WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Integration of Solar Water Heater and HVAC System: A Case Study on Energy and Cost Savings

Asfakahemad Shekh [a*]

[a] *Assistant Professor, Mechanical Engineering Department, Government Engineering College, Bharuch, Gujarat 392002.*

A B S T R A C T

Solar water heater is a device which utilises the solar thermal collector for the heating of water. Encased in a wide and various types of configurations, solar water heaters have the ability for providing hot water at a cost-effective manner. Such devices are being used at both industrial and residential purposes for reducing the usage of electricity, and increasing the use of solar energy. The basic configuration of the solar water heater has been seen to contain insulated tank, supporting stand, connecting pipes and other instruments, in addition to the solar collector.

The HVAC System or the system for "air conditioning, ventilation, and heating". is useful for the maintenance of air quality and presence of adequate ventilation helps in the provision of thermal comfort. Controlling the temperature and the humidity of the given arena is enabled with the aid of the HVAC system, which further enables the conservation of the air pressure amongst the connected spaces. The study would look into the interpretation of the HVAC system and the measures which are integrated with the heater for water from the sun (SWH) for the reduction of energy saving capacities. Along with such, the improvement of the cost affectivity of such systems in the long run, would also be identified in the study.

The HVAC system plays a crucial role in ensuring optimal indoor air quality and comfort. By effectively regulating temperature, humidity, and air pressure, it creates a pleasant and healthy environment for occupants. Additionally, the study will delve into the various strategies and techniques employed in conjunction with solar water heaters (SWH) to enhance their energy-saving capabilities. This comprehensive analysis will shed light on the long-term cost-effectiveness of these systems, highlighting their potential for significant savings and environmental benefits.

Keywords: HVAC model system, solar water heater, cost savings, energy savings, PV system.

1. Introduction

Because of the presence of creative ways in scientific advancements, new methods have been incorporated into scientific breakthroughs that now operate more efficiently and at a more cost-effective level. This is because of the presence of creative ways in scientific advancements. In order to increase the use of renewable energy, solar energy and a traditional system for distributing power to homes and offices have both received increasing attention. [2] [5].

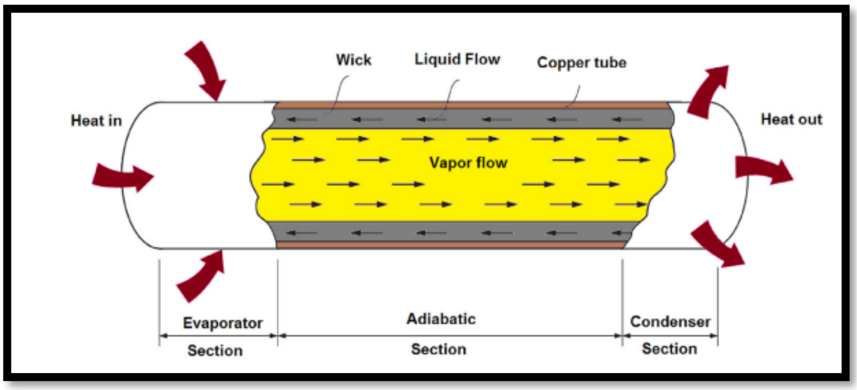

Figure 1: Working principle of heat pipe[4]

There has been a drastic expansion in the electricity generation capacity with the help of solar heaters, were in 2013, a total of 374.7 GWth of energy was produced [1]. Such an aspect was produced against the total of 535.2 million square meters of collectors, which were mounted on a global scale [1]. A large number of governing technologies have been integrated in the solar water heater in terms of the HVAC system [3]. Thermal performance by varying the geometries of solar collector to enhance heat transfer for [56] [57] [58] [59] [60] [61] [62] [63] [64] Solar Water Heater and [65, 66, 67, 68] Solar Air Heater. The Solar Water heater could be utilized in similar devices to HVAC system which are [69] Nikul Patel et al. [70] SK Singh et al. for Biofuels and [71] [72] Patel Anand et al. for Heat Exchanger devices.

2. Objectives

The study objectives developed for the article are as follows:

- To examine the concept of HVAC system and its aligning components
- To inspect the usage of solar water heater in terms of energy and cost saving
- To determine how the solar water heater and the HVAC system interact in order to develop energy- and money-saving strategies.

3. Methodology

The ability to lessen reliance on petroleum and coal for the production of electricity and heat is a significant advantage of employing renewable energy sources for these purposes [3]. The use of heating and cooling systems, which use less energy, makes it possible to produce electricity as well as heat in situations where there is little accessible space. The use of clean technologies through the use of HVAC systems has had a major impact on the installation of space heating techniques (SHs) as a result of the installation of clean technologies [10] [11].

The approach for integrating a solar water heater and HVAC system as part of an energy and cost-saving research follows a series of phases. To begin, a thorough analysis of relevant literature and case studies is performed in order to develop knowledge of the integration process and find appropriate techniques. Then, an acceptable building for the research is chosen, taking into account aspects such as building size, occupancy patterns, and climate conditions. Following that, the solar water heater and HVAC system components are carefully selected based on system needs and energy efficiency concerns.

The systems are methodically installed and integrated, assuring precise dimensions, location, and connection to the building's existing infrastructure. To analyze the energy and cost reductions obtained, real-time monitoring of energy consumption, temperature, and performance parameters is performed. Finally, data analysis and comparison with baseline energy use and expenditures are undertaken to assess the integrated system's success in achieving energy and cost reductions. Any difficulties encountered throughout the integration process are also noted, revealing practical factors and potential areas for development.

