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Editorial

Heat Transfer and Heat Recovery Systems

Krzysztof Rajski * **and Jan Danielewicz**

Faculty of Environmental Engineering, Wroclaw University of Science and Technology, 50-377 Wroclaw, Poland
* Correspondence: krzysztof.rajski@pwr.edu.pl

1. Introduction

Heat transfer is present in all modern engineering applications and plays a fundamental role in improving the efficiency of energy conversion systems. Within these systems, the efficiency and overall performance of various energy conversion processes are predominantly determined by the mechanisms of heat transfer. Hence, a comprehensive understanding of these mechanisms is essential for the development of sustainable and efficient energy management practices.

In addition, the mitigation of energy consumption via the retrieval of waste heat is deemed as the predominant course of action towards accomplishing sustainable energy management. One promising strategy to improve energy efficiency is to capture and recycle waste heat from different sources. Waste heat recovery technologies have been increasingly adopted in several industrial processes to retrieve and repurpose heat that would otherwise be lost to the surroundings. This approach holds immense potential in reducing energy consumption and greenhouse gas emissions, thereby promoting sustainable energy management.

The goal of this Special Issue is to showcase the latest developments in the field of heat transfer technology and heat recovery systems that promote sustainable development. While considerable attention has been paid to heat recovery systems, there remains a persistent demand for innovative solutions to address the vast array of challenges in this field. Therefore, this Special Issue endeavors to emphasize and provide novel solutions for these challenges.

2. A Review of the Contributions in This Issue

A word cloud has been created to offer a more comprehensive grasp of the content featured in the Special Issue, as depicted in Figure 1. This figure presents a visual representation of the frequently used words in the titles and abstracts of the published research papers, revealing insights into the key topics explored in this collection. Upon conducting a thorough examination of the articles featured in this Special Issue, four primary categories that encapsulate the majority of the content were identified. These categories consist of heat transfer and heat exchangers, heat recovery, renewables, and domestic hot water preparation systems.

2.1. Heat Transfer and Heat Exchangers

Baig et al. investigated a slotted fin minichannel heat sink (SFMCHS) to manage high heat flux generated in microprocessors [1]. The SFMCHS was developed by modifying a conventional straight integral fin minichannel heat sink (SIFMCHS). The study numerically compared SFMCHSs with fin spacings of 0.5 mm, 1 mm, and 1.5 mm with SIFMCHSs. Two slots per fin minichannel heat sink (SPFMCHS) reduced the base temperature by 9.20%, 8.74%, and 7.39% for 0.5 mm, 1 mm, and 1.5 mm fin spacings, respectively, compared to SIFMCHSs. The 0.5 mm-spaced SPFMCHS had better heat transfer performance compared to 1 mm and 1.5 mm fin spacings, with a uniform temperature distribution at the heat sink base observed in all cases.

Citation: Rajski, K.; Danielewicz, J. Heat Transfer and Heat Recovery Systems. *Energies* **2023**, *16*, 3258. https://doi.org/10.3390/en16073258

Received: 3 April 2023
Accepted: 4 April 2023
Published: 5 April 2023

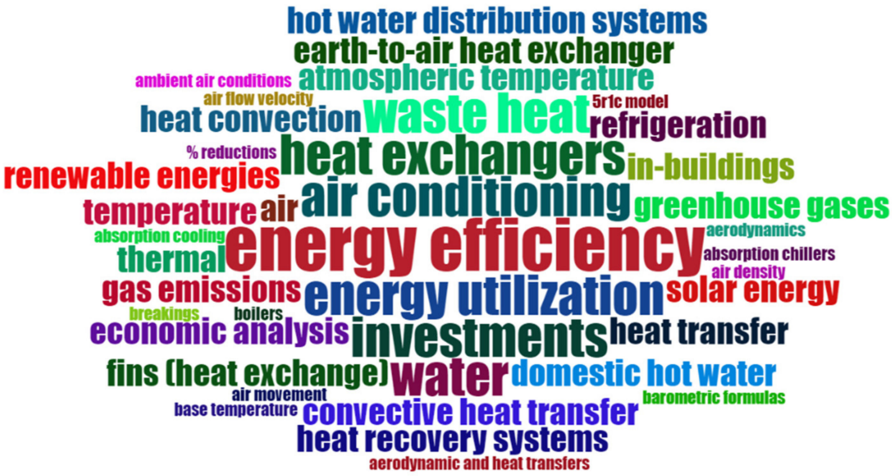

Figure 1. A word-cloud created from the articles published in the Special Issue.

