Paper ID: 504

Techno-Economic Feasibility Analysis of Integrated Heat Pump and Solar System for Commercial Building

Surovi Aktar Nupur[1], Souman Rudra[2], A. S. M. Sayem[3]
[1,3]Department of Mechanical Engineering, CUET
[2]Department of Engineering and Science, University of Agder (UiA), Norway
E-mail: suroviaktarnupur984@gmai.com, souman.rudra@uia.no, a.sayem@cuet.ac.bd

Abstract

Assessing techno-economic feasibility of integrated heat pump and solar systems for commercial buildings is consequential. This paper investigates techno-economic feasibility of Ground Source Heat Pump (GSHP) and Solar System for i4Health building of University of Agder considering performance evaluation, cost-effectiveness, and environmental impact. Firstly, GSHP performance has been analyzed by evaluating Coefficient of Performance (COP), and Solar System performance has been analyzed by Performance Ratio and Solar Ratio. Secondly, Annual Cost Savings and Payback Periods present cost-effectiveness. Lastly, CO_2 reductions have been estimated for analyzing environmental impact. The findings present COP varies around 3.26-5.7 per week according to demand. Performance ratio of solar system varies 89-96%. GSHPs and solar system save 1-1.899 NOK/kwh and 0.87-2.35 NOK/kwh respectively. GSHP and solar payback periods are 9.7 years and 10.56 years based on investment. This research also evaluates that GSHP and solar system give positive impact environmentally reducing 30–40 tons CO_2 per year.

Keywords: Renewable energy; Building energy; Cost effectiveness; Environmental impact.

1. Introduction

Fossil fuel consumption for electricity in the public, commercial, and residential sectors is a preeminent contributor to climate change, which poses a serious warning to our environment [1]. The European Union (EU) wants to cut its greenhouse gas emissions from 1990 levels by 80–95% by the year 2050. This lofty objective requires the energy industry to decarbonize significantly [2],[3]. The goal of Norway is to diminish emissions by 55% by 2030 and 90–95% by 2050. But, according to projections, there will be a 27% decrease by 2030 and an 80% decline by 2050 when compared to 1990 [4]. The substitution of renewable energy sources for fossil fuels is a practical and effective way that must significantly cut energy-induced greenhouse gas emissions so as to meet climate commitments [5].

Power may be produced from healthy, renewable sources of energy including wind, solar, biomass, and heat pumps without contributing to air pollution or upsetting vast tracts of land or water [6]. Due to their many benefits versus electricity, heat pumps (HPs) have grown more in residential applications [7] and among the heat pumps ground source heat pumps are a tested renewable energy innovation that can cut production of greenhouse gases by at least 66% [6] when used for indoor heating and cooling. The alluring benefits of high energy and environmental performances have led to the widespread usage of ground-source heat pump (GSHP) systems in both residential and commercial buildings worldwide. Likewise, among the most essential and reasonably priced technological solutions for the building industry to meet its decarbonization targets is the renewable electricity produced on residential buildings' rooftops PV arrangements [2] at its growing installation rate including 60% on buildings [8]. One can potentially reduce fuel costs and significantly improve the well-being of later generations by implementing each of the green energy solutions [6].

Considering i4Health Building of University of Agder (UiA), a detailed picture of ground source heat pump has been analyzed on basis of performance efficiency, economic efficiency and environmental impact as well as the building's rooftop solar energy source. Energy from heat pump and solar system being used for the building's space heating and for other allowances, a cost-effective contribution of heat pump as well as solar system to the building's total power consumption has been determined along with the payback periods. With the performance efficiency and economic efficiency, green contribution to reduce CO_2 emissions with the building's ground source heat pump and rooftop solar system has been developed.

