, the demand limitation mechanism charges the storage at a higher energy rating, whereas during peak hours, the quantity of accessible energy is reduced. This happens while the storage is being charged. Heat pumps are a major electric power consumer in homes, even though they only need a little amount of power to transfer a larger amount of heat. Additionally, heat pumps cannot operate well without heat pumps. Prices for electricity have risen significantly due to existing energy shortages, inflation, and other factors. How much electricity is exchanged for might change drastically in various marketplaces. There are several instances when the costs of energy are very cheap. Because of the effects of wind power generation, this happens. The total cost of trading energy has risen more than before, as is evident from this. TES role in peak load shifting has piqued interest in its potential use in domestic heating systems, where it might help lower heating costs (Javaherneshan, 2024).

5. RESEARCH QUESTION

- ✚ What is the impact of the storage of Latent Heat on Techno-Economic Viability?
- ✚ What is the effect of techno-economic viability on indoor comfort control?

6. RESEARCH METHODOLOGY

- **Research Design:**

The quantitative data analysis used SPSS version 25. The odds ratio and 95% confidence interval were used to evaluate the strength and direction of the statistical association. The researchers established a statistically significant threshold of $p < 0.05$. A descriptive analysis was conducted to ascertain the principal features of the data. Quantitative approaches are often used to examine data obtained from surveys, polls, and enquiries, as well as information analysed by statistical software.

- **Sampling:**

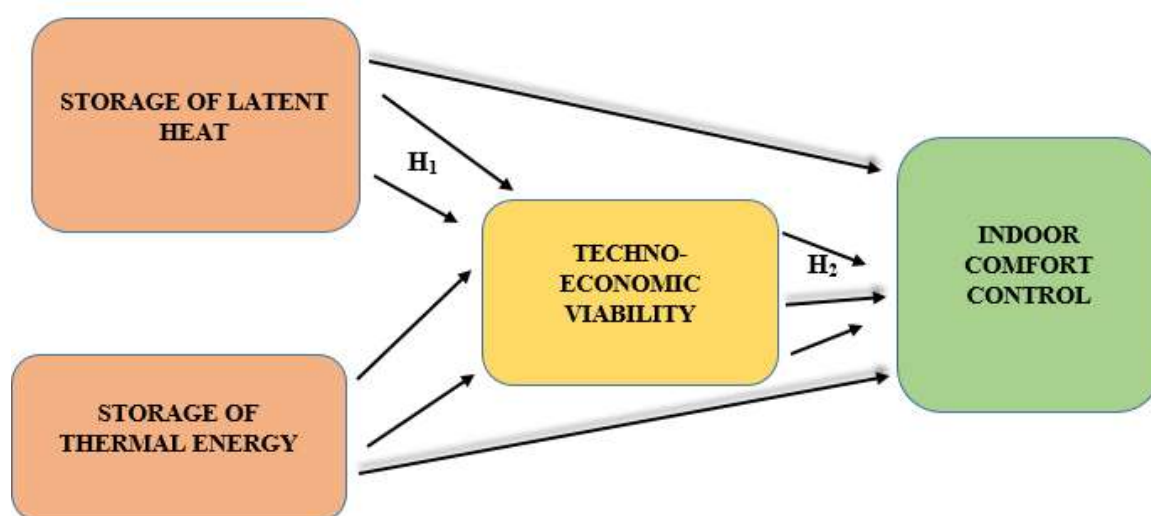
Study participants filled out questionnaires to provide data for the research. Employing the Rao-soft algorithm, researchers selected a study cohort of 1,386 people, leading to the distribution of 1,512 questionnaires. The researchers obtained 1456 replies, removing 47 due to insufficient participation, yielding a final sample size of 1409.

- **Data and measurement:**

A questionnaire served as the primary instrument for data collection in this research. Part A of the survey solicited fundamental demographic information, whereas Part B used a 5-point Likert scale to gather answers about attributes associated with online and offline channels. A multitude of sources, particularly internet databases, provide more information.