Zhao et al. aimed to optimize the flow and heat transfer performance of channels with frustums of a cone by using Response Surface Methodology (RSM) and multi-objective genetic algorithm [2]. Central composite face-centered design (CCF) was used for the experimental design of channel parameters, and response surface models were constructed. The sensitivity of the channel parameters was analyzed using Sobol's method. Four optimized channels were selected from the Pareto solution set. The response surface models had high accuracy with an RSME of less than 0.25 and R^2 of greater than 0.93.

Basok et al. analyzed the heat transfer and aerodynamics in a high-temperature recuperation system's duct [3]. The research involved a flat duct with a thickness-to-height ratio of 1:10, length of 400a, and one-sided heat input, and mixed air movement. The objective was to determine the average temperatures, air temperature distribution, and heat flow densities along with the heat exchange coefficients and Nusselt numbers. The research method comprised mathematical numerical experimentation and physical modeling. The results showed a difference in the intensity of convective heat transfer between the hot and non-heated surfaces of the duct. The findings suggest that the resistance of the boundary layer in high-temperature heat exchangers and recuperation systems will not exceed 10% of the total pressure losses in the system.

Moreover, the use of plate fin-tube heat exchangers is prevalent in various industries, including air conditioning and refrigeration systems. However, during the manufacturing process, errors can lead to the formation of an air gap between the tube and fin. The effect of the air gap on heat transfer was studied by Łęcki et al. [4] using numerical simulations for a symmetric section of the heat exchanger under periodic flow conditions. The results showed that the fin discontinuity along the circumference reduces the heat transfer rate compared to the perfect fin-tube contact case. The location and size of the gap also affect heat transfer, with the rear gap position being the worst scenario. Reversing the flow direction can lead to up to a 15% increase in heat transfer, especially if the rear gaps are present.

Pavlenko and Koshlak discussed the dynamic interaction between boiling particles in an emulsion, which leads to droplet breakup [5]. They analyzed the forces that determine the breaking of non-boiling and boiling droplets and determine the displacement, deformation, and fragmentation of the dispersed phase. They also studied the dynamics of bubbles in a compressible liquid with consideration for interfacial heat and mass transfer and the effect of standard and system parameters on cavitation processes. The study proposed a new method to assess dynamic effects, which considers all determining factors and accurately represents thermophysical system parameters. The method was validated using superheated emulsion boiling with a sharp decrease in pressure. This study should be considered as the initial stage of rational designs and optimal operating modes of cavitating devices for solving various technological problems.

The process of two-phase expansion, where a fluid undergoes a pressure drop in the liquid-vapor dome, is gaining interest for various processes, especially in low-temperature two-phase heat-to-power cycles. However, modeling and understanding the phenomena in volumetric two-phase expanders are still limited. This topic was reviewed by van Heule et al. [6]. While screw expanders can be modeled using the homogeneous equilibrium model, reciprocating expanders require further investigation. The boiling delay model and homogeneous relaxation model are promising techniques, but more research is needed to apply them. More experimental data on different expander types is also required to understand the impact of design parameters. The review provided a comprehensive overview of available data and modeling techniques, but more research is necessary to achieve efficient volumetric expansion machines.

2.2. Heat Recovery

Liu et al. analyzed the potential of a combined heat and power (CHP) system for heating a building with an indoor swimming pool in Korea, which traditionally uses boilers and heat storage tanks that emit greenhouse gases [7]. The CHP system uses electricity and waste heat from a Phosphoric Acid Fuel Cell (PAFC) system and was analyzed for energy savings, CO_2 reduction, efficiency, and economic feasibility. A dynamic simulation model was developed, and results showed that the CHP system can save up to 15% of energy compared to the conventional heating system, and the FTO model presents the highest efficiency and CO_2 reduction. The FTO model also presents a better economic feasibility than the ELT model.

