ASSESSMENT OF THE STATE OF THE ART AND PERFORMANCE OF HYBRID WATER–AIR SOLAR COLLECTORS

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Abstract. This study is devoted to the assessment of the state-of-the-art development and performance characteristics of hybrid water–air solar collectors, analyzing their structural configurations, heat transfer mechanisms, and operational efficiency aspects. Recent studies indicate that the implementation of dual-flow channels and optimized absorber designs significantly enhances thermal efficiency and temperature stability compared to conventional single-medium collectors. The analysis considers key performance indicators such as thermal efficiency, heat gain, and system adaptability under varying climatic conditions. Despite technological advancements, further optimization of absorber materials, flow configurations, and thermal storage integration remains necessary. The results confirm that hybrid water–air solar collectors provide effective solar energy utilization in residential and small-scale applications and play an important role in the development of sustainable and energy-efficient thermal systems.

Keywords: hybrid renewable energy systems, residential buildings, energy efficiency, near-zero energy building, carbon emission reduction, sustainable heating, energy storage.

The residential building sector remains one of the most energy-intensive components of the built environment, accounting for a substantial proportion of global energy demand and associated carbon emissions. The persistent dependence of conventional heating systems on fossil-based energy sources underscores the critical necessity for transitioning towards low-carbon and sustainable heating solutions. Within this framework, the systematic assessment and optimization of hybrid renewable energy systems for residential building heating emerge as a highly relevant research domain, as such systems offer enhanced operational stability, improved energy efficiency, and significant potential for mitigating environmental impacts while supporting the development of near-zero energy buildings.

Energy constitutes the economic backbone of a country, and industrialization-based economies are among the primary drivers of increasing energy consumption [1]. The industrial sector accounts for approximately 38% of global energy demand and represents the most energy-intensive sector worldwide [2]. In manufacturing industries, fuel and natural gas are commonly used as primary energy sources. However, the combustion of fossil fuels generates greenhouse gas emissions that contribute significantly to rapid climate change and environmental degradation [3]. Addressing this challenge in the industrial sector, particularly the reduction of air pollution levels, requires the effective utilization of alternative energy sources [4].

In this context, the implementation of renewable energy-based systems and the improvement of energy efficiency are essential for mitigating environmental impacts. Among renewable energy sources, solar energy represents the largest available resource with nearly zero environmental impact in terms of atmospheric emissions [5]. Solar radiation can be utilized through two principal methods: direct conversion into electrical energy using photovoltaic cells, and direct conversion into thermal energy through the application of solar collectors [6].

The utilization of solar thermal energy in industry became a major focus during the 1970s under the initiatives of the International Energy Agency and the Solar Heating and Cooling Programme [7]. By the end of 2019, the installed solar thermal capacity reached approximately 700 MW, with the total installed collector area worldwide exceeding one million square meters [8]. The principal industrial sectors utilizing solar energy in production processes include the food, textile, paper, metallurgy, polymer, and chemical industries [9].

Depending on the type of industrial process, solar collectors are generally classified into three temperature categories: low-temperature (<150°C), medium-temperature (150–400°C), and high-temperature (>400°C) systems [10]. However, most commercial and industrial applications typically require operating temperatures below 250°C [11].

The most widely used type of solar collector is the flat-plate solar collector (FPSC), which belongs to the category of non-concentrating collectors. FPSCs are extensively applied due to their simple design, low cost, ease of maintenance, and capability to achieve relatively high operating temperatures. Typically, flat-plate collectors operate within a temperature range of up to 75°C; however, higher temperatures can be attained using high-efficiency collector designs. In such cases, since the boiling point of water is 100°C, water must be replaced with an alternative heat transfer fluid to enable operation at elevated temperatures [12].

Flat-plate solar collectors operate effectively under both direct and diffuse solar radiation conditions and require minimal maintenance [13]. They are typically installed on the rooftops of buildings or other structures. Flat-plate collectors are characterized by long service life and reliable performance. Compared to other types of collectors, they offer significant advantages, particularly because they can be effectively applied even in regions with high precipitation levels. Due to their widespread application and stable performance, flat-plate collectors are often considered a benchmark technology against which other solar collector types are evaluated [14].

Due to relatively high heat losses, flat-plate solar collectors are generally not suitable for operation at elevated temperatures, particularly above 80°C. When higher operating temperatures are required, it becomes necessary to minimize thermal losses from the collector as much as possible.

Solar thermal collectors are devices that convert solar radiation into thermal energy, and they are classified according to their design and operational characteristics [15]. The main factors to be considered when installing solar thermal systems in industrial applications include required operating temperature, energy demand, and economic criteria [16]. The most common types of solar collectors include solar air collectors (SAC), solar water collectors, evacuated tube collectors, evacuated flat-plate collectors, and parabolic trough collectors.

