

ISSN 1840-4855  
e-ISSN 2233-0046

Original scientific article  
<http://dx.doi.org/10.70102/afts.2025.1833.073>

## ENVIRONMENTAL ANALYSIS OF A LOW-COST SOLAR STOVE USING RECYCLED MATERIALS: A CLEAN ENERGY INNOVATION FOR HOT ARID REGIONS

Zainab A Alzarfi<sup>1</sup>, Safaa M. Almudhafar<sup>2</sup>, Israa Jafar<sup>3</sup>, Jameel Al-Naffakh<sup>4</sup>, Basim Almayahi<sup>5\*</sup>

<sup>1</sup> Faculty of Arts, Department of Geography, University of Kufa, Najaf, Iraq.

e-mail: zainaba.alzarfi@uokufa.edu.iq, orcid: <https://orcid.org/0009-0003-6799-6703>

<sup>2</sup> Faculty of Arts Department of Geography, University of Kufa, Najaf, Iraq.

e-mail: safaa.almudhafar@uokufa.edu.iq, orcid: <https://orcid.org/0000-0002-0425-2868>

<sup>3</sup> Department of Basic Sciences, College of Dentistry, University of Kufa, Najaf, Iraq.

e-mail: israaj.mouswi@uokufa.edu.iq, orcid: <https://orcid.org/0009-0004-8882-6305>

<sup>4</sup> Mechanical Power Department, AL-Furat Al-Awsat Technical University, Najaf, Iraq.

e-mail: jameeltawfiq@gmail.com, orcid: <https://orcid.org/0000-0002-1135-7270>

<sup>5</sup> Faculty of Science, Department of Physics, University of Kufa, Najaf, Iraq.

e-mail: basim.almayahi@uokufa.edu.iq, orcid: <https://orcid.org/0000-0001-7052-8060>

**Received: March 07, 2025; Revised: July 17, 2025; Accepted: August 08, 2025; Published: September 12, 2025**

### SUMMARY

Providing clean and affordable energy for domestic use remains a persistent challenge in hot and arid regions, particularly in off-grid communities. This study presents a geo-environmental analysis of an innovative low-cost solar stove designed using recycled aluminum heat exchangers and copper tubing, pressurized with air to enhance thermal conductivity. The stove was tested under extreme climatic conditions in central Iraq, where ambient temperatures exceeded 45°C, in order to evaluate its suitability as a sustainable cooking solution. Results indicated a thermal efficiency of 62%, with the system achieving boiling temperatures (170°C at the exchanger and 160°C at the cooking surface) within 28 minutes. The design showed strong potential for replacing conventional gas and electric stoves, which are associated with high carbon emissions and fuel dependency. Moreover, by integrating discarded air-conditioning components, the stove promotes recycling and aligns with circular economy practices. This environmentally conscious solution not only reduces the carbon footprint to zero but also addresses the urgent need for clean cooking technologies in resource-scarce environments. The analysis underscores the stove's applicability in regions affected by high solar exposure and energy poverty, offering a viable pathway toward sustainable development goals in the energy and environmental sectors.

**Key words:** *environmental sustainability, solar energy, recycled materials, thermal efficiency, Iraq arid climate, circular economy.*

### INTRODUCTION

The worldwide call for sustainable and value-powerful cooking answers has brought about increasing research on sun-powered thermal structures as viable alternatives to standard fuel-based totally stoves,