- **Statistical Software:** The statistical analysis was conducted using SPSS 25 and Microsoft Excel.
- **Statistical Tools:** The descriptive analysis technique was used to comprehend the fundamental characteristics of the data. The researcher must analyse the data using ANOVA.

7. CONCEPTUAL FRAMEWORK



8. RESULT

- **Factor Analysis**

A common use of Factor Analysis (FA) is to uncover hidden variables in observable data. The standard technique necessitates the use of correlation coefficients for evaluation when diagnostic or visually apparent indicators are lacking. Models are essential for success in FA. Modelling naturally involves mistakes, intrusions, and identifiable relationships. The Kaiser-Meyer-Olkin (KMO) Test is a method for evaluating datasets generated by multiple regression analyses. This signifies that the variables in the model and the sample are authentically representative. The statistics indicate data redundancy. Data becomes more comprehensible when proportions are reduced. The execution of KMO yields a result ranging from 0 to 1. A suitable sample size is represented by a KMO value ranging from 0.8 to 1. Kaiser delineates the allowable parameters: Kaiser has implemented the following supplementary entrance criteria:

A lamentable range of 0.050 to 0.059 and a lamentable range of 0.60 to 0.69

The standard range for middle grades is 0.70 to 0.79.

Exhibiting a quality point score ranging from 0.80 to 0.89.

The interval from 0.90 to 1.00 astonishes them.

Table 1: Evaluation of Sampling Adequacy using KMO and Bartlett's Test indicates a Kaiser-Meyer-Olkin metric of 0.865.

The results of Bartlett's sphericity test are as follows: The chi-square statistic is around 190, with a significance level of 0.000.

This substantiates that assertions made for sampling reasons are authentic. The researchers used Bartlett's Test of Sphericity to determine the significance of the correlation matrices. A satisfactory sample is indicated by a result of 0.865 on the Kaiser-Meyer-Olkin measure. Bartlett's sphericity test yields a p-value of 0.00. Due to the absence of a unique value in the association matrix, it successfully passes Bartlett's circularity test.

Table 1: KMO and Bartlett's Test

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

The matrix of correlations has been demonstrated to be statistically significant by the Bartlett Test of Sphericity. The Kaiser-Meyer-Olkin statistic indicates a sample adequacy of 0.865. The researchers obtained a p-value of 0.00 using the Bartlett circularity test. The significant

outcome of Bartlett's test of sphericity leads the researcher to acknowledge the inaccuracy of the correlation matrix.

❖ INDEPENDENT VARIABLE

✚ Storage of Latent Heat

Using PCMs, a method for storing thermal energy is called latent heat storage (LHS). Commonly called PCMs, to absorb and release energy as the material undergoes phase transitions, such as melting and freezing. This method takes advantage of the fact that phase transitions absorb and release a lot of energy. This allows it to efficiently store and extract energy. Among the many uses for LHS systems are climate control in buildings, industrial processes, and renewable energy power production systems due to their high energy density and temperature stability. One way to save the heat from a solid turning into a liquid is to utilise a phase-change material, which stores heat during a phase transition and makes use of the large amount of latent heat that is produced. Latent heat can be thought of as a form of hidden energy that can be added or subtracted to affect the state of a material without changing its temperature or pressure. This class includes the latent heats of fusion, vaporisation, and sublimation, which are responsible for the transformation of solids into liquids, gases, and vapours, respectively. Latent heat is the heat that either a body or a thermodynamic system emits or absorbs while a process is taking place at a fixed temperature. One well-known example is the process of a change in the state of matter, which is called a phase transition. Despite the system's absorption (or release) of heat, its temperature remains constant throughout this operation. The latent heat associated with solid-state transformations like melting or liquid-state freezing is called the heat of fusion. The heat of vaporisation is the latent heat associated with the processes of evaporation and condensation of a liquid or solid (Allam & Nehari, 2024).