2. Literature review

Based on major energy source for each type of building, a parametric solar photovoltaic (PV) size study is carried out. Total life cycle cost, renewable fraction, and greenhouse gas (GHG) emissions are computed in this paper. Result shows that GHG emissions from residential buildings can be instantly reduced by up to 50% when PV is combined with heat pumps. If renewable energy targets are satisfied, this effect will increase with time and result in a decrease in building emissions of nearly 90% [9]. By integrating heat pump with solar system, thermal storage , and an intelligent rule-based system of controls that enables focused heat pump operation with on-site PV electricity, this paper examined the prospect of reducing grid electricity use. Two refurbishment scenarios involving space heating and domestic hot water preparation in a Zurich single-family home were simulated. Results show that 5 kW of PV can reach the shortest payback period of 17.1 years. The system reduced grind electricity 29% [10]. In order to assess viability of PV+HP systems in northern regions of North America, this research employs economic analysis and numerical simulations. Findings demonstrate that homeowners in North America may now affordably build residential PV+HP systems to meet all of their heating and electricity needs. In the United States, these systems can yield returns of up to 1.9%, and in Canada, up to 2.7%. PV-only systems have better returns—up to 4.3%—but have less than half the PV capacity [11]. This study examines the power production and energy efficiency of a PV-integrated variable refrigerant flow (VRF) heat pump unit in a five-story residential structure in Cyprus. In the chosen areas, annual horizontally radiation intensity varies between 1,784 and 1,882 kWh/m2. VRF power usage varies from 14005 to 18,710 kWh per year, and a 13kW photovoltaic array may provide 23,200 to 23,650 kWh per year. According to economic feasibility analysis, installing PV for this application in all areas under investigation is financially advantageous [12]. Research investigates parametric techno-economic analysis of integrated solar and heat pump systems in order to pinpoint crucial economic factors influencing profitability based on a case study in Vienna. Result shows that GSHP with PV is profitable. Subsidies and capital expenses have a significant impact on the benefit-to-cost ratio (BCR), but natural gas prices have the biggest impact. For both HP and PV, a 0.01 €/kWh, or 17%, increase in natural gas costs will suffice to replace all other intricate subsidies. This might lead to a 45%–60% decrease in the release of CO_2 in multi-family homes [13].

The main contribution to the field is assessing the feasibility of GSHP and solar system with the point of view performance efficiency, cost efficiency and environmental pros at the same time. The analysis of performance can lead the project of finding more energy saving process. Evaluation of cost savings can make the GSHP and solar system more reliable. Installation of GSHP and Solar system mitigates the fossil fuel consumption and hence the greenhouse gas reduction. This paper contributes to analyzation of reduction of CO_2 emission by using GSHP and solar system of i4Health building that proves again the significance of installing renewable energy sources to the households and commercial buildings.

3. Methodology

For evaluation to meet the objectives, necessary data such as building's demand, power production from renewable sources, driving power is being provided from https://www.ens-portalen.no/ as well as from the authority of i4Health building's energy system for the year 2022 and 2023 on the basis of 52 weeks for each year. Performance evaluation is undergone by three parameters; COP for heat pump's performance, PR and SR for solar systems performance. COP of heat pump HP IK01/02 and HP IK03 is evaluated from the ratio of heat pump power generation to the amount of driving power from grid needed to generate the power for analyzing the heat pump performance for the year 2022 and 2023 based on weekly values. Performance of solar system is estimated through performance ratio (PR) which indicates how efficiently a solar system can produce power actually with respect to the power assumed to be produced theoretically. For building, solar ratio is evaluated from solar power divided by building's total demand.

Secondly, for cost effectiveness analyzation, there are two parameters considered: Cost savings from heat pump and solar system which means how much cost can be saved for supplying power from those renewable sources instead of from grid. Payback period indicates how many years are needed to retrieve the system's investment for installing. Payback period is estimated dividing the investment cost by the annual cash flow, here cost savings for a year is considered as annual cash flow.

