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DESIGN AND FABRICATION OF WASTE HEAT RECOVERY USING PHASE CHANGE MATERIAL FOR DOMESTIC APPLICATIONS

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Abstract: Waste heat recovery (WHR) from domestic appliances and processes offers a significant opportunity to improve energy efficiency and reduce household energy bills. Phase Change Materials (PCMs) are a promising technology for WHR due to their ability to store and release thermal energy at specific temperatures. This project proposes the design and fabrication of a WHR system using PCMs for domestic applications. The system aims to capture waste heat from various domestic appliances and processes, such as clothes dryers, ovens, or range hoods, and store it in PCMs. The stored thermal energy can then be released for various applications, including preheating water, space heating, or even cooking. The project presents a conceptual design of the system, identifies potential PCM candidates, and outlines fabrication and testing procedures. It also highlights the potential benefits of the system, such as reduced energy consumption, sustainability, improved comfort, and scalability. The project acknowledges the challenges of material selection, heat exchanger design, leakage prevention, and system integration. It concludes by emphasizing the need for further research and development to optimize materials, design, and fabrication processes for a commercially viable domestic WHR system using PCMs The system will target specific waste heat sources, such as exhaust from clothes dryers, ovens, or range hoods. A compact and efficient heat exchanger will be designed to transfer heat from the waste source to the PCM. The PCM will be contained in a sealed and insulated container to prevent leakage and minimize heat loss. The stored thermal energy in the PCM can be released for various domestic applications, such as preheating water for showers or dishwashing, space heating, or even cooking. The system will be fabricated and tested, and its efficiency in capturing waste heat, storing it in the PCM, and releasing it for various applications will be evaluated. The project has the potential to significantly reduce energy consumption, promote sustainable living, and improve domestic comfort.

Keywords: Waste heat recovery,Phase change material (PCM),Domestic applications,Energy efficiency Thermal energy storage,Heat transfer,Renewable energy,Sustainable technology

1.INTRODUCTION

Traditional chimneys are essential components of heating systems, commonly found in homes with fireplaces, wood stoves, or furnaces. These chimneys serve the purpose of expelling waste heat produced during combustion processes. However, this waste heat often goes unused and dissipates into the environment, representing a significant energy loss. This report explores the concept of Extracting the waste heat for various domestic applications, providing a sustainable and efficient way to utilize this waste heat for heating applications.

Concept of harnessing chimney waste heat to improve energy efficiency and provide heating is a promising approach in sustainable engineering. By capturing and utilizing the otherwise wasted heat from chimneys, we can contribute to both reducing energy consumption and environmental impact. This innovative solution holds the potential to make heating systems eco-friendlier and more cost-effective.

Domestic chimneys release significant amounts of waste heat, often reaching temperatures between 150°C and 400°C. Recovering this heat for domestic applications like space heating, water heating, or even cooking can significantly improve energy efficiency and reduce reliance on conventional fuel sources. This project proposes the design and fabrication of a system using phase change materials (PCMs) to capture and store this waste heat for later use. The global energy landscape is facing increasing pressure to reduce reliance on fossil fuels and mitigate the impact of climate change. One promising approach to address these challenges is waste heat recovery (WHR), which involves capturing and utilizing heat that would otherwise be lost to the environment. In domestic settings, chimneys represent a significant source of waste heat, as flue gases from residential heating systems often carry substantial thermal energy. PCMs are materials that can absorb and store large amounts of thermal energy by undergoing a phase change from solid to liquid or vice versa. This unique property allows PCMs to effectively capture and store waste heat from flue gases, which can then be utilized for various domestic applications, such as preheating domestic hot water or providing supplemental space heating.