Manouchehri and Collins validated a model that can predict the performance of drain water heat recovery (DWHR) systems, which are used in residential buildings to recover energy from greywater [8]. The model was implemented into software to perform energy simulations and analyze the impact of different plumbing configurations on energy savings. The study found that the plumbing configuration significantly affects the energy savings expected from DWHR heat exchangers, with the greatest savings achieved in equal-flow configurations. However, the mains temperature could dictate which configuration provides higher energy savings, and designers should consider this when implementing a DWHR heat exchanger. Manufacturers are encouraged to adjust the coil diameter to improve heat transfer rates and increase energy savings when equal flow rates through the heat exchanger are not possible.

The low-grade waste heat generated by data centers is difficult to recover due to its decentralized and low-quality nature, making it a challenge to maximize energy efficiency and utilize heat recovery. However, absorption chiller systems are a promising solution for this issue. In the study by Amiri et al. [9], the feasibility of using an absorption chiller system for waste heat recovery from data centers was analyzed. The proposed system could save 4.3 GWh/year and 13.0 GWh/year of electricity, resulting in a reduction of 3068 and 9208 tons of CO_2 equivalent greenhouse gas emissions annually. The payback period for investors was estimated to be 2.76 and 2.56 years for a 4.5 MW and 13.5 MW data center, respectively. The study highlights the need to consider technical and economic aspects simultaneously. Future research could focus on employing higher-performance absorbers and generators to enhance the capacity of the absorption chiller system.

2.3. Renewables

The depletion of fossil reserves has led to a shift towards renewable energy sources, particularly solar power plants. However, the construction of these plants requires a feasibility study to estimate the solar potential in a particular region. Ayaz et al. [10] compared ground-based measurements of global horizontal irradiance (GHI) and direct normal irradiance (DNI) in Peshawar, Pakistan, with satellite-based model SUNY. The data revealed a significant difference between the two, with maximum differences of 42.90% for GHI and 55.86% for DNI. The study recommends establishing more ground measurement stations across the country to assess solar resources more accurately. It also recommends future studies in different locations with longer time series data. The difference between satellite and ground-based measurements is considerable, and relying solely on satellite-modeled data is not recommended for establishing solar energy programs in Pakistan. Real-time ground measurements are necessary for accurate estimates of solar energy resources.

The feasibility of a desiccant dehumidification-based Maisotsenko cycle evaporative cooling (M-DAC) system for greenhouse air-conditioning in Multan, Pakistan was investigated by Ashraf et al. [11]. Traditional cooling methods were deemed unsuitable for greenhouse production due to their high energy costs and inability to provide an optimum microclimate. The M-DAC system was proposed as an alternative solution. The study aimed to evaluate the system's thermodynamic performance in relation to temperature gradient, relative humidity, vapor pressure deficit (VPD), and dehumidification gradient. Results showed that the M-DAC system achieved a maximum air temperature gradient of 21.9 °C at 39.2 °C ambient air conditions, which was considered optimal for most greenhouse crops. The system also created a dehumidification gradient of 16.8 g/kg at 24 g/kg ambient air conditions, which was within the optimum humidity range for greenhouse growing conditions.

Air conditioning is responsible for consuming around one-fifth of the total power used in buildings worldwide. To reduce energy consumption and its impact on the environment, Earth-to-Air Heat eXchangers (EAHX) are being utilized. Greco et al. reviewed the different applications and peculiarities of EAHX and focused on the hybrid applications where EAHXs are coupled with advanced systems [12]. An IoT-based EAHX control system was proposed to optimize energy efficiency and thermal comfort under different operating conditions. EAHXs utilize geothermal energy, which is renewable and sustainable, and do not emit greenhouse gases. Different parameters such as pipe diameter, length of pipe, and number of pipes affect the performance of EAHX. EAHXs are effective in heating the air during winter and cooling it during summer. Hybrid EAHX systems based on Phase-Change Materials and an Air-Source Heat Pump, finned vertical solar chimney, and placed upstream of air conditioning systems' AHU can achieve improvements in terms of energy performance and reduce greenhouse gas emissions.