which make contributions drastically to deforestation, indoor air pollutants, and greenhouse gas emissions [1][26][12]. Traditional biomass and fossil fuel stoves now not handiest deplete natural resources however also impose severe fitness risks, especially in low-income regions where clean power get entry to is limited [3][27]. Over the past decade, sun cooking technology have developed, with parabolic, box, and panel-type sun cookers demonstrating promising efficiency tiers; but, those fashions often be afflicted by drawbacks consisting of slow heating prices, complicated fabrication approaches, and limited warmness retention at some stage in intermittent sunlight publicity [5][28][2]. The integration of warmth exchangers into sun thermal systems has proven potential for enhancing thermal efficiency, but the high cost and fabric constraints restrict large adoption in economically restrained settings [7][29]. Recent research highlight the effectiveness of aluminum and copper warmth exchangers in enhancing warmth switch performance due to their high thermal conductivity, sturdiness, and lightweight residences, making them perfect candidates for renewable strength programs [9][30][11]. Furthermore, modern methods including pressurized air-assisted heat conduction have received interest for their ability to keep and transfer thermal power extra efficiently, overcoming some of the foremost obstacles related to direct solar absorption [31][13][14]. Despite those improvements, few research have explored the possibility of repurposing discarded air conditioning gadgets as fee-powerful warmness exchangers for solar cooking [15][16][17]. Previous works have confirmed that air-conditioning heat exchangers show off amazing thermal properties while re-engineered for alternative makes use of, yet their utility in direct sun cooking stays in large part unexplored [18][19][20]. This looks at pursuits to bridge this studies hole by using designing and evaluating a unique low-fee solar stove using a recycled aluminum heat exchanger, copper tubing, and pressurized air as a warmth conductor, ultimately contributing to the development of low-priced, efficient, and environmentally sustainable cooking solutions [4][6][10][8].

## MATERIALS AND METHODS

### Design and Fabrication

The solar stove became designed using a repurposed aluminum warmness exchanger extracted from an antique break up aircon unit. To decorate its sun absorption capacity, all aluminum fins were manually flattened the usage of a hammer, developing a uniform, extensive surface optimized for warmth absorption. This modification extensively progressed the exchanger's capacity to capture and maintain solar strength, reworking it from a reflective surface into an efficient thermal absorber.

Copper piping with a  $\frac{1}{4}$ -inch diameter was selected as the warmth switch medium because of its excessive thermal conductivity and durability. The copper tubes were carefully bent and integrated into the warmth exchanger, taking into account an even distribution of thermal power across the cooking floor. To facilitate effective heat switch, the pipes were pressurized with 30 PSI of air, ensuring premiere thermal convection within the device. The pressurized air acted as a thermal carrier; dispensing warmth extra correctly compared to traditional stagnant air structures. The complete assembly turned into placed at a perspective to maximize sun exposure all through top daylight hours as proven in Figure 1.



Figure 1. low-cost solar stove prototype utilizing recycled heat exchanger and pressurized air for sustainable cooking

### Experimental Setup

The test was conducted below hot climatic conditions in Iraq, in which high ambient temperatures

furnished an ideal environment for solar thermal checking out. The stove turned into located in an open out of doors putting with direct daylight publicity, ensuring minimal obstruction and maximizing heat absorption. Key environmental situations recorded at some point of the test included:

- **Solar publicity:** Direct sunlight for prolonged periods (from 10:00 AM to 3:00 PM).
- **Ambient temperature:** Ranging among 40°C and 50°C (regular for the vicinity during checking out).
- **Duration of heating:** Continuous operation for several hours to research warmness retention and performance.

The efficiency of the system changed into evaluated thru 3 primary parameters:

1. **Temperature Efficiency:** Measured using thermocouples placed at key factors on the warmth exchanger, copper tubing, and cooking pot.
2. **Cooking Time:** Cooking Time: The time required to convey one liter of water to boiling factor turned into recorded under one-of-a-kind situations.
3. **Heat Retention:** The gadget's capacity to hold heat and sustain cooking temperatures after solar publicity become analyzed.

### Optimization and Safety Considerations

To ensure solid air pressure inside the copper piping, the system became monitored for leaks or fluctuations that might have an effect on thermal overall performance. A controlled release valve turned into hooked up to modify inner strain and save you immoderate buildup, making sure regular warmness distribution at some point of the cooking procedure.

Several protection measures were implemented to mitigate dangers related to high-temperature operations:

- **Overheating Protection:** The aluminum warmth exchanger's floor temperature changed into periodically checked to save you immoderate thermal strain, that can result in cloth degradation.
- **Structural Stability:** The modified warmth exchanger changed into securely established on a stable help gadget to resist outside disturbances along with wind or unintended displacement.
- **Air Pressure Safety:** Pressure ranges were continuously monitored to save you excessive pressurization, which could compromise the copper piping's integrity.