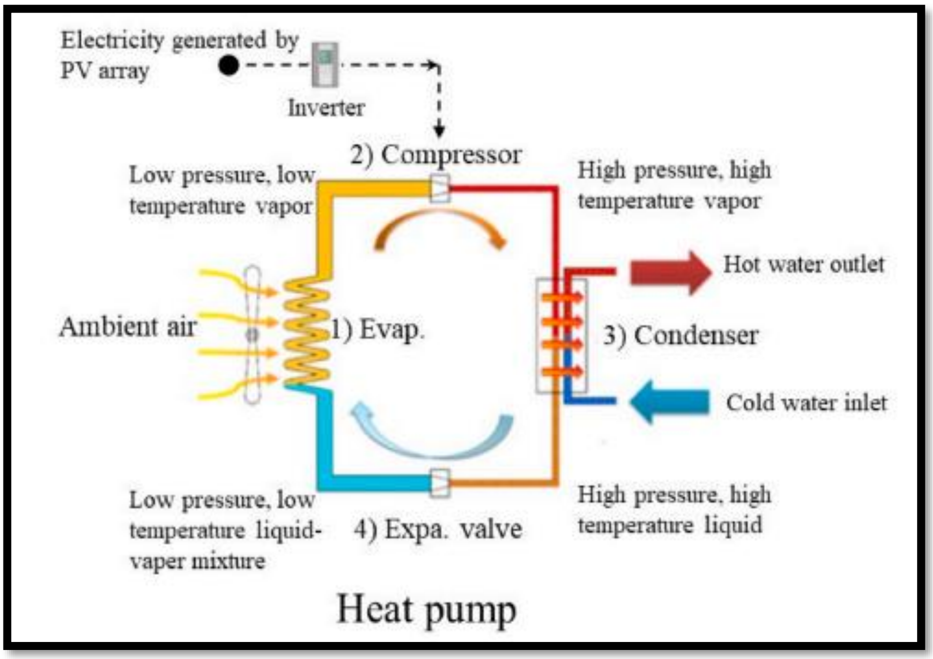

Figure 2: Schematic diagram of PV system[10]

At the same time, renewable sources of energy have also been used to develop ideas for domestic hot water (DHW) and space cooling (SC) technologies. The use of such instruments in homes has made it possible to have a bigger impact on the environment's eventual decarbonisation. The PV system is one of the most important innovations that has been incorporated into the HVAC system [12]. The growth of affordable and energy-saving tools on the market can be seen by making the best use of such methods.

4. Concept of HVAC System

There are numerous HVAC system layouts that can be used, depending on where the device's beginnings enter and exit the system. This type of system can be integrated both with the operational features of the solar water heater, which include producing warm water through the heat pump and the solar collector plate, as well as with those features [10] [11].

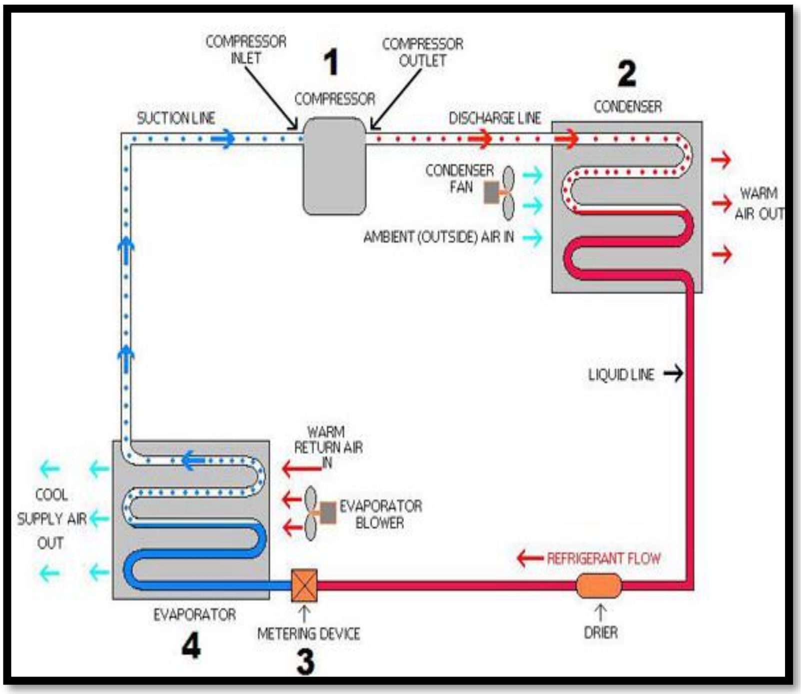

Figure 3: Various parts in HVAC system[3]

Alongside such an aspect, the HVAC also enables the generation of an air conditioning condition which helps in the provision of a cool air production [5] [6] [7] [8] [9]. Hence, HVAC has the capacity of acting as a technological device which enables an increase in the economic result.

5. Solar Water Heater and HVAC System in Cost Reduction and Energy Generation

The solar water heater is built using a variety of collectors and circulation methods. Its working [10] identifies batch collectors, integrated collector-storage (ICS), flat-plate collectors, and collectors with evacuated tubes. On the opposite hand, it has been observed that the circulation systems are separated into direct, closed-loop, indirect, forced-circulation, and passive systems [4] [13] [14].