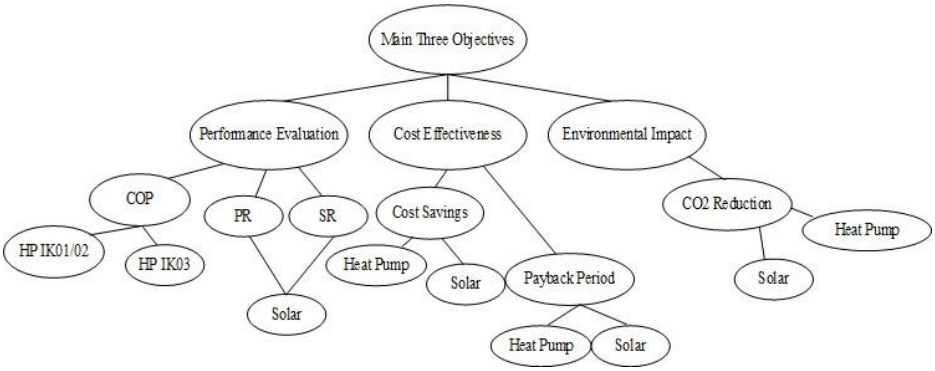


Fig.1. Evaluation of different parameters

Thirdly, the environmental impact by using GSHP and solar system in i4Health building is analyzed through measuring the reduction of CO_2 gas emission using GSHP and solar system with respect to grid energy. CO_2 emission factor is considered to measure the amount of emission reduction. CO_2 emission factor for GSHP is 0.15 kg/kwh [14],[15] 0.041 kg/kwh for solar system [16] and 0.28 kg/kwh for grid electricity [17] is considered.

4. Result and Discussion

This section consists of several sub-sections displaying the achieved results chronologically targeting to meet the objectives.

4.1 Ground source heat pump and solar system performance evaluation

Coefficient of performance (COP) of heat pump IK01/02 varying throughout the year of 2022 is presented in the Fig. 2. Heat Pump IK01/02 has higher COP value from week 1 to 16 with a varying COP range from 4.98 to 5.54 as power production is high in those weeks to fulfill the required energy demand for space heating. The weeks are between mid-winter to mid-spring season. After the week 16, COP has started to decrease from week 16 to 23 according to the decreasing thermal energy demand as well as power production from last of spring to starting of the Summer. The value remains in the range from 4.1 to 4.43 in the week 23 to 31 during the time of whole summer. From the last of Summer to the whole Autumn, COP has started to increase again till week 43 at a highest value of 5.7. For the variation of demand, COP value has fell down till the week 50. The starting of winter starts to increase the demand so as the COP. Fig. 3 presents weekly COP of heat pump IK03 throughout the year 2022. Week 1 to 14 has lower COP value between 3.59 to 3.78.

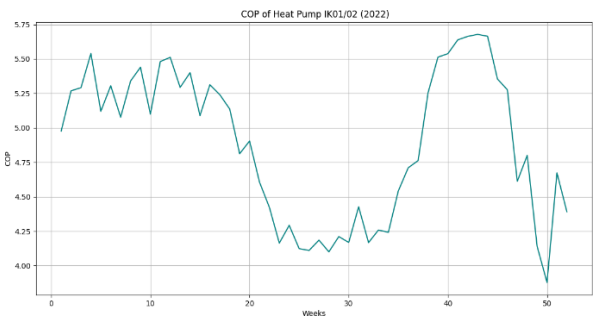


Fig. 2. COP of HP IK01/02

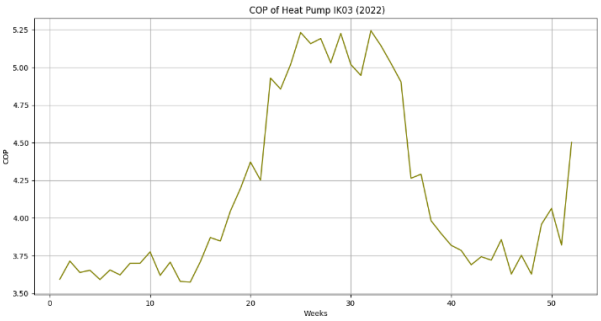


Fig. 3. COP of HP IK03

The performance coefficient starts to rise gradually after week 14 to 25 having a high COP value 5.23 in week 25. COP value remains at range 4.95 to 5.24 from week 25 to 32 and then, starts to fall gradually to 3.69 in week 42. After week 42, the value remains at a lower range and it starts rising again from week 51.