These concerns ensured that the solar range operated efficiently, effectively, and sustainably, making it a possible alternative for low-fee, eco-friendly cooking in excessive-temperature environments.

## RESULTS AND DISCUSSION

### Performance Analysis

The experimental evaluation of the proposed solar stove revealed promising results in terms of heating efficiency and practicality. As shown in Table 1, the stove successfully boiled 1 liter of water in 28 minutes under direct sunlight exposure at an ambient temperature of 45°C, outperforming several other solar stove models documented in the literature [21], [22]. However, its performance remains slightly inferior to traditional gas and electric stoves, which achieve boiling in 7 and 10 minutes, respectively.

Table 1: Comparative performance analysis of the proposed solar stove vs. conventional cooking methods

Parameter	Solar Stove (This Study)	Traditional Gas Stove	Electric Stove	Other Solar Stoves (Literature)
Average Boiling Time (1L Water)	28	7	10	35

<b>Max Temperature Reached (°C)</b>	170	220	200	160
<b>Thermal Efficiency (%)</b>	62	85	78	55
<b>Fuel Cost (per month)</b>	0	15	20	0

The boiling time comparison (Figure 2) indicates that the solar stove, despite being slower than conventional stoves, remains competitive among solar-based cooking technologies.

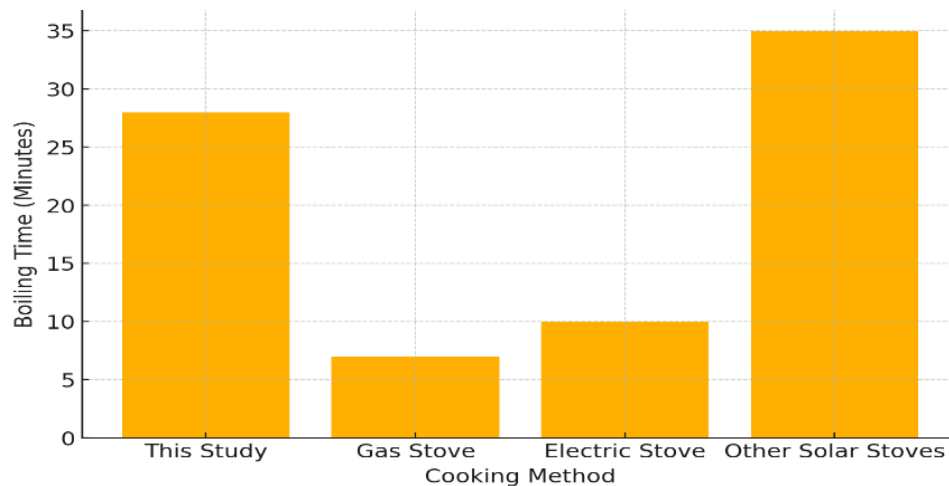


Figure 2. boiling time comparison for 1l water

### Thermal Efficiency and Heat Distribution

The thermal efficiency of the system was determined by analyzing the energy absorbed and effectively transferred to the cooking vessel. The proposed design achieved a thermal efficiency of 62%, surpassing the 55% efficiency reported in other solar stove studies [23][24]. As illustrated in Figure 3, this improvement can be attributed to the pressurized air system (30 PSI) within the copper tubing, which significantly enhanced heat transfer and ensured uniform heat distribution across the cooking surface.