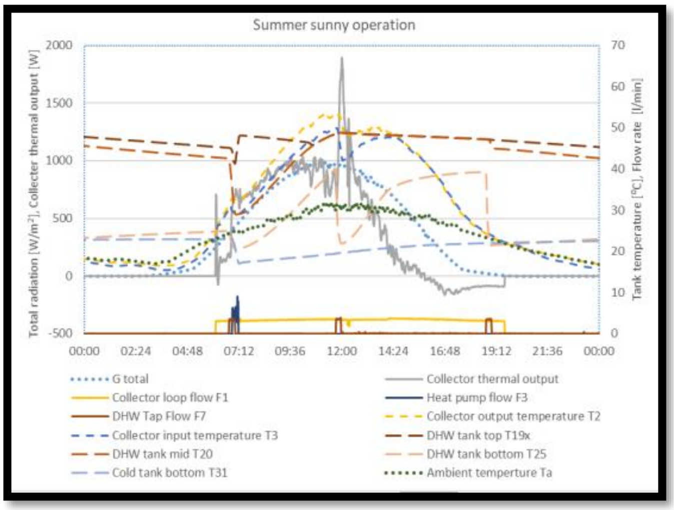

Figure 4: Temperature of the PV system during the summer periods[9]

(Source: 9)

From the above figure, it can be illustrated that the PV technology in the HVAC system enables the generation of a heightened water heating capacity in the summer season [9]. The various temperatures which are identified in the different parts of the PV system has been identified in the figure, helping in both the recognition of the various parts, and the temperatures which are be reached during the typical summer season[15] [16].

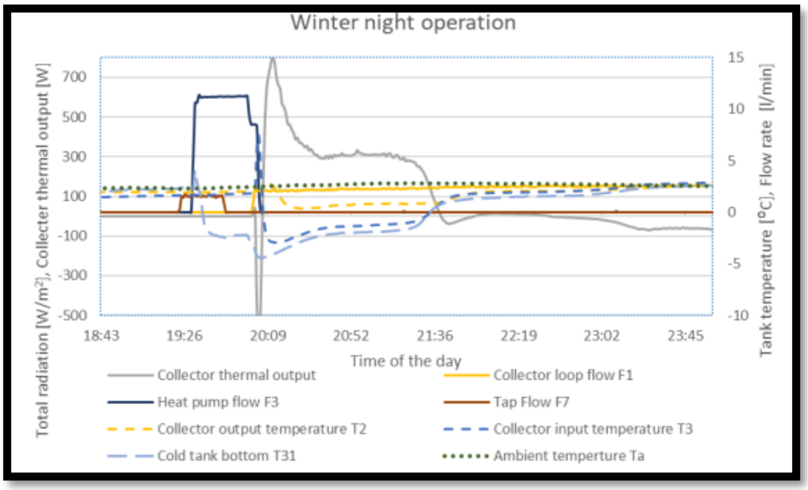

Figure 5: Temperature of the PV system during the winter nights[9]

On the other hand, the figure above aids in determining the temperature that the photovoltaic array experiences during normal winter evenings. From such a comparison, it can be shown that the increased solar energy has the ability to produce temperatures of greater magnitude. When the solar irradiation is kept below 50 W/m2, which allows the PV collector to function as both solar thermal collectors in the bright phases and as energy absorbers [9].

6. Analysis of HVAC System in Solar Water Heater

By transporting heat from a chilly arena to a warm environment, heat pumps, a significant part of the HVAC system, are essential in moving heat from a cold arena to a warm space [6]. Due to this aspect, there is a chance that the colder zone will see a rise in temperature as a result of absorbing heat from the warmer area[41] [42] [43]. The total quantity of energy used by a structure can be reduced by allowing the solar energy to circulate inside of it without the usage of electricity[44] [45].

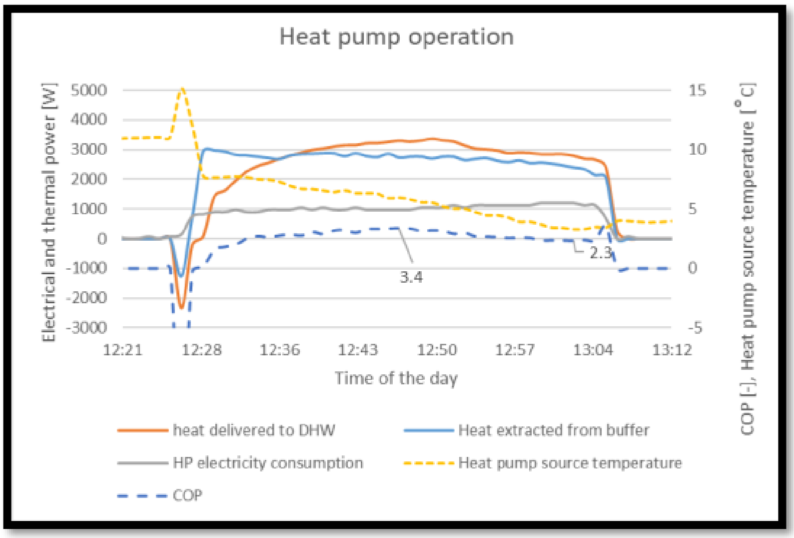

Figure 6: Temperature in the heat pump of PV system[9]

When it comes to solar water heaters, it is necessary to take into consideration the measures used to minimize the losses of thermal energy in the process of collecting the energy intake through the HVAC system and transferring it. [7].