❖ DEPENDENT VARIABLE

✚ Indoor Comfort Control

Air quality is only one aspect of what is referred to as "indoor comfort"; other aspects include thermal, optical, and auditory comfort as well. Experts in the field have managed to circumvent every single one of these challenges. When scientists speak about comfort, they imply "a pleasant feeling of being relaxed and free from pain." This is the ultimate in convenience for some people. The Cambridge English Dictionary defines comfort as a state of mind. This definition was given by the dictionary. Room temperatures between 20 and 25 degrees Celsius (68 and 77 degrees Fahrenheit) are generally considered ideal for most people under typical circumstances (i.e., with appropriate humidity and appropriate clothing). On the other hand, some demographics, such as very young children or the elderly, as well as individual preferences and levels of physical activity, can cause this range to shift somewhat. In general, people feel most rested when the temperature is between 18 and 20 degrees Celsius (65 and 68 degrees Fahrenheit). A person's general sense of comfort is greatly affected by a number of elements, such as ventilation, human metabolism, and environmental humidity. Indoor comfort solutions are essential for individuals to maintain a safe and pleasant environment in their homes and workplaces by addressing issues related to lighting, acoustics, and air quality. When it comes to meeting the requirements of individuals, researchers have a lot of options. The several types of household appliances displayed here include soundproofing panels, heating, ventilation, and air conditioning systems, humidifiers, smart thermostats, and heaters. 9 These alternatives ensure that researcher's rooms stay cool in the summer, cosy in the winter, and dry and dust-free. Many of us engage in this activity. Consider the ease of the interior space when

making decisions regarding the usage of curtains or smart lighting to reduce glare and improve mood in addition to temperature. With the use of modern smart systems that incorporate cutting-edge technologies, Researchers can now control the level of comfort in their home just by speaking to it or pressing a button. Study up on the most common varieties, discover methods to make it more pleasant, and use this data to pick the one that's best suited to researchers' study needs (Lygouras et al., 2023).

❖ **MEDIATING VARIBALE**

✚ **Techno economic Feasibility**

Technical and financial feasibility are both examined in depth within the framework of a detailed evaluation known as a Techno-Economic Feasibility Study (TEFS). Utilising this decision-making tool is crucial for ensuring that the project is technically feasible, financially stable, and ecologically sustainable. This research offers a data-driven evaluation of the project's feasibility through a combination of engineering analysis, economic modelling, and risk assessment approaches. Any company or organisation thinking about starting a new venture or investing in an existing one needs to do a Techno-Economic Feasibility Study, or TEFS for short. A project's feasibility study is the procedure by which the technical and financial elements of the project are evaluated to ascertain the probability of the project's actual success. The technical and financial feasibility of a project are examined in depth within the framework of a comprehensive assessment known as a TEFS. Utilising this decision-making tool is crucial for ensuring that the project is technically feasible, financially stable, and ecologically sustainable. It is usual practice to use a techno-economic model when conducting evaluations of this kind. A techno-economic model can help researcher comprehend the procedures and associated costs more clearly. Considerations such as equipment size, process modelling and design, and evaluation of operational and capital costs are all part of it (Shan et al., 2024).

✚ **Relationship between Storage of Latent Heat and Techno economic Feasibility**

When it comes to the technological and economic viability of thermal energy storage systems, the fact that they can keep latent heat is the most important thing. Phase change materials, or PCMs, are the parts that make up latent heat storage. This kind of heat storage lets researcher store and release a lot of heat at temperatures that are fairly steady and have a high energy density. Because of this, it works well in a number of fields, such as solar thermal energy, waste heat recovery, heating, ventilation, and air conditioning systems, and other air conditioning and ventilation systems. Systems that store latent heat might be more efficient, smaller, and better at keeping their temperatures stable, all of which would make the system work better. People also think that latent heat storage systems take up less space. This is because new technologies have made it possible to make gadgets that store latent heat. PCMs and containment systems may have greater starting costs than sensible heat storage; however, the money that is saved over the long term as a consequence of increased efficiency, less running expenses, and fewer space needs frequently makes up for the difference. This is because sensible heat storage takes up less space. When it comes to constructing and using long-term energy solutions, latent heat storage is a crucial issue that needs to be thought about. This is because there is a strong connection between how well the system works and how cost-effective it is as a whole (Aalto, 2025).