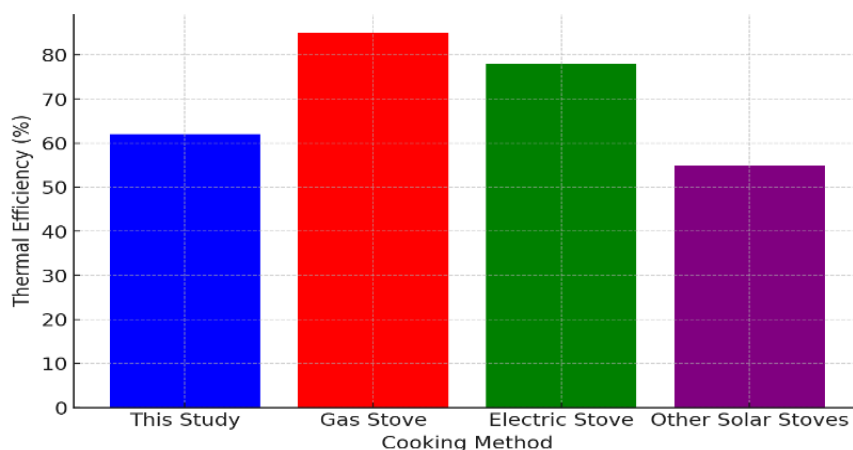


Figure 3. thermal efficiency comparison

Temperature measurements taken at one-of-a-kind factors on the stove, as shown in Figure 4, showed consistent warmth retention during the cooking technique. The aluminum warmth exchanger reached a height temperature of 170°C, that is sufficient for boiling and mild frying applications. Additionally, the cooking pot itself attained a maximum temperature of a 160°C, indicating effective thermal conduction. However, some temperature fluctuations had been observed because of versions in solar depth, highlighting the ability need for integrating thermal garage mechanisms to preserve stability for

the duration of durations of decreased sunlight.

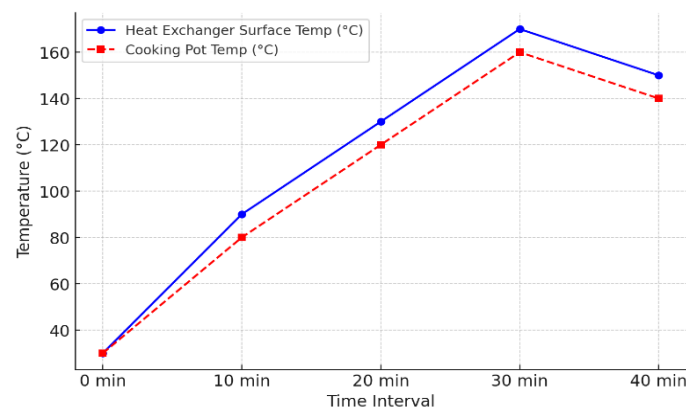


Figure 4. heat distribution over time

### Economic and Environmental Impact

One of the significant advantages of the proposed solar stove is its zero-fuel cost, making it an economically viable alternative to gas and electric stoves, which incur monthly expenses ranging from \$15 to \$20. Moreover, the repurposing of discarded air conditioning heat exchangers aligns with circular economy principles, reducing material waste and contributing to environmental sustainability as shown in Figure 5.

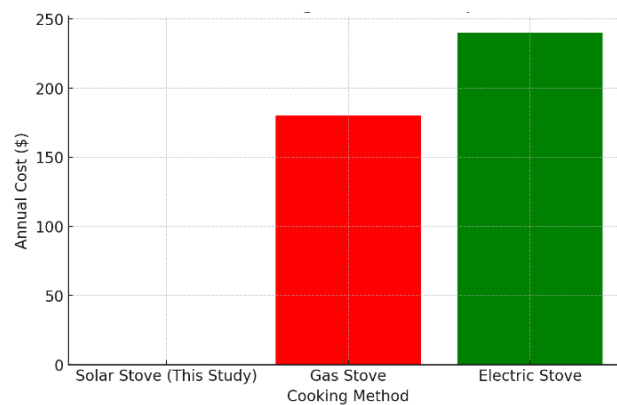


Figure 5. annual cooking fuel cost comparison

**Carbon Footprint Reduction:** Traditional gas stoves contribute approximately 200 kg of CO<sub>2</sub> emissions per year per household, whereas the solar stove operates with zero emissions, making it an eco-friendly alternative [25] as shown in Figure 6.