It is eye-catching that the COP graph of HP IK03 seems quite opposite of COP graph of HP IK01/02. The reason behind this is, HP IK03 is an auxiliary and supporting heat pump for HP IK01/02. When HP IK01/02 has higher performance, the performance of HP IK03 becomes lower and vice-versa showing by Fig. 4 for keeping a balance performance to overall heat pump system.

Performance of solar cell power production can be assessed through various parameters. For solar system of i4Helse building, the production performance has been evaluated by Solar Performance Ratio and Solar Ratio.

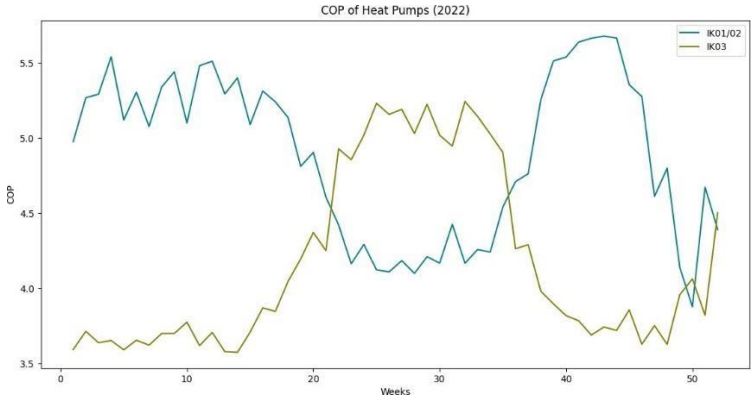


Fig. 4. COP of HP IK01/02 and HP IK03

Fig. 5 represents the Performance Ratio (PR) of i4Helse building's solar system for the year 2022 and 2023. In 2022, Performance Ratio (PR) is 96 % that means the solar system has produced actual power 96 % of the expected power and, the PR has higher value in 2022 than 2023. Solar system has produced actual power 89% of the expected generation in 2023.