2.LITERATURE REVIEW

This paper deals with the study of waste heat recovery from chimney working on phase change material which produces high amount of heat. It shows that the advantages over the conventional systems. Moreover, their versatility in application of cooling and power generation also makes them considerable over electrically powered devices. The modules discussed in the above invention are used in this research paper [1].
This research paper deals with the electricity generation from flue gases via thermoelectric generator. In our research paper we are going to generate high amount of electricity by using more efficient and method and advanced Industrial chimney design [2].
This paper deals with heat generation from exhaust gas of IC engine using thermoelectric generator module working on See Beck effect [3].
This research paper deals with the study of waste heat recovery by using the different thermodynamics assumptions and processes [4].
The electricity generation in this paper is somehow same as our project. But the advancement in this project is the use of water jacket which increases temperature difference and hence increases power generation [5].
This paper deals the electricity generation by same module by creating turbulence also. In our paper, black coating is also provided to increase the inside temperature of waste which ultimately increases temperature difference. Hence efficiency increases [6].
This paper deals with the structure of solar chimney tower for production of electricity. Hence via this system will get heat only in summer and hence this system needs to replace to improve efficiency [7] PCMs and their potential for waste heat recovery Current research delves into novel PCMs with tailored properties for specific applications. For instance, studies explore PCMs with tuneable melting temperatures using eutectic mixtures [8] or incorporating nanomaterials like carbon nanotubes for enhanced thermal conductivity [9].
This opens doors for optimizing PCMs for specific chimney flue gas temperatures and heat transfer requirements.Heat exchanger design and considerations: Recent advancements in heat exchanger design aim to maximize efficiency and address specific challenges. Compact heat exchangers using microchannels [10]
offer superior surface area-to-volume ratios, leading to faster heat transfer and smaller system footprints. Additionally, research explores self-cleaning heat exchanger designs to mitigate clogging issues, especially in low-temperature applications [11].
PCM encapsulation and container materials: Novel encapsulation techniques continue to emerge, focusing on improved thermal performance, leakage prevention, and cost- effectiveness. Shape-stabilized PCMs embedded in porous materials like expanded graphite [12]
offer excellent thermal stability and leakage protection. Meanwhile, microencapsulation using biocompatible polymers [13]
shows promise for safe and sustainable PCM applications. Control systems and system integration: Advanced control systems are being developed to optimize heat management and prevent overheating. Machine learning algorithms are being integrated to predict heat demand and adjust HTF flow dynamically [14].
Additionally, research explores decentralized control strategies for modular PCM-based systems, enabling flexible integration with various heat sources and domestic appliances [15].

3.METHODOLOGY

1. Heat Collection: Install a heat collection system on the chimney to capture the high-temperature gases. This could be in the form of a heat exchanger or a specialized system designed to efficiently collect heat.
2. Phase Change Material (PCM): Integrate a Phase Change Material (PCM) intoyour system. PCMs are substances that can absorb and release a large amount of thermalenergy during a phase change (e.g., solid to liquid or liquid to gas). Select a PCM with a phase change temperature suitable for your application.

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3. Heat Transfer to PCM: Transfer the heat collected from the chimney gases to the PCM. This can be done by circulating a heat transfer fluid (e.g., water or air) through the heat exchanger and then through the PCM to facilitate the phase change.
4. Storage and Release: The PCM absorbs the heat and undergoes a phase change,storing thermal energy. When you need to heat a space or water, allow the PCM to release the stored energy as it reverts back to its original phase (solidification or condensation).
5. Distribution System: Use a distribution system to transfer the heat released from the PCM to the target application, such as a heater, radiators, or a hot water tank.
6. Control System: Implement a control system to manage the process, ensuring that the PCM is charged when there's excess heat from the chimney and discharged when heat is needed.
7. Efficiency and Monitoring: Regularly assess the system's efficiency and monitor the PCM's state to ensure it's ready for the next phase change cycle.
8. Safety Measures: Incorporate safety measures to prevent overheating or system failures, such as thermal cutoffs and pressure relief mechanisms. Utilizing a Phase Change Material in this manner can efficiently store and release thermal energy, making it a sustainable way to repurpose waste chimney heat for various heating applications.

4. SYSTEM DESIGN

The Proposed System Consists Of Three Main Components:
Copper Tube: Located Near The Heat Source (Appliance Exhaust), It Extracts Thermal Energy From The Waste Heat Stream.
Phase Change Material (PCM): Encapsulated Within A Container, It Absorbs The Captured Heat During Its Melting Phase.
Heat Transfer Unit: Transfers The Stored Thermal Energy From The Molten PCM To The Desired Application (E.G., Water Tank) When Needed.

PCM Selection:
Once the heat source has been characterized, appropriate PCMs can be selected. PCMs are chosen based on their melting temperature, latent heat storage capacity, thermal conductivity, and long-term stability. The melting temperature of the PCM should match the temperature of the flue gases to ensure efficient heat capture. The latent heat storage capacity of the PCM determines the amount of heat that can be stored per unit mass. Thermal conductivity is important for heat transfer between the flue gases and the PCMs. Long-term stability ensures that the PCMs do not degrade over time and maintain their heat storage capacity.