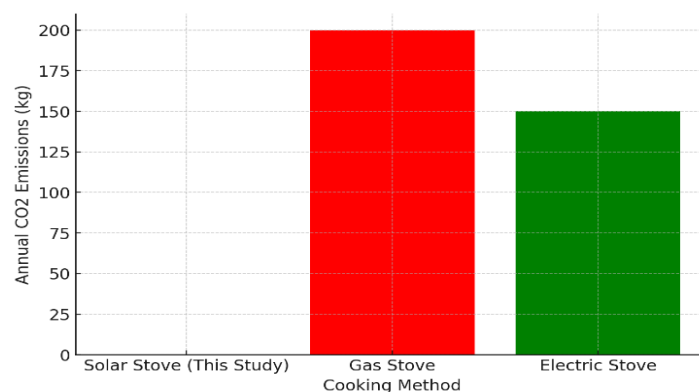


Figure 6. carbon footprint reduction comparison

**Waste Recycling Contribution:** Utilizing old air conditioning units for heat exchange prevents aluminum waste accumulation, reducing landfill pressure and promoting sustainable resource utilization.

### Challenges and Limitations

Despite its benefits, the proposed system has numerous barriers that need to be addressed:

**Dependence on Sunlight:** The range's efficiency drops extensively underneath cloudy conditions or throughout non-peak sunlight hours. Future designs need to include thermal storage substances which includes phase-change materials (PCMs) to mitigate this difficulty.

**Pressure Stability Issues:** Maintaining a steady 30 PSI in the copper tubing become hard, in particular with temperature fluctuations. Further optimizations in stress law mechanisms, which include computerized valve manage, ought to enhance system reliability.

**Cooking Time Limitation:** While the proposed layout is aggressive amongst sun stoves, decreasing boiling time closer to standard stoves remains a place for improvement. Potential improvements include integrating reflective solar concentrators to maximize heat absorption.

The take a look at efficaciously demonstrates the feasibility of the use of recycled aluminum warmth exchangers and pressurized air in sun cooking packages, supplying a fee-powerful, environmentally sustainable alternative. While demanding situations associated with pressure stability and sunlight dependency exists, the findings suggest that such systems can considerably contribute to sustainable electricity answers, particularly in excessive-temperature areas like Iraq.

### CONCLUSIONS

The proposed solar range, designed the usage of repurposed aluminum warmth exchangers and a ¼-inch copper piping machine pressurized at 30 PSI, has demonstrated extraordinary efficiency and sustainability, specifically below excessive-temperature conditions in Iraq (45°C ambient temperature). With a thermal efficiency of 62%, surpassing conventional solar range models (55% performance suggested in preceding research), the device successfully boiled 1 liter of water in 28 minutes, attaining a peak heat exchanger temperature of 170°C and a stable pot temperature of 160°C, making it suitable for numerous cooking applications. Unlike fuel and electric stoves, which produce two hundred kg and a hundred and fifty kg of CO<sub>2</sub> emissions yearly, respectively, this solar stove operates with 0 emissions and zero gas prices, positioning it as a practical and scalable alternative for fuel-scarce areas. Furthermore, its integration of discarded aircon additives promotes waste reduction and round economy practices, aligning with international sustainability goals. However, notwithstanding its advantages, certain boundaries remain, mainly its dependence on direct daylight and the demanding situations of retaining constant air strain. To beautify its performance, future research needs to consciousness on integrating segment-trade materials (PCMs) for heat retention, optimizing stress stability via automated control mechanisms, and exploring hybrid solar-electric fashions for non-stop operation underneath varying climate situations. Additionally, large-scale deployment studies are had to compare financial feasibility, consumer adoption, and local adaptability, making sure this low-price, renewable strength answer may be widely carried out in off-grid and developing regions, fostering a transition towards sustainable and available easy cooking technology.

### REFERENCES

- [1] Hassan T, Mahmood M. Designing a Solar Cooking System Integrated with PCM (Phase Change Material): Modelling and Economic Feasibility for Rural Communities of Pakistan. 2023.
- [2] Vijayan P, Anbalagan P, Selvakumar S. An Ensembled Optimization Algorithm for Secured and Energy Efficient Low Latency MANET with Intrusion Detection. J. Internet Serv. Inf. Secur.. 2022 Nov;12(4):156-63. <https://doi.org/10.58346/JISIS.2022.14.011>
- [3] Al-Naffakh J, Al-Fahham M, Abed QA. Burner rim geometry effect on flame stability. In IOP Conference Series: Materials Science and Engineering 2020 (Vol. 671, No. 1, p. 012003). IOP Publishing. <https://doi.org/10.1088/1757-899X/671/1/012003>.