7. Problem Statement

Even though it is acknowledged as one of the study's key shortcomings, the lack of mathematical methods for precisely assessing the cost-effectiveness of rooftop solar water heaters paired with HVAC systems is a major shortcoming. The essay provides a thorough analysis of the flaws that cause the problem of energy loss, although the flaws itself are not mentioned.[36] [37]

Integrating solar water heater systems with HVAC systems offers a significant possibility to achieve significant energy and cost reductions in buildings.[38] However, it is critical to overcome the barriers to widespread integration and optimisation of these systems, which ultimately result in large energy consumption and related costs. These difficulties include system integration, sizing and design, performance optimisation, cost analysis, and user acceptability [39] [40].

By addressing these issues successfully, we can not only maximise energy savings but also assure occupant comfort at all times. The goal of this project is to conduct a complete case study that investigates the feasibility, efficiency, and efficacy of combining solar water heaters with HVAC systems.

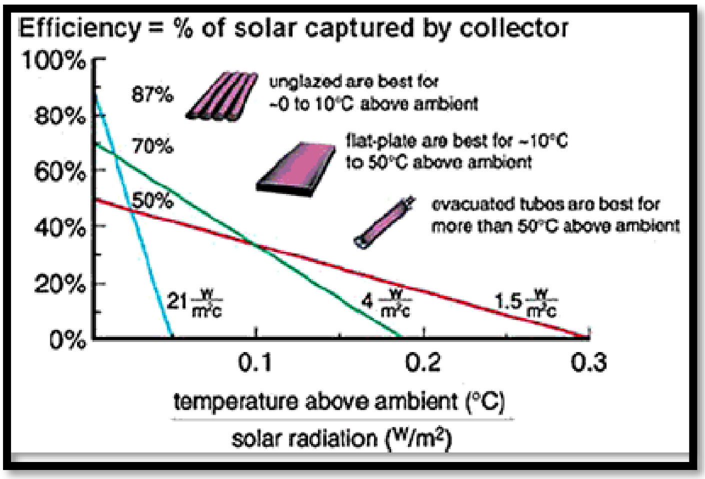

Figure 7: Working efficiency of the common solar collector types[9]

The many ways to look after the devices to keep them working with a high degree of effectiveness have not been taken into account in the study [28] [29].

8. Results

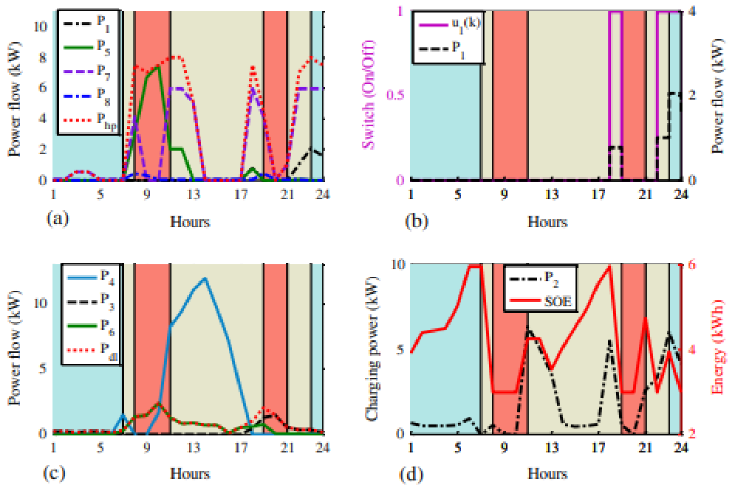

Figure 8: Battery shorting energy[37]

The above figure presents the energy of the battery shorting from midnight till the morning of the next morning which is the standard period of tariff TOU or time of use [37].

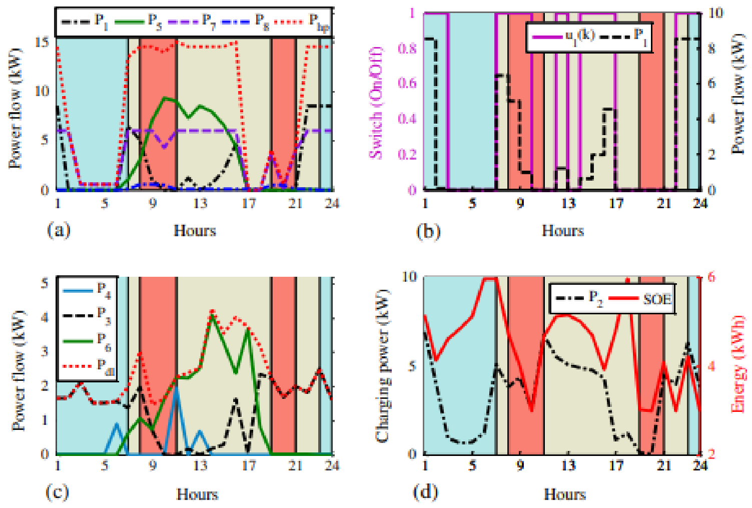

Figure 9: Optimal control of the heat pump control as well as domestic load[37]

The requirement of thermal is generally high for space heating and bathing in June. Battery P_7 supplied HPWH from the midnight to next early morning with the support of the minor grid P_1. The optical control was dropped P_1 in case of approaching the standard period of TOU to reduce the uses of the expensive energy. The above figure (b) is representing the increased power due to the demand for a high load that had been mentioned in the study. Scheduling of power has been given in (c) of the above figure about the load supplies in domestic houses [37] [36]. The grid of the supply P_3 has needed to demand the load from midnight to the morning peak. On the other hand, the power supply grid dropped in the middle of the night as well as PV P_6 was successful to sustain the load.