To evaluate the relationship between Storage of Latent Heat and Techno economic Feasibility, the researcher developed the following hypothesis based on the ensuing discourse.

“H₀₁: There is no significant relationship between Storage of Latent Heat and Techno economic Feasibility.”

“H₁: There is a significant relationship between Storage of Latent Heat and Techno economic Feasibility.”

Table 2: H₁ ANOVA Test

ANOVA					
Sum					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39588.620	444	5244.531	979.919	.000
Within Groups	492.770	964	5.352		
Total	40081.390	1408			

This investigation will yield substantial results. The F statistic is 979.919, achieving significance with a p-value of .000, which is below the .05 alpha threshold. The hypothesis posits that ***“H₁: There is a significant relationship between Storage of Latent Heat and Techno economic Feasibility.”*** The alternative hypothesis is validated, whereas the null hypothesis is rejected.

✚ Relationship between Techno-Economic Viability and Indoor Comfort Control

One of the main aims of linking technical economic viability with regulating indoor comfort is to have the best possible level of technological efficiency while also getting the best possible level of quality in the indoor environment. One of the main goals of the link is this. HVAC, lighting, and smart building technology are some of the parts that make up interior comfort management systems. These systems were made to make sure that the individuals who work in the facility can perform their jobs well and are comfortable. However, putting these systems in place and running them may cost a lot of money and require a lot of energy during their lives. Techno-economic viability is the idea that researchers need to figure out whether these systems can maintain a balance between their technical performance and their economic costs over a long period of time. Using renewable energy sources, advanced controls, and energy-efficient technology makes it feasible to lower operating costs without losing comfort. A big part of making the most use of and embracing these solutions is figuring out how feasible they are from a technical and economic point of view. One reason for this is because a system that is both technically sound and economically sound may make a building more comfortable in a manner that is good for the environment (Mazzoni et al., 2021).

In response to the above discussion, the researcher has offered the following hypothesis to examine the correlation between Techno-Economic Viability and Indoor Comfort Control.

“H₀₁: There is no significant relationship between Techno-Economic Viability and Indoor Comfort Control”

“H₁: There is a significant relationship between Techno-Economic Viability and Indoor Comfort Control”

Table 2: H₁ ANOVA Test

ANOVA					
Sum					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39588.620	205	5636.527	1052.376	.000
Within Groups	492.770	1203	5.356		
Total	40081.390	1408			

This investigation will provide substantial results. The F statistic is 1052.376, achieving significance with a p-value of .000, which is below the .05 alpha threshold. The hypothesis posits that *“H₁: There is a significant relationship between Techno-Economic Viability and Indoor Comfort Control”* The alternative hypothesis is validated, while the null hypothesis is rejected.

9. DISCUSSION

The storage of thermal energy is one technology that could lead to better energy conservation. Energy from the sun and the wind are two such examples. This technique has several uses, but one of them is making use of waste heat or free cooling. Other uses include making it possible to shift energy consumption and reduce the system's peak load. Using a multi-layer hot water storage tank is one way to maintain the heat on the safe side. This is one possible approach to store heat. However, thermal energy storage systems (such as layered chilled water) that are feasible need a bigger storage capacity. The primary driver behind this is the need for more capacious storage capacities. The reason for this is because there is a certain temperature range within which cold storage actions are effective. Here researchers have the situation's justification. There may be many advantages to using PCMs as a storage medium in LHTES. Among PCMs' many advantages is the large amount of thermal energy they can store with very little variation in temperature. The low phase change temperatures of ice and water, two of the most common PCMs, make them useless for producing an efficient indoor cooling environment, despite their popularity. Multiple phase-change materials with "various phase change energies" have been the subject of much investigation and experimentation by researchers and scientists in recent years. Much study and inquiry has focused on the relevant materials.