A solar air collector consists of an airtight, insulated enclosure containing an absorber plate made of a thermally conductive material, covered by a transparent glazing layer. Air is used as the heat transfer medium and is subsequently applied for space heating or drying processes. In conventional solar air collectors, the relatively low heat capacity of air and the limited heat transfer between the absorber plate and the airflow restrict the achievable outlet temperature. In recent years, various modifications have been introduced to the absorber plate design to enhance efficiency and increase outlet temperature. Numerous studies aimed at intensifying heat transfer processes in solar air collectors have contributed to the growing global utilization of this technology [17].

Conclusion. The intensification of thermo-hydrodynamic processes in hybrid water–air solar collectors significantly enhances solar energy utilization efficiency. By improving heat transfer performance, optimizing flow structure, and reducing thermal losses, higher outlet temperatures and overall thermal efficiency can be achieved. This expands the applicability of such collectors in low- and medium-temperature processes.

In particular, the integration of these hybrid collectors into desalination systems contributes to the enhancement of evaporation processes, reduction of energy consumption, and improvement of freshwater production capacity. Consequently, thermo-hydrodynamically optimized hybrid water–air solar collectors play a crucial scientific and practical role in the development of sustainable, energy-efficient, and environmentally responsible water supply systems.

References

1. Koçak B., Fernandez A. I. Paksoy H. "Review on sensible thermal energy storage for industrial solar applications and sustainability aspects," *Solar Energy*, 2020, vol. 209. pp. 135-169.

2. IEA. (2020) World energy balances: Overview. Available: https://bit.ly/3jEw90a.

3. Farjana S.H., Huda N., Mahmud M.P., Saidur R. "Solar industrial process heating systems in operation - current ship plants and future prospects in Australia," *Renewable and Sustainable Energy Reviews*, 2018, vol. 91. - pp. 409-419.

4. Pranesh V., Velraj R., Christopher S., Kumaresan V. "A 50 year review of basic and applied research in compound parabolic concentrating STHC for domestic and industrial applications," *Solar Energy*, vol. 2019, 187. pp. 293-340.

5. Farjana S.H., Huda N., Mahmud M.P., Saidur R. "Solar process heat in industrial systems - a global review," *Renewable and Sustainable Energy Reviews*, 2018, vol. 82. - pp. 2270-2286.

6. Verma S.K., Gupta N.K., Rakshit D. "A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion," *Solar Energy*, vol. 2020, 208. - pp. 1114-1150.

7. Schoeneberger C.A., McMillan C.A., Kurup P., Akar S., Margolis R., Masanet E. "Solar for industrial process heat: A review of technologies, analysis approaches, and potential applications in the united states," *Energy*, 2020, vol. 206.

8. Weiss W., Spörk-Dür M. *Solar Heat Worldwide*. IEA Solar Heating & Cooling Programme, Austria, 2020.

9. Ravi Kumar K., Krishna Chaitanya N.V., Sendhil Kumar N., "Solar thermal energy technologies and its applications for process heating and power generation – a review," *Journal of Cleaner Production*, 2021, vol. 282.

10. IEA. Renewable energy for industry. 2017. Available: https://bit.ly/3BGLYty.

11. Bolognese M., Viesi D., Bartali R., Crema L., "Modeling study for low-carbon industrial processes integrating solar thermal technologies. a case study in the italian alps: The felicetti pasta factory," *Solar Energy*, 2020, vol. 208. - pp. 548-558.

12. Jesko Z. Classification of solar collectors // Engineering for Rural development, May 29-30, 2008, Jelgava, Latvia. – Latvia University of Agriculture, 2008. – p. 22-27.

13. Duffie J.A., Beckman W.A. Solar engineering of thermal processes. – New jersey: John Wiley&Sons, Inc, 2006. – p. 908.

14. Ramlow B., Nusz B. Types of solar collectors [online] [viewed 2007.11.25]. Available: http://oikos.com/library/solarwaterheating/collector_ types.html.

15. Evangelisti L., De Lieto Vollaro R., Asdrubali F. Latest advances on solar thermal collectors: A comprehensive review," *Renewable and Sustainable Energy Reviews*, 2019, vol. 114.

16. Ghazouani M., Bouya M., Benaissa M. Thermo-economic and exergy analysis and optimization of small ptc collectors for solar heat integration in industrial processes," *Renewable Energy*, 2020, vol. 152, pp. 984-998.

17. Ajay P., Mahesh K., Himanshu M., Rahul G. A review on solar flat plate air collector with different design modifications. International Multidisciplinary Conference-2021. ISBN: 978-93-91535-12-4. – p. 65-78.