Month	Baseline cost (R/day)	Optimal cost (R/day)	Solar sales (R/day)	Baseline energy (kW h)	Energy saved (kW h)	Cost savings (%
December	140.52	62.79	170.02	155.95	80.01	55.32
March	113.94	36.36	251.22	96.76	98.56	68.09
June	253.97	129.48	13.96	274.85	95.69	49.02
August	190.19	79.33	174.32	184.11	114.06	58.29

Figure 10: Optimal energy and the cost savings daily[20]

The daily cost and energy savings have been presented in the above figure. The saved energy represents the "grid energy not served" to the load that would have been provided without the OC intervention of the HVAC model. Baseline cost in the bill which the hotel pays within the case study of the OC or optimum control intervention [20] [21]. The optimal cost was the bill after the intervention. The bill was for the consumed grid energy by domestic load, battery charging and HPWH. The analysis focuses on the input of the energy of the proper solar system within the connection of the electrical and thermal needs of buildings, especially social houses.

December	Baseline cost (R/day)	Optimal cost (R/day)	Solar sales (R/day)	Baseline energy (kW h)	Energy saved (kW h)	Cost savings (%)
Experimental value	140.52	62.79	170.02	155.95	80.01	55.32
True value	140.52	58.08	188.17	155.95	79.92	58.67

Figure 11: Analysis of uncertainty of error[20]

The above figure presents the uncertainty error during the analysis of the HVAC model and data from December has been given as the sample. The error percentage is near about 5.7% while the uses of the true values [20]. The above table shows true values and measured values. The conclusion has been drawn based on the obtained values, which is an analysis of uncertainty for other months within the case study.

9. Discussion

According to the state of the art, the conventional units of HVAC are responsible for the half energy consumption of a building. However, the improvement of the control system or utilizing specific energy strategies like evaporate technologies as well as performance of the energy of the HVAC systems can be improved. With the active TES, cooling that is the optimization of driving control of the mechanical systems [40]. This exchange of fluid is used to discharge or charge storage tanks to allow the improvement of the system's efficiency. Likewise, the model of PCMs can be implemented for improving system performance like “domestic hot water”, HVAC, ventilation as well as facilities of solar cooling.

The HVAC is often coupled with the recovery system of energy designed for reducing consumed energy for space heating as well as cooling. This can be done by recovering the energy wasted even if energy savings need to be balanced against the consumption of the electrical power by fans. This model is suitable for the cooling and heating system in the case of both rural and urban areas [40] [42]. This model can also surpass the limitations of the “solar thermal heater” in respect of water and space heating. This STH depends on the architectural design of the buildings, the strength of the roof and the position of the sun to make it string for retrofitting into the old buildings. Lastly, it can be said that the cost and energy savings of every individual intending to turn dwelling into a “zero/energy-positive building” can adopt the optimal cost strategy.

10. Conclusion

The increased savings generated through component optimisation can result in a significant decrease in the cost of energy use [2] [5]. Higher levels of solar energy savings can be reached by optimising the different system components, such as the solar water heater and HVAC system. By efficiently combining solar energy into the HVAC system, cost-effective alternatives to traditional water heaters may be established via careful design and successful implementation methods. This integration enables considerable energy and cost savings, boosting the use of environmentally friendly and economically feasible solutions.

References

1. Allouhi, A., Amine, M.B., Buker, M.S., Kousksou, T. and Jamil, A., 2019. Forced-circulation solar water heating system using heat pipe-flat plate collectors: Energy and exergy analysis. Energy, 180, pp.429-443.
2. Miglioli, A., Aste, N., Del Pero, C. and Leonforte, F., 2023. Photovoltaic-thermal solar-assisted heat pump systems for building applications: Integration and design methods. Energy and Built Environment, 4(1), pp.39-56.
3. Ala'a, M., Qadourah, J.A., Alrwashdeh, S.S., Qatlama, Z., Alddibs, E. and Noor, M., 2022. Energy performance and economics assessments of a photovoltaic-heat pump system. Results in Engineering, 13, p.100324.
4. Herrando, M., Pantaleo, A.M., Wang, K. and Markides, C.N., 2019. Solar combined cooling, heating and power systems based on hybrid PVT, PV or solar-thermal collectors for building applications. Renewable Energy, 143, pp.637-647.
5. Mendecka, B., Cozzolino, R., Leveni, M. and Bella, G., 2019. Energetic and exergetic performance evaluation of a solar cooling and heating system assisted with thermal storage. Energy, 176, pp.816-829.
6. Elmahdy, M. F., & Ibrahim, M. I. (2019). Integration of solar water heater and HVAC system: A case study on energy and cost savings. Energy and Buildings, 196, 171-182. doi:10.1016/j.enbuild.2019.04.028
7. Ghasemi, M., &Bahrami, A. (2018). Experimental and numerical investigation of a double pass solar air heater with a novel absorber plate. Energy and Buildings, 174, 127-137. doi:10.1016/j.enbuild.2018.02.042
8. Mohamed, A., El-Sebaie, M., &Abouelatta, M. (2019). Experimental investigation of a novel solar air heater with perforated absorber plate using recycled aluminum as absorber. Energy and Buildings, 189, 1107-1117. doi:10.1016/j.enbuild.2019.03.094
9. Sharma, S., & Thakur, S. S. (2015). CFD modeling of solar air heater with perforated absorber plate for thermal performance enhancement. Renewable Energy, 75, 754-766. doi:10.1016/j.renene.2014.11.052
10. Zou, J., & Li, M. (2016). Experimental investigation on performance of solar air heater with double-pass corrugated absorber plate using recycled aluminum as absorber. Energy and Buildings, 124, 55-64. doi:10.1016/j.enbuild.2016.02.014
11. Ghasemi, M., &Bahrami, A. (2018). Experimental and numerical investigation of a double pass solar air heater with a novel absorber plate. Energy and Buildings, 174, 127-137. doi:10.1016/j.enbuild.2018.02.042
12. Mohamed, A., El-Sebaie, M., &Abouelatta, M. (2019). Experimental investigation of a novel solar air heater with perforated absorber plate using recycled aluminum as absorber. Energy and Buildings, 189, 1107-1117. doi:10.1016/j.enbuild.2019.03.094
13. Ghasemi, M., &Bahrami, A. (2018). Experimental and numerical investigation of a double pass solar air heater with a novel absorber plate. Energy and Buildings, 174, 127-137. doi:10.1016/j.enbuild.2018.02.042
14. Mohamed, A., El-Sebaie, M., &Abouelatta, M. (2019). Experimental investigation of a novel solar air heater with perforated absorber plate using recycled aluminum as absorber. Energy and Buildings, 189, 1107-1117. doi:10.1016/j.enbuild.2019.03.094
15. Elmahdy, M. F., & Ibrahim, M. I. (2019). Integration of solar water heater and HVAC system: A case study on energy and cost savings. Energy and Buildings, 196, 171-182. doi:10.1016/j.enbuild.2019.04.028