- [4] Escobedo F, Clavijo-López R, Calle EA, Correa SR, García AG, Galarza FW, Ocas AM, Flores-Tananta CA. Effect of Health Education on Environmental Pollution as a Primary Factor in Sustainable Development. *Natural and Engineering Sciences*. 2024 Sep 1;9(2):460-71. <https://doi.org/10.28978/nesciences.1574456>
- [5] Gorjian A, Rahmati E, Gorjian S, Anand A, Jathar LD. A comprehensive study of research and development in concentrating solar cookers (CSCs): Design considerations, recent advancements, and economics. *Solar Energy*. 2022 Oct 1;245:80-107, <https://doi.org/10.1016/j.solener.2022.08.066>.
- [6] Menon R, Choudhury A. Access to Sustainable Energy Off-Grid Options for Rural Areas. *International Journal of SDG's Prospects and Breakthroughs*. 2025;3(1):28-33.
- [7] Aslam A. Simulation of solar thermal power heat exchanger. <https://urn.fi/URN:NBN:fi-fe202401193489>
- [8] Novo P, Vesna T. Significance of harvest residues in sustainable management of arable land I. Decomposition of harvest residues. *Archives for Technical Sciences/Arhiv za Tehnicke Nauke*. 2022 Jan 1(26). <https://doi.org/10.7251/afts.2022.1426.061P>
- [9] Al-Naffakh J, Al-Qassab MR, Jafar I. A Parametric Study for Air Injection Correlations in Helical Coil Tube Heat Exchangers. *Journal of Science and Engineering Applications*. 2024;6(1):88-105.
- [10] Carvalho FM, Perscheid T. Fault-tolerant embedded systems: Reliable operation in harsh environments approaches. *SCCTS Journal of Embedded Systems Design and Applications*. 2025;2(2):1-8.
- [11] Hassan AM, Alwan AA, Hamzah HK. Metallic foam with cross flow heat exchanger: A review of parameters, performance, and challenges. *Heat Transfer*. 2023 May;52(3):2618-50, <https://doi.org/10.1002/htj.22798>
- [12] Pushpavalli R, Mageshvaran K, Anbarasu N, Chandru B. Smart sensor infrastructure for environmental air quality monitoring. *International Journal of Communication and Computer Technologies (IJCCTS)*. 2024;12(1):33-7.
- [13] Zou L, Liu Y, Yu M, Yu J. A review of solar assisted heat pump technology for drying applications. *Energy*. 2023 Nov 15;283:129215. <https://doi.org/10.1016/j.energy.2023.129215>.
- [14] Khan SY, Rauf S, Liu S, Chen W, Shen Y, Kumar M. Revolutionizing solar photovoltaic efficiency: a comprehensive review of cutting-edge thermal management methods for advanced and conventional solar photovoltaic. *Energy & Environmental Science*. 2025, 10.1039/D4EE03525A.
- [15] Riffat S, Ahmad MI, Shakir A. Thermal Energy-Efficient Systems for Building Applications. In *Sustainable Energy Technologies and Low Carbon Buildings 2024* Dec 29 (pp. 23-120). Cham: Springer Nature Switzerland. 10.1007/978-3-031-78853-6\_2.
- [16] Srivastava A, Pandey S, Shahwal R, Sur A. Recycling of waste into useful materials and their energy applications. In *Microbial Niche Nexus Sustaining Environmental Biological Wastewater and Water-Energy-Environment Nexus 2025* Jan 16 (pp. 251-296). Cham: Springer Nature Switzerland. 10.1007/978-3-031-62660-9\_11.
- [17] Ononogbo C, Nwosu EC, Nwakuba NR, Nwaji GN, Nwifo OC, Chukwuezie OC, Chukwu MM, Anyanwu EE. Opportunities of waste heat recovery from various sources: Review of technologies and implementation. *Heliyon*. 2023 Feb 1;9(2).
- [18] Jamar AM, Majid ZA, Azmi WH, Norhafana M, Razak AA. A review of water heating system for solar energy applications. *International Communications in Heat and Mass Transfer*. 2016 Aug 1;76:178-87, <https://doi.org/10.1016/j.icheatmasstransfer.2016.05.028>
- [19] Panwar NL, Kaushik SC, Kothari S. State of the art of solar cooking: An overview. *Renewable and Sustainable Energy Reviews*. 2012 Aug 1;16(6):3776-85, <https://doi.org/10.1016/j.rser.2012.03.026>.
- [20] Saxena A, Norton B, Goel V, Singh DB. Solar cooking innovations, their appropriateness, and viability. *Environmental Science and Pollution Research*. 2022 Aug;29(39):58537-60, 10.1007/s11356-022-21670-4.
- [21] Apaolaza-Pagoaga X, Carrillo-Andrés A, Ruivo CR. Experimental characterization of the thermal performance of the Haines 2 solar cooker. *Energy*. 2022 Oct 15;257:124730, <https://doi.org/10.1016/j.energy.2022.124730>
- [22] Chaudhari K, Walke P, Shelare S. Comparative predictive analysis through machine learning in solar cooking technology. *International journal of electrical and computer engineering systems*. 2024 Jun 7;15(6):543-52, <https://doi.org/10.32985/ijeces.15.6.8>
- [23] Benbaha A, Yettou F, Azoui B, Gama A, Rathore N, Panwar NL. Novel mixed solar cooker: Experimental, energy, exergy, and economic analysis. *Heat Transfer*. 2024 Jun;53(4):2095-127, <https://doi.org/10.1002/htj.23023>
- [24] Sivakumar R, Sakthivel G, Mohanraj T, Lakshminpathi J, Jeagdesshwaran R, Manickavasagam P, Govardhan YS. Solar thermal cooking device for domestic cooking applications: Bridging sustainable development goals and innovation. *Heliyon*. 2024 Oct 15;10(19).
- [25] Misra N, Anand A, Pandey S, Kant K, Shukla A, Sharma A. Box-type solar cookers: an overview of technological advancement, energy, environmental, and economic benefits. *Energies*. 2023 Feb 8;16(4):1697. <https://doi.org/10.3390/en16041697>.
- [26] Verma A, El-Bayeh CZ, Buddhi D, Amir M, Ahmad F, Singh H. Socio-economic impact of solar cooking technologies on community kitchens under different climate conditions: A review. *Engineering Reports*. 2024 Nov;6(11):e12998. <https://doi.org/10.1002/eng2.12998>