Michalak analyzed the impact of air density variation on the operation of earth-to-air heat exchangers (EAHE) coupled with the ventilation system of a residential building [13]. The analysis took into account air density variation with ambient air temperature as Polish hourly typical meteorological years do not contain atmospheric pressure. The energy use for space heating and cooling was computed using the 5R1C thermal network model of EN ISO 13790. Depending on the chosen method, a reduction in annual heating and cooling needs of 7.5% to 8.8% in heating and from 15.3% to 19% in cooling was obtained. The study shows the need to include atmospheric pressure in typical Polish meteorological years and indicates the need for future consideration about an assessment of air humidity impact on the simulated EAHE performance.

2.4. Domestic Hot Water Preparation Systems

A comparison of various methods for calculating the peak power required for domestic hot water (DHW) preparation in buildings was presented by Amanowicz [14]. The study highlighted that DHW has become an important component of energy consumption in buildings, and its peak power can be as high as that required for heating and ventilation. This makes it necessary to select the correct peak power of the heat source, particularly when using renewable energy sources, as it affects the size, investment cost, and economic efficiency of the system. The study showed that accumulative systems with hot water storage tanks are more suitable for modern buildings as they are less sensitive to design errors and result in acceptable peak power for DHW.

Żukowski and Jezierski used a mathematical approach to investigate the impact of various factors on the thermal performance of solar domestic hot water (SDHW) systems in different European climates [15]. They created three deterministic mathematical models using data from computer simulations of SDHW systems in Madrid, Budapest, and Helsinki. The models consider the influence of five factors: volume of heat storage tanks, solar collector total area, maximum efficiency, heat loss coefficient of solar collector, and daily consumption of DHW on the annual useful energy output. The results of the optimization procedure indicate that the maximum annual useful energy output is 1303 kWh/m^2 for Madrid, 918.5 kWh/m^2 for Budapest, and 768 kWh/m^2 for Helsinki.

Żelazna and Gołębiowska proposed a multi-criteria analysis for selecting system parameters such as collector type and solar tank volume [16]. A model of the SHW system was used to calculate possible solutions, ensuring the same comfort of usage for several design options. Three indicators, Simple Payback Time (SPBT), Primary Energy consumption (PE), and IMPACT 2002+, were calculated for the analyzed model. The most favorable solution included a heat-pipe-evacuated tube collector, copper pipes, and a 200 dm^3 water tank. The multi-criteria analysis can be used as a tool for the optimization of selection in the green designing process, significantly improving the environmental balance of analyzed technologies.

3. Conclusions

The heat transfer and heat exchangers category of the Special Issue discusses the development of new heat sink designs and the optimization of existing heat exchangers to improve the efficiency of heat transfer mechanisms in various industrial processes. The heat recovery category highlights the importance of capturing and recycling waste heat from different sources to reduce energy consumption and greenhouse gas emissions. The studies examine combined heat and power systems, acid fuel cells, and drain water heat recovery systems in residential and commercial buildings. The renewables category explores the use of renewable energy sources such as solar thermal energy, biomass, and geothermal energy to provide sustainable energy solutions. The domestic hot water preparation systems category focuses on developing efficient water heating systems for residential buildings. The studies emphasize the importance of reducing energy consumption in water heating processes and developing sustainable solutions.

The articles in this Special Issue provide innovative solutions to address the challenges in heat transfer technology and heat recovery systems, promoting sustainable development and energy efficiency. These solutions can be applied in various settings to improve energy management practices and reduce greenhouse gas emissions.

Author Contributions: Conceptualization, K.R.; writing—original draft preparation, K.R.; writing—review and editing, K.R. and J.D. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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