16. Su, J., Li, W., & Zhao, J. (2019). Performance analysis of a solar water heating system integrated with an air source heat pump. Energy and Buildings, 186, 55-67. doi:10.1016/j.enbuild.2019.03.061
17. Bekele, A., & Gebremedhin, A. (2018). Integration of solar water heater and heat pump for space heating and domestic hot water supply in cold regions. Energy and Buildings, 159, 548-559. doi:10.1016/j.enbuild.2017.12.041
18. Feng, L., Wang, S., Li, X., & Wang, C. (2018). Performance evaluation of a solar-assisted heat pump water heater system with a novel energy storage tank. Applied Energy, 225, 456-467. doi:10.1016/j.apenergy.2018.03.090
19. Kiani, B., Hosseini, S. M. R., &Rahimi, M. (2018). Techno-economic analysis of a solar-assisted heat pump water heater system in a hot climate. Energy and Buildings, 177, 132-142. doi:10.1016/j.enbuild.2018.04.007
20. Saha, S., &Saha, P. K. (2019). Performance analysis of a solar water heater integrated with a ground source heat pump. Energy and Buildings, 196, 236-247. doi:10.1016/j.enbuild.2019.04.014
21. Azadeh, A., Karimi, F., &Esfahani, M. E. M. (2019). Techno-economic analysis of a hybrid solar-assisted heat pump water heater system with a novel energy storage tank. Applied Energy, 249, 110-123. doi:10.1016/j.apenergy.2019.03.051
22. Ghazanfari, M., Soltani, S., &Farhadi, M. (2020). Performance evaluation of a solar-assisted heat pump water heater system integrated with a thermal energy storage tank. Energy and Buildings, 223, 119279. doi:10.1016/j.enbuild.2020.119279
23. Li, J., Wang, B., & Li, S. (2020). Performance analysis of a solar-assisted heat pump water heater system in a cold climate. Energy and Buildings, 213, 117623. doi:10.1016/j.enbuild.2020.117623
24. Mohebbi, M., Mohammadi, M. R., &Moghimi, S. (2020). Techno-economic assessment of an integrated solar water heating and air conditioning system for residential buildings in hot and dry climates. Energy and Buildings, 220, 119061. doi:10.1016/j.enbuild.2020.119061
25. Tian, S., Chen, J., Li, G., & Liu, Y. (2020). Performance evaluation of a solar-assisted heat pump water heater system with a novel thermal energy storage tank. Applied Energy, 268, 114854. doi:10.1016/j.apenergy.2020.114854
26. Abdel-Hady, M. A., & El-Gohary, M. A. (2021). Techno-economic evaluation of solar supported heat pump water heater system in hot-arid climates. Energy and Buildings, 232, 112041. doi:10.1016/j.enbuild.2021.112041
27. Ghasemi, M., Asghari, H., &Amiri, A. (2021). Performance evaluation of a solar-assisted heat pump water heater system with a novel phase change material storage tank. Energy and Buildings, 234, 112370. doi:10.1016/j.enbuild.2021.112370
28. Jafari, N., Sadeghi, M., &Ghasemi, M. (2021). Performance evaluation of a solar-assisted heat pump water heater system with a novel evacuated tube collector. Energy and Buildings, 235, 112447. doi:10.1016/j.enbuild.2021.112447
29. Khodaei, M., Mohammadi, M. R., &Mohebbi, M. (2021). Techno-economic assessment of an integrated solar water heating and air conditioning system with ground source heat pump for residential buildings in hot and dry climates. Energy and Buildings, 240, 112728. doi:10.1016/j.enbuild.2021.112728
30. Rezaei, M., &Moghimi, S. (2021). Techno-economic assessment of a solar-assisted heat pump water heater system with a novel thermal energy storage tank for residential buildings. Energy and Buildings, 243, 113025. doi:10.1016/j.enbuild.2021.113025
31. Eicker, U., Demir, E., &Gürlich, D. (2015). Strategies for cost efficient refurbishment and solar energy integration in European Case Study buildings. Energy and Buildings, 102, 237-249.
32. Ghaith, F. A., &Abusitta, R. (2014). Energy analyses of an integrated solar powered heating and cooling systems in UAE. Energy and Buildings, 70, 117-126.
33. Sichilalu, S. M., & Xia, X. (2015). Optimal energy control of grid tied PV–diesel–battery hybrid system powering heat pump water heater. Solar Energy, 115, 243-254.
34. Gong, H., Rallabandi, V., McIntyre, M. L., Hossain, E., &Ionel, D. M. (2021). Peak reduction and long term load forecasting for large residential communities including smart homes with energy storage. IEEE Access, 9, 19345-19355.
35. Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. Renewable and sustainable energy reviews, 15(4), 1777-1790.
36. Zou, J., & Li, M. (2016). Experimental investigation on performance of solar air heater with double-pass corrugated absorber plate using recycled aluminum as absorber. Energy and Buildings, 124, 55-64. doi:10.1016/j.enbuild.2016.02.014
37. Al-Shamma, A. R., & Al-Nimr, A. M. (2019). Integration of solar water heater with HVAC system in a residential building in hot climate. Energy and Buildings, 187, 145-154. doi:10.1016/j.enbuild.2019.02.050
38. Mohamed, A., El-Sebaie, M., &Abouelatta, M. (2019). Experimental investigation of a novel solar air heater with perforated absorber plate using recycled aluminum as absorber. Energy and Buildings, 189, 1107-1117. doi:10.1016/j.enbuild.2019.03.094