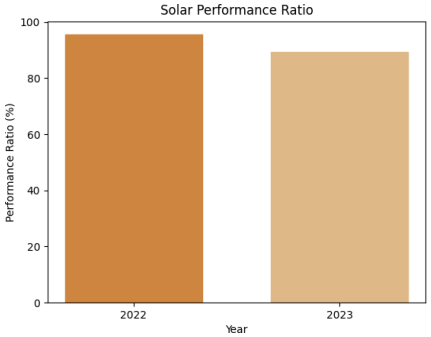


Fig. 5. Performance ratio of solar system

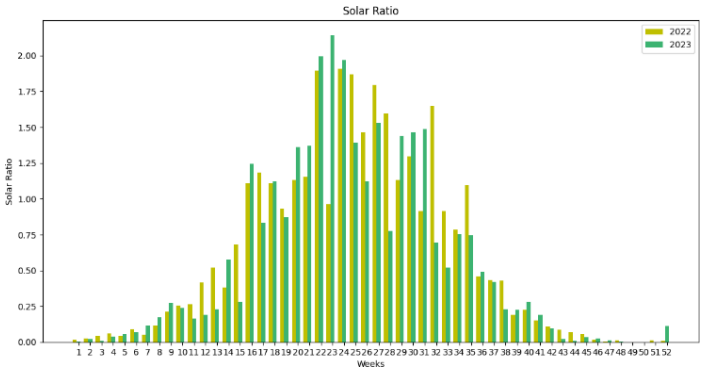


Fig. 6. Solar ratio of solar system

The PR value of the solar system indicates high performance solar system working in i4helse building of UiA. Solar Ratio (SR) indicates the total power production from solar system that can be used for the building's total demand including the electrical appliances and energy for heat pump operation. SR greater than 1 means there is addition power available after meeting the building's demand and the addition power can be stored or supplied to the grid. SR increases with the increase of production and can vary with the total demand. Among 2022 and 2023 shown in the Fig. 6 there is SR greater than 1 almost after week 15 to 33 in 2022 and week 15 to 31 in 2023 when the temperature was high as well as the solar power generation. In those weeks, additional power can be sold to the grid or can be stored. SR has a pick value 1.922 in week 24 of 2022 and 2.136 in week 23 of 2023. This additional production contributes to the buildings energy economy directly by selling power.

4.2 Ground source heat pump and solar system economic evaluation

Cost saving means the amount of cost can be saved using power from GSHP as well as solar system instead of grid. Depending on the weekly price of grid power, cost savings are evaluated for the year 2022 and 2023 showing in the Fig. 7 for heat pump and Fig. 8 for solar system.

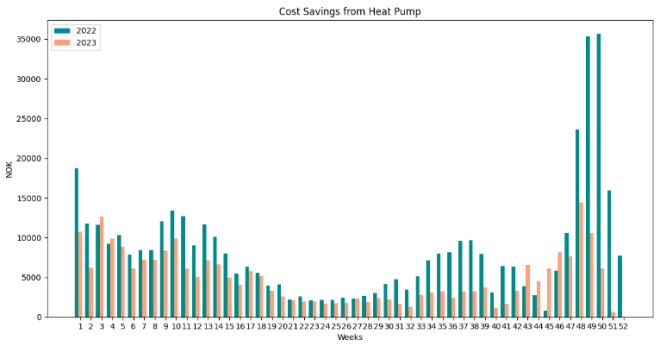


Fig. 7. Cost savings from GSHP

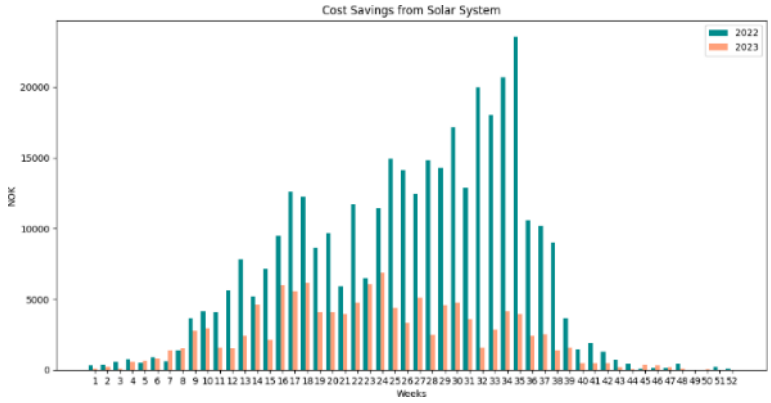


Fig. 8. Cost savings from solar system

In 2022, amount of cost savings from heat pump is in a range of nok 822.164-18761.463 between the week 1 to 45 on the basis of variation of power price and power production from heat pump. Savings is very high in week 49 and 50 for higher power price and higher power production in those weeks. A total amount of NOK 436336.16 is saved in 2022 and the savings is 1.899 NOK/KWh. In 2023, amount of cost savings from heat pump is lower than 2022 because power price was high in 2022 for Russia-Ukraine war. Savings is almost constant around NOK 2000 in the weeks 20 to 42. Week 48 has the pick value of savings NOK 14440 in 2023. Total amount of NOK 253682.11 is saved in 2023 at a savings rate is 1 NOK/KWh.
Result shows cost savings is increased highly in 2022 with a pick value NOK 23580. Total annual savings in 2022 is NOK 355121.69 at the rate 2.35 NOK/KWh. Cost savings is lower in 2023 almost every week than 2022. The total annual savings is 122414.82 at a rate 0.87 NOK/KWh with the highest value is NOK 6840 in week 24.
Payback period is the indicator of how many years need to retrieve the installation costs of the project. In the basis of cost savings from GSHP and solar system of the year 2022 and 2023, payback period has been evaluated considering total investment cost with VAT. Heat pump need around 9.78 years based on 2022 cost savings and 16.33 years based on 2023 cost savings whereas solar system needs 10.56 years and 30.63 years according to 2022 and 2023 respective cost savings. Payback period for the total integrated system is 10.07 years and 20.83 years with respect to 2022 and 2023. Payback period is 30.63 years is not feasible for solar system.