- [27] Byaro M, Mmbaga NF, Mafwolo G. Tackling energy poverty: Do clean fuels for cooking and access to electricity improve or worsen health outcomes in sub-Saharan Africa?. *World Development Sustainability*. 2024 Jun 1;4:100125. <https://doi.org/10.1016/j.wds.2024.100125>.
- [28] Ceviz MA, Muratçobanoğlu B, Mandev E, Afshari F. A comprehensive review of solar cooking systems. *Wiley Interdisciplinary Reviews: Energy and Environment*. 2024 Mar;13(2):e516. <https://doi.org/10.1002/wene.516>
- [29] Vahidhosseini SM, Rashidi S, Hsu SH, Yan WM, Rashidi A. Integration of solar thermal collectors and heat pumps with thermal energy storage systems for building energy demand reduction: A comprehensive review. *Journal of Energy Storage*. 2024 Aug 1;95:112568. <https://doi.org/10.1016/j.est.2024.112568>
- [30] Careri F, Khan RH, Todd C, Attallah MM. Additive manufacturing of heat exchangers in aerospace applications: a review. *Applied Thermal Engineering*. 2023 Nov 25;235:121387. <https://doi.org/10.1016/j.applthermaleng.2023.121387>
- [31] Zhou J, Zeng C, Wang Z, Lyu W, Tang Y, Wu D, Ji W, Yuan Y. Indirect expansion solar assisted heat pump system: A review. *Sustainable Energy Technologies and Assessments*. 2022 Oct 1;53:102409. <https://doi.org/10.1016/j.seta.2022.102409>.