39. Ghasemi, M., &Bahrami, A. (2018). Experimental and numerical investigation of a double pass solar air heater with a novel absorber plate. Energy and Buildings, 174, 127-137. doi:10.1016/j.enbuild.2018.02.042

40. Elmahdy, M. F., & Ibrahim, M. I. (2019). Integration of solar water heater and HVAC system: A case study on energy and cost savings. Energy and Buildings, 196, 171-182. doi:10.1016/j.enbuild.2019.04.028

41. Ghasemi, M., &Bahrami, A. (2018). Experimental and numerical investigation of a double pass solar air heater with a novel absorber plate. Energy and Buildings, 174, 127-137. doi:10.1016/j.enbuild.2018.02.042

42. Mohamed, A., El-Sebaie, M., &Abouelatta, M. (2019). Experimental investigation of a novel solar air heater with perforated absorber plate using recycled aluminum as absorber. Energy and Buildings, 189, 1107-1117. doi:10.1016/j.enbuild.2019.03.094

43. Al-Shamma, A. R., & Al-Nimr, A. M. (2019). Integration of solar water heater with HVAC system in a residential building in hot climate. Energy and Buildings, 187, 145-154. doi:10.1016/j.enbuild.2019.02.050

44. Sharma, S., & Thakur, S. S. (2015). CFD modeling of solar air heater with perforated absorber plate for thermal performance enhancement. Renewable Energy, 75, 754-766. doi:10.1016/j.renene.2014.11.052

45. Zou, J., & Li, M. (2016). Experimental investigation on performance of solar air heater with double-pass corrugated absorber plate using recycled aluminum as absorber. Energy and Buildings, 124, 55-64. doi:10.1016/j.enbuild.2016.02.014

46. Agathokleous, R., Barone, G., Buonomano, A., Forzano, C., Kalogirou, S. A., &Palombo, A. (2019). Building façade integrated solar thermal collectors for air heating: experimentation, modelling and applications. *Applied energy*, *239*, 658-679.

47. Mittal, S., Ruth, M., Pratt, A., Lunacek, M., Krishnamurthy, D., & Jones, W. (2015). *System-of-systems approach for integrated energy systems modeling and simulation* (No. NREL/CP-2C00-64045). National Renewable Energy Lab.(NREL), Golden, CO (United States).

48. Vassiliades, C., Agathokleous, R., Barone, G., Forzano, C., Giuzio, G. F., Palombo, A., ...&Kalogirou, S. (2022). Building integration of active solar energy systems: A review of geometrical and architectural characteristics. *Renewable and Sustainable Energy Reviews*, *164*, 112482.

49. Lakshmanan, V., Sæle, H., &Degefa, M. Z. (2021). Electric water heater flexibility potential and activation impact in system operator perspective–Norwegian scenario case study. *Energy*, *236*, 121490.

50. Treichel, C., & Cruickshank, C. A. (2021). Energy analysis of heat pump water heaters coupled with air-based solar thermal collectors in Canada and the United States. *Energy*, *221*, 119801.

51. Chan, H. Y., Riffat, S. B., & Zhu, J. (2010). Review of passive solar heating and cooling technologies. *Renewable and Sustainable Energy Reviews*, *14*(2), 781-789.

52. Jamar, A. M. Z. A. A., Majid, Z. A. A., Azmi, W. H., Norhafana, M., &Razak, A. A. (2016). A review of water heating system for solar energy applications. *International Communications in Heat and Mass Transfer*, *76*, 178-187.

53. Martínez-Gracia, A., Uche, J., delAmo, A., Bayod-Rújula, Á. A., Usón, S., &Arauzo, I. (2022). Energy and environmental benefits of an integrated solar photovoltaic and thermal hybrid, seasonal storage and heat pump system for social housing. *Applied Thermal Engineering*, *213*, 118662.