10. CONCLUSION

There are several benefits of using organic or inorganic personal computing materials (PCMs) with the technology-enabled systems (TES) that are now under discussion. They have various benefits, such as not phase separating, less trouble with subcooling, and compatibility with

steel containers. The materials have several downsides, including a high price tag, poor heat conductivity, and an absence of reliable data about their thermal properties. The high cost of these materials is a key consideration. To find the enthalpy change of an unknown material, one might utilise the T-History technique, which is a novel way to evaluate material attributes by comparing it to a known reference sample from the past. This method relies on several crucial conditions that, when satisfied, guarantee its correctness. The following are some of these considerations: low Biot number, reproducible heat flow, high sensitivity of the temperature sensor, and familiarity with the reference material. This research examines the orientation of the T-History setup and evaluates thermophysical properties of different materials, which contributes to the development of a complex calculation method. Researchers examine both of those aspects in this study. Researchers will demonstrate the specific heat capacity of PCMs using a basic modified Dirac delta function. Doing so will help show how the function works. This function will provide findings that are quite similar to the trials. Conversely, there are limits that, under no circumstances, may be crossed. This was the situation with the performance evaluation for charging and discharging. When researchers compare the model to the data collected during testing, they could notice this. A conduction/convection model that takes into account variations in "material viscosity above and below the phase change temperature" is necessary to accomplish the objective of assessing the effectiveness of non-gelled storage. This step was crucial for finishing the job. A "15% time difference in the mushy" zone is seen when PCM is present in both the liquid and solid phases, according to the study's conclusions, which include both experimental and numerical investigations. This conclusion is borne out by the findings of the research. One of the main reasons for the ongoing debate is that there is no consensus on when exactly the convective heat transfer mechanism ceases to function.

REFERENCES

- Aalto, L. (2025). Economic viability of latent thermal energy storage as part of multi-optimization in buildings.
- Allam, B., & Nehari, T. (2024). Performance prediction and techno-economic analysis of a thermal storage system (Doctoral dissertation).
- Gao, X., Li, Z., Yu, J., Gao, J., Yang, X., & Sundén, B. (2023). Thermo-Economic Performance Analysis of Modified Latent Heat Storage System for Residential Heating. *Energies*, 16(19), 6915.
- Javaherneshan, D. (2024). Technoeconomic analysis of storing industrial waste heat in a novel heat storage.
- Li, Z. L., Zhang, C. L., Liu, H. M., & Wang, X. C. (2024). Feasibility analysis of thermal storage defrosting method for air source heat pump: From energetic and economic viewpoints. *Applied Thermal Engineering*, 236, 121828.

- Lygouras, E., Papatsounis, A. G., Botsaris, P. N., & Pechtelidis, A. (2023). Optimization & techno-economic analysis of a hybrid system with thermal energy storage within a LEC. *Renewable Energy*, 215, 118920.
- Mazzoni, S., Sze, J. Y., Nastasi, B., Ooi, S., Desideri, U., & Romagnoli, A. (2021). A techno-economic assessment on the adoption of latent heat thermal energy storage systems for district cooling optimal dispatch & operations. *Applied Energy*, 289, 116646.
- Shan, L., Martin, A., & Chiu, J. N. (2024). Techno-economic analysis of latent heat thermal energy storage integrated heat pump for indoor heating. *Energy*, 298, 131291.
- Thakar, K., Patel, R., & Patel, G. (2021). Techno-economic analysis of district cooling system: A case study. *Journal of Cleaner Production*, 313, 127812.
- Tran, T. V., Oni, A. O., Gemechu, E., Carrier, Y., Tezel, F. H., & Kumar, A. (2021). Developing a techno-economic model to evaluate the cost performance of a zeolite 13X-based space heating system. *Energy Conversion and Management*, 244, 114325.