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Review of Heat Pipe Heat Exchangers in HVAC and R Systems

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Abstract

The domain of Waste Heat Recovery is particularly crucial for countries facing energy consumption deficiencies. Stringent environmental regulations act as a catalyst, propelling the evolution of innovative technologies and equipment. Striking a balance between economically viable, technically feasible, and environmentally sound waste heat recovery methods is imperative, extending beyond Air Conditioners to encompass various processes. Swift advancements are required to effectively recover waste heat from diverse processes. HVAC systems, like many engineering systems, generate waste heat that holds the potential for recovery and reuse in alternative applications. This study focuses on exploring noble recovery methods, utilizing hot air reclaimed from the condenser of an HVAC system, determined through mass and energy balance considerations. Numerous experimental and theoretical investigations have been undertaken on High-Performance Heat Exchangers (HPHE) since Akachi first proposed them in 1990. However, due to the intricate interplay of hydrodynamics and thermodynamics, the operational mechanism of HPHE remains highly complex and not entirely elucidated. With high expectations for HPHE applications in the HVAC and Refrigeration (R) sector, this paper undertakes a comprehensive review of its development. It systematically summarizes the latest findings from both experimental and theoretical studies, with a specific focus on the HVAC and R field. Additionally, the paper highlights promising and innovative applications of HPHE. The intention is to furnish a foundational reference for future research endeavors in this evolving field.

Keywords

Waste heat recovery; HVAC and R; Heat pipe heat exchangers

1. Introduction

This statement underscores the global energy crisis currently confronting humanity. Continuous depletion of finite energy resources, coupled with their improper utilization leading to wastage, highlights the urgent need for reducing such inefficiencies.

A significant portion of heat energy is dissipated to the surroundings during thermal processes, commonly referred to as waste heat, a phenomenon explained by the first law of thermodynamics. Efforts to address this wastage through heat recovery methods can transform this otherwise lost heat into a useful form of energy. This initiative holds the potential to enhance the efficiency of thermal processes and mitigate overall energy consumption. Reports, such as the one titled 'Technology Roadmap' by Energetic Inc. for the Department of Energy (DOE) and various studies conducted by the European Commission, emphasize that a substantial proportion of produced energy is lost to the environment due to diverse factors, accounting for approximately a 66% loss in electric value. The identification of waste heat, particularly in final processes like cooling by air conditioners, provides an opportunity to minimize energy losses by redirecting waste heat towards generating useful forms of energy. This proactive approach aligns with the imperative goal of optimizing energy utilization and combating the challenges posed by the global energy crisis.

2. Energy Consumption: Global Scenario

Researchers and engineers are forced to concentrate on the urgent problem of energy consumption in buildings due to the rising standards of living and the depleting fossil fuel supplies. Air conditioning, heating, and ventilation (HVAC) systems stand out among the many components that affect a building's energy usage since they are essential to occupant comfort. That being said, they also rank among the building's biggest energy consumers. A compelling opportunity to significantly reduce overall energy usage exists in the potential to improve the efficiency of conventional HVAC systems. It's interesting to know that maintaining interior thermal comfort levels in commercial buildings accounts for over 50% of energy demand [1]. Acknowledging the critical role HVAC systems play in energy usage and putting efficiency measures into place becomes critical to addressing environmental issues as well as the need for sustainable energy practices.

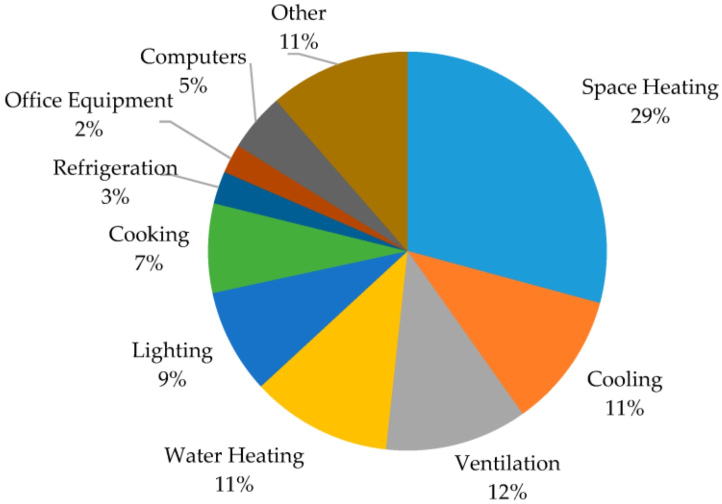

Figure 1. US Energy Consumption in Commercial building

Furthermore, because most people spend more than 90% of their time inside [2], it is imperative to develop fossil fuel-free HVAC systems that are energy-efficient in order to reduce energy consumption. A more detailed look at the amount of energy used worldwide by HVAC equipment yields some startling statistics: In the US, HVAC systems use more than 50% of the energy used in buildings [3]. Over the past 20 years, China's building energy consumption has increased steadily at a rate of roughly 10% annually, making up nearly 20.7% of the country's overall energy usage by 2004 [4]. In Europe, buildings, including residential and commercial, account for around 40% of energy use [5]. Significantly, HVAC systems in non-residential buildings in Australia account for 70% of electricity usage [6]. These figures highlight how important HVAC systems are to the world's building energy use. Achieving sustainability objectives and reducing the environmental effect of energy usage need addressing their energy efficiency.