Selection of PCMs:
The selection of PCMs for the container is critical for optimizing the waste heat recovery system. The PCMs should have suitable melting temperatures, latent heat storage capacity, and thermal conductivity to match the specific application and operating conditions.

Integration with the heat exchanger
The PCM container should be properly integrated with the heat exchanger to ensure efficient heat transfer between the flue gases and the PCMs. The flow of flue gases through the heat exchanger should be carefully controlled to maximize heat transfer without overheating the PCMs.
Overall, PCM containers play a vital role in waste heat recovery systems using PCMs for domestic applications. Their design, construction, and integration with the heat exchanger are crucial for ensuring the efficient and effective capture, storage, and utilization of waste heat from chimneys.

4.2 PHASE CHANGE MATERIAL:
A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units.

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PCMs latent heat storage can be achieved through solid-solid, solid-liquid, solid-gas and liquid-gas phase change. However, the only phase change used for PCMs is the solid-liquid change. Liquid- gas phase changes are not practical for use as thermal storage due to the large volumes or high pressures required to store the materials when in their gas phase. Liquid-gas transitions do have a higher heat of transformation than solid-liquid transitions. Solid-solid phase changes are typically very slow and have a rather low heat of transformation.

Organic Pcms Paraffin (Cnh2n+2) And Fatty Acids (Ch3(Ch2)2ncooh)
Advantages:
1. Availability In A Large Temperature Range
2. Freeze Without Much Super Cooling
3. Ability To Melt Congruently
4. Self-Nucleating Properties
5. Compatibility With Conventional Material Of Construction
6. No Segregation 7. Chemically Stable
8. High Heat Of Fusion
9. Safe And Non-Reactive
10. Recyclable

Disadvantages:
Low thermal conductivity in their solid state. High heat transfer rates are required during the freezing cycle.
Volumetric latent heat storage capacity is low
Flammable. This can be easily alleviated by a proper container Due to cost consideration only technical grade paraffins may be used which are essentially paraffin mixture and are completely refined of oil

4.3 BENEFITS:
Energy Savings:
PCM-based WHR systems can significantly reduce energy consumption for domestic heating by utilizing waste heat that would otherwise be lost through chimneys. Studies have shown that these systems can achieve energy savings of up to 30% compared to conventional heating methods (Abedin et al., 2021; Liu et al., 2022). This translates to lower energy bills and a smaller environmental footprint.
Sustainable Energy Utilization:
By capturing and utilizing waste heat, PCM-based WHR systems contribute to a more sustainable energy future by reducing reliance on conventional energy sources and conserving natural resources. This aligns with the global transition towards cleaner and more sustainable energy practices.
Versatility and Adaptability:
PCM-based WHR systems can be integrated with various domestic heating systems, such as water heaters, space heaters, and underfloor heating systems. This versatility makes them adaptable to different household configurations and heating needs.
Passive Operation:
PCMs operate passively, absorbing and releasing heat without requiring additional energy input. This passive nature simplifies system operation and reduces maintenance requirements, making them a cost-effective solution.
Environmental Benefits:
By reducing reliance on conventional energy sources, PCM-based WHR systems contribute to lower greenhouse gas emissions and a smaller environmental footprint. This aligns with the global efforts to mitigate climate change and promote environmental sustainability.
Economic Benefits:

The energy savings achieved through PCM-based WHR systems translate to lower energy bills for homeowners. Additionally, government incentives and subsidies can further enhance the economic attractiveness of these systems.

Enhanced Thermal Comfort:

PCM-based WHR systems can help maintain a more stable and comfortable indoor temperature by storing and releasing heat as needed. This can improve thermal comfort for occupants, especially during periods of intermittent heating or cooling demand.

Reduced Reliance on Fossil Fuels:

By utilizing waste heat instead of relying solely on conventional energy sources, PCM- based WHR systems help reduce dependence on fossil fuels, which are major contributors to greenhouse gas emissions and air pollution.

Scalability for Large-Scale Adoption:

PCM-based WHR systems can be easily scaled up for implementation in larger buildings, such as apartment complexes or commercial facilities, further expanding their potential impact on energy consumption and environmental sustainability.

4.4 CHALLENGES:

Initial investment: The cost of materials and fabrication might seem high initially, although long-term savings in energy bills can offset the investment.

System complexity: Compared to traditional heating systems, the PCM-based system might require more maintenance and monitoring.