4.3 Environmental impact of ground source heat pump and solar system economic evaluation

There has been widespread agreement on objectives and plans for lowering greenhouse gas (GHG) emissions and energy consumption in order to address the problems posed by climate change and resource scarcity. Power production from fossil fuels is the major causes of increasing Green House Gases (GHGs). Installation of GSHP and solar system can reduce the GHG emission in a significant way. For i4Health building, Fig. 9 shows the amount of CO_2 reduction for the year 2022 and 2023. Heat pump reduces 32.28 ton of CO_2 than from grid in 2022 and 35.66 ton in 2023 whereas solar system reduces 36.05 ton in 2022 and 33.69 ton in 2023. The reduction of CO_2 gas emissions contributes to the zero-emission goal and makes the place of GSHP and solar system more sustainable.

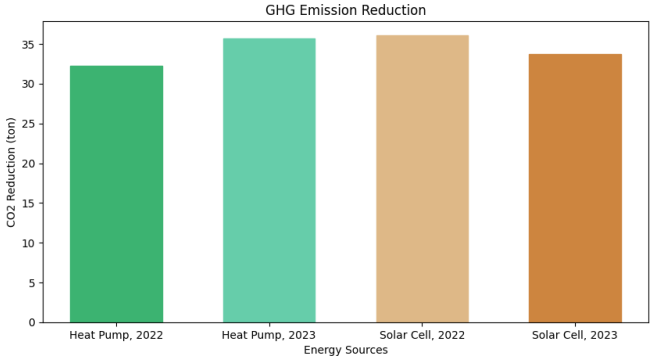


Fig. 9. Reduction of CO_2 emission

5. Conclusion

This paper meets the main objectives about GSHP and solar system of i4Health building including performance evaluation, cost effectiveness and environmental impact. COP of Ground Source Heat Pump varies weekly around 4.98-5.7 in cold weather and around 3.26-4.43 per week in warm weather. PR of solar system is 96% in 2022 whereas 89% in 2023. Heat pump saves costing at 1.899 NOK/kwh in 2022 and 1 NOK/kwh in 2023. Solar system saves costing NOK 355121.69 in 2022 and NOK 122414.82 in 2023. Payback period for heat pump and solar is 16.33 and 10.56 years respectively. This research also finds that heat pump reduces 32.28 tons CO2 in 2022 and 35.66 ton in 2023. And, 35.66 ton and 33.69 ton in 2023. And, solar system reduces 36.05 tons CO2 in 2022 and 33.69 ton in 2023. The research should be conducted before doing investment for GSHP and solar system for knowing the overall idea for making a proper plan. But, doing the research now contributes to get an overall idea from here to imply it for other commercial buildings before doing investment. Results and analysis opens further research opportunities. For future research and development, the following recommendations are proposed:

- The solar system of i4Health building is traditional, the further research can be conducted based on the techno-economic feasibility of updated rooftop solar systems such as PV system attached with the rooftop or window glasses for the building.
- This paper is conduction depends on limited data resources; further research needs to be worked with wide data.
- Techno-economic feasibility of integrated heat pump and solar system analyzing is also applicable for other commercial buildings instead of only i4Health building.