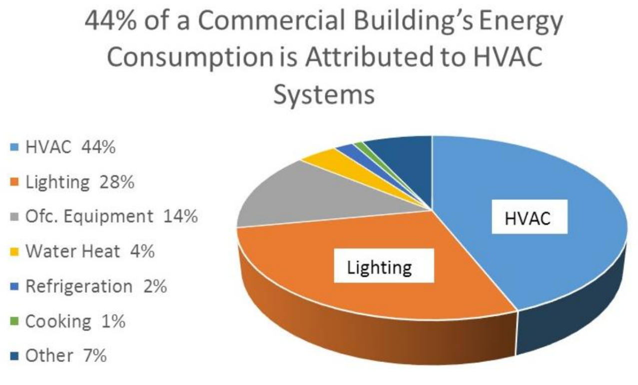

Figure 2. Overall Energy Consumption in Commercial building

About 32% of the power used in buildings in India is used for air conditioning systems [7]. In 2006, air conditioning and refrigeration systems accounted for thirty-three percent of the power used in sub-tropical Hong Kong [8]. In the Middle East, the support of cooling systems accounts for almost 70% of building energy usage [9]. According to estimates, there was a 58% rise in global energy use between 2001 and 2005 [10]. Even with this increase, fossil fuels still provide around 80% of the energy utilized [11, 12]. Energy consumption has significantly increased as a result of the growing use of HVAC systems in commercial, industrial, and residential settings, particularly during the summer. The development of energy-efficient HVAC systems is essential to both protecting customers from rising electricity bills and the environment from the damaging effects of greenhouse gas emissions linked to the usage of energy-inefficient electrical equipment. This highlights how urgently sustainable and energy-efficient HVAC technology techniques are needed to solve both financial and environmental issues.

3. Heat Pipe and HVAC & R

In the quickly changing fields of science and technology, energy-efficient HVAC systems can be achieved through a variety of techniques. However, a thorough grasp of building comfort conditions is necessary to construct effective systems. In this context, thermal comfort—which is centered on how happy people are with their thermal surroundings—is quite important. Standards like ASHRAE standard 55-2004 should be followed in the design and calculation of air conditioning systems, which are intended to regulate the temperature environment while preserving a suitable level of air quality inside a building [13].

The energy used to run heating, ventilation, and air conditioning (HVAC) systems accounts for almost 60% of the world's total building energy usage [15]. This percentage is anticipated to climb as populations expand and prosperity levels rise [16]. The search is still ongoing for low-cost technology, such as creative waste heat recovery techniques, to increase HVAC efficiency. According to research submitted to the US Department of Energy [14], existing energy recovery and management systems may be able to cut a building's energy use by as much as 50%. Utilizing temperature differences between cold and hot air streams in HVAC duct systems, advanced waste heat recovery/ventilation technologies have the potential to lower the energy required for conditioning ventilation make-up air.

Numerous waste heat recovery/ventilation technologies have been investigated, including oscillating heat pipe heat exchangers (OHP-HEs), enthalpy wheels, flat plate heat exchangers, and heat pipe heat exchangers. Every technology has a unique set of benefits and features. For instance, with different pressure drops, the effectiveness of flat plate heat exchangers and enthalpy wheels, respectively, is between 50 and 75% and 50 and 85%. Heat pipe heat exchangers, utilizing conventional heat pipes, have proven their efficacy in high heat transport capability, although they come with certain operating limitations. On the other hand, oscillating heat pipes (OHP) operate as passive, two-phase heat transfer devices with characteristics such as high thermal conductivity and the ability to operate in various orientations.

Though a lot of experimentation has been done on OHP for electronics cooling, not much research has been done on characterization of the OHP for HVAC or energy related systems. Numerous investigations have examined the usefulness of OHPs for air preheating and heat recovery in various contexts, such as exhaust gas heat recovery and air-drying cycles. The influence of the OHP's performance on the coefficient of performance (COP) of space radiator systems, split-type air conditioning systems, and other systems has been evaluated. With waste heat recovery and air-to-air heat exchange, the current work attempts to characterize the usefulness of a single closed-loop, tubular OHP for improving the efficiency of ducted AC systems. In this work, a novel large form factor OHP functioning in the forced-convection condition common to adjacent-duct HVAC systems is fabricated and evaluated. Comparing the OHP's thermal resistance, heat transfer properties, and aerodynamic performance—including pressure drop—with an evacuated or empty OHP of the same overall dimensions reveals important differences. The usage of n-pentane as an eco-friendly working fluid for low-grade heat flux situations is also explored in this study.

The study also examines how different configurations of a fined U-shaped heat pipe heat exchanger (HPHE) might lower the energy used in HVAC systems for cooling and reheating. We talk about the dehumidification capacity, the efficiency of the U-shaped HPHE, and the coefficient of performance (COP) of the HVAC system when combined with the HPHE. For various U-shaped HPHE setups, the study considers the effects of fresh air temperature and velocity throughout the evaporator portion.

As HVAC systems are recognized as sources of waste heat, the research proposes noble recovery methods utilizing hot air recovered from the condenser of an HVAC system. The study involves the development of an in-house code using mass and energy balance, which will be validated through experimental results obtained from a setup developed for this purpose. Additionally, the paper considers the possibility of proposing a commercial design as a first step toward industrializing this waste heat recovery system.

4. Conclusion

Reviews of the literature have repeatedly shown how adding a heat pipe heat exchanger (HPHE) in a building's various designs may improve efficiency and help lower the amount of energy used by HVAC systems for heating and cooling. Notwithstanding recent progress, fresh developments in the field of heat pipe applications are still required, especially when it comes to investigating a wider variety of uses.

Numerous research works have investigated the use of a vertical finned-type heat pipe heat exchanger to reduce the amount of energy used for cooling and heating HVAC systems. These studies have looked at several topics, such as the dehumidification capacity of these systems, the efficacy of the HPHE, and the coefficient of performance (COP) of the HVAC system when combined with variously shaped HPHEs. In order to identify the best design for improving system performance, specific study has examined the effects of fresh air temperature and velocity over the evaporator section, especially in one- and two-row configurations of the HPHE.

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