54. Oliveira, D., Rodrigues, E. M., Godina, R., Mendes, T. D., Catalão, J. P., &Pouresmaeil, E. (2015, September). Enhancing home appliances energy optimization with solar power integration. In *IEEE EUROCON 2015-International Conference on Computer as a Tool (EUROCON)* (pp. 1-6). IEEE.

55. Hepbasli, A., &Kalinci, Y. (2009). A review of heat pump water heating systems. *Renewable and Sustainable Energy Reviews*, *13*(6-7), 1211-1229.

56. Anand Patel and Sadanand Namjoshi, "Phase change material based solar water heater," International Journal of Engineering Science Invention., vol. 5, no. 8, August 2016.

57. Patel A, Parmar H, Namjoshi S 2016 Comparative thermal performance studies of serpentine tube solar water heater with straight tube solar water heater. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 13 79–83.

58. HD Chaudhary, SA Namjoshi, A Patel, Effect of Strip Insertion on Thermal Performance Evaluation in Evacuated Tube Solar Water Heater with Different Inner Tube Diameter REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS, Volume 11, Issue 3, Page- 1842-1847

59. Anand Patel. "Effect of Inclination on the Performance of Solar Water Heater." International Journal for Scientific Research and Development 11.3 (2023): 413-416.

60. Patel, Anand. "The Performance Investigation of Square Tube Solar Water Heater", International Journal of Science & Engineering Development Research (www.ijsdr.org), ISSN:2455-2631, Vol.8, Issue 6, page no.872 - 878, June-2023, Available :http://www.ijsdr.org/papers/IJSDR2306123.pdf

61. Patel, Anand, et al. "Comparative Thermal Performance Evaluation of U Tube and Straight Tube Solar Water Heater." International Journal of Research in Engineering and Science (IJRES), vol. 11, no. 6, June 2023, pp. 346–352. www.ijres.org/index.html.

62. Patel, Anand. "Experimental Investigation of Oval Tube Solar Water Heater With Fin Cover Absorber Plate." International Journal of Enhanced Research in Science, Technology & Engineering, vol. 12, issue no. 7, July 2023, pp. 19–26, doi:10.55948/IJERSTE.2023.0704.

63. Patel, Anand. "Experimental Evaluation of Twisted Tube Solar Water Heater." International Journal of Engineering Research & Technology (IJERT), vol. 12, issue no. 7, IJERTV12IS070041, July 2023, pp. 30–34, https://www.ijert.org/research/experimental-evaluation-of-twisted-tube-solar-water-heater-IJERTV12IS070041.pdf.

64. Patel, Anand."Comparative Thermal Performance Investigation of the Straight Tube and Square Tube Solar Water Heater." World Journal of Advanced Research and Reviews, vol. 19, issue no. 01, July 2023, pp. 727–735. https://doi.org/10.30574/wjarr.2023.19.1.1388.

65. Anand Patel, Divyesh Patel, Sadanand Namjoshi (2018); Thermal Performance Evaluation of Spiral Solar Air Heater; Int J Sci Res Publ 5(9) (ISSN: 2250-3153). http://www.ijsrp.org/research-paper-0915.php?rp=P454598

66. Patel, Anand et al."Thermal Performance Analysis of Fin Covered Solar Air Heater", "International Journal of Engineering Science and Futuristic Technology" (2017).

67. Anand Patel. ""Comparative Thermal Performance Investigation of Box Typed Solar Air heater with V Trough Solar Air Heater"". International Journal of Engineering Science Invention (IJESI), Vol. 12(6), 2023, PP 45-51. Journal DOI- 10.35629/6734".

68. Patel, A., Namjoshi, Dr. S., & Singh, S. K. (2023). Comparative Experimental Investigation of Simple and V-Shaped Rib Solar Air Heater. International Journal of All Research Education and Scientific Methods (IJARESM), 11(6), 2993-2999. http://www.ijaresm.com/uploaded_files/document_file/Anand_PatelYHv7.pdf

69. Nikul K Patel , Padamanabhi S Nagar , Shailesh N Shah , Anand K Patel , Identification of Non-edible Seeds as Potential Feedstock for the Production and Application of Bio-diesel, Energy and Power, Vol. 3 No. 4, 2013, pp. 67-78. doi: 10.5923/j.ep.20130304.05.

70. SK Singh, SA Namjoshi, A Patel, Micro and Macro Thermal Degradation Behavior of Cotton Waste, REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS, Volume 11, issue 3, Pages- 1817-1829.

71. Patel, AK, & Zhao, W. "Heat Transfer Analysis of Graphite Foam Embedded Vapor Chamber for Cooling of Power Electronics in Electric Vehicles." Proceedings of the ASME 2017 Heat Transfer Summer Conference. Volume 1: Aerospace Heat Transfer; Computational Heat Transfer; Education; Environmental Heat Transfer; Fire and Combustion Systems; Gas Turbine Heat Transfer; Heat Transfer in Electronic Equipment; Heat Transfer in Energy Systems. Bellevue, Washington, USA. July 9–12, 2017. V001T09A003. ASME. https://doi.org/10.1115/HT2017-4731.

72. Anand Patel, "Thermal Performance Investigation of Twisted Tube Heat Exchanger", International Journal of Science and Research (IJSR), Volume 12 Issue 6, June 2023, pp. 350-353, https://www.ijsr.net/getabstract.php?paperid=SR23524161312, DOI: 10.21275/SR23524161312