Space requirements: The heat exchanger and PCM container might occupy additional space within the chimney flue or surrounding area.

Heat Source Characterization: Accurately characterizing the heat source, including the temperature and flow rate of flue gases, is crucial for designing an efficient heat exchanger and selecting appropriate PCMs.

PCM Selection: Choosing PCMs with suitable melting temperatures, latent heat storage capacity, thermal conductivity, and long-term stability is critical for optimizing system performance and ensuring long-term reliability.

Heat Exchanger Design: Designing a heat exchanger with high heat transfer efficiency, compact size, and compatibility with the chimney flue and PCM container is essential for maximizing heat capture and minimizing heat loss.

System Integration: Seamlessly integrating the WHR system with the existing chimney and domestic plumbing infrastructure is necessary for practical implementation and compatibility with existing heating systems. Control and Optimization: Implementing control strategies and optimization techniques can further enhance system performance, energy savings, and adaptability to varying heat source conditions.

4.5 Practical Challenges:

Cost-Effectiveness: Balancing the initial cost of the system, including the heat exchanger, PCM container, and control system, with the long-term energy savings is crucial for ensuring economic feasibility.

Installation and Maintenance: Developing user-friendly installation and maintenance procedures is essential for widespread adoption and ensuring the long- term performance and reliability of the system.

User Acceptance: Educating homeowners about the benefits, limitations, and operational requirements of PCM-based WHR systems is crucial for fostering user acceptance and encouraging adoption.

Market Availability: Ensuring the availability of high-quality PCMs, efficient heat exchangers, and qualified installers is essential for wider adoption and market penetration of PCM-based WHR systems.

4.6 EXPECTED OUTCOME: Efficient Heat Recovery: The project should result in an efficient system for capturing waste heat from chimneys, ensuring that a significant amount of heat energy that was previously wasted can be effectively harnessed.

Sustainable Heating: By integrating Phase Change Materials (PCMs) into the system, the project aims to provide a sustainable and renewable heating solution that can significantly reduce reliance on conventional heating methods.

Energy Cost Savings: The efficient conversion of waste heat into usable heating energy can lead to substantial cost savings for residential or industrial users, reducing their energy bills.

Environmental Impact: The project's success can contribute to a reduction in carbon emissions and the overall environmental impact by utilizing waste heat as a clean energy source.

Improved Energy Efficiency: The system's efficiency in capturing and storing thermal energy can contribute to increased overall energy efficiency, which is essential in the context of sustainability and resource conservation.

Versatile Applications: Depending on the project's design, the outcome may include a heating solution applicable to a variety of settings, such as residential homes, commercial buildings, or industrial processes.

Data and Research: The project's findings and data can add to the body of knowledge about waste heat recovery and PCM-based heating systems, potentially contributing to future research and innovation in this field.

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Commercial Potential: If the system proves to be both efficient and cost-effective, it may have commercial potential for manufacturing and implementation in the broader market.
Educational and Outreach Materials: The project's success can result in educational materials and case studies that can be used to raise awareness about sustainable energy solutions.
Regulatory and Policy Insights: The project's findings may offer insights into potential policy changes or incentives that encourage waste heat recovery and sustainable heating practices.
The expected outcome of the project is to create an efficient, environmentally friendly, and economically viable solution for converting chimney waste heat into a valuable heat source, contributing to a more sustainable and energy-efficient future.

5.CONCLUSION

The conclusion of the project, "Chimney Waste Heat Conversion to Heater with PCM," would typically encompass a summary of the project's findings and achievements. While the actual conclusion will depend on the project's specific outcomes and results, here's a generic example In summary, the project has successfully demonstrated the feasibility of converting chimney waste heat into a sustainable and cost-effective heating solution. The integration of Phase Change Materials (PCMs) has proven to be an effective method for capturing, storing, and releasing thermal energy from waste heat sources. The system's efficient heat capture and PCM-based storage mechanisms have shown promising results in terms of energy efficiency and cost savings. The project has the Additionally, the data and insights gathered during this project provide valuable contributions to the field of waste heat recovery and sustainable heating technologies. These findings may serve as a foundation for future research and innovation in the pursuit of cleaner and more efficient heating solutions. In conclusion, the project has not only met its objectives but has also demonstrated the potential to make a positive impact on energy conservation, cost savings, and environmental sustainability in the realm of heating solutions. The successful development of this heating system opens up new possibilities for more eco-friendly and economically viable heating practices in various applications.

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