11. References

[1] D. Feliciano, B. Slee, and P. Smith, "The potential uptake of domestic woodfuel heating systems and its contribution to tackling climate change: A case study from the North East Scotland," *Renew. Energy*, vol. 72, pp. 344–353, 2014, doi: 10.1016/j.renene.2014.07.039.

[2] K. Dennis, "Environmentally Beneficial Electrification: Electricity as the End-Use Option," *Electr. J.*, vol. 28, no. 9, pp. 100–112, 2015, doi: 10.1016/j.tej.2015.09.019.

[3] K. Dennis, K. Colburn, and J. Lazar, "Environmentally beneficial electrification: The dawn of 'emissions efficiency,'" *Electr. J.*, vol. 29, no. 6, pp. 52–58, 2016, doi: 10.1016/j.tej.2016.07.007.

[4] B. D. Solomon, "Energy transition," *Dict. Ecol. Econ. Terms New Millenn.*, p. 191, 2023, doi: 10.4337/9781788974912.E.103.

[5] C. Bernath, G. Deac, and F. Sensfuß, "Influence of heat pumps on renewable electricity integration: Germany in a European context," *Energy Strateg. Rev.*, vol. 26, no. September 2018, p. 100389, 2019, doi: 10.1016/j.esr.2019.100389.

[6] A. Mustafa Omer, "Ground-source heat pumps systems and applications," *Renew. Sustain. Energy Rev.*, vol. 12, no. 2, pp. 344–371, 2008, doi: 10.1016/j.rser.2006.10.003.

[7] E. Psimopoulos, E. Bee, J. Widén, and C. Bales, "Techno-economic analysis of control algorithms for an exhaust air heat pump system for detached houses coupled to a photovoltaic system," *Appl. Energy*, vol. 249, no. April, pp. 355–367, 2019, doi: 10.1016/j.apenergy.2019.04.080.

[8] S. Schopfer, V. Tiefenbeck, and T. Staake, "Economic assessment of photovoltaic battery systems based on household load profiles," *Appl. Energy*, vol. 223, no. November 2017, pp. 229–248, 2018, doi: 10.1016/j.apenergy.2018.03.185.

[9] F. Padovani, N. Sommerfeldt, F. Longobardi, and J. M. Pearce, "Decarbonizing rural residential buildings in cold climates: A techno-economic analysis of heating electrification," *Energy Build.*, vol. 250, p. 111284, 2021, doi: 10.1016/j.enbuild.2021.111284.

[10] A. Heinz and R. Rieberer, "Energetic and economic analysis of a PV-assisted air-to-water heat pump system for renovated residential buildings with high-temperature heat emission system," *Appl. Energy*, vol. 293, no. April, 2021, doi: 10.1016/j.apenergy.2021.116953.

[11] J. M. Pearce and N. Sommerfeldt, "Economics of grid-tied solar photovoltaic systems coupled to heat pumps: The case of northern climates of the U.S. and Canada," *Energies*, vol. 14, no. 4, 2021, doi: 10.3390/en14040834.

[12] H. A. Gilani, S. Hoseinzadeh, H. Karimi, A. Karimi, A. Hassanzadeh, and D. A. Garcia, "Performance analysis of integrated solar heat pump VRF system for the low energy building in Mediterranean island," *Renew. Energy*, vol. 174, pp. 1006–1019, 2021, doi: 10.1016/j.renene.2021.04.081.

[13] T. Schreurs, H. Madani, A. Zottl, N. Sommerfeldt, and G. Zucker, "Techno-economic analysis of combined heat pump and solar PV system for multi-family houses: An Austrian case study," *Energy Strateg. Rev.*, vol. 36, no. July, p. 100666, 2021, doi: 10.1016/j.esr.2021.100666.

[14] P. Blum, G. Campillo, W. Münch, and T. Kölbel, "CO2 savings of ground source heat pump systems - A regional analysis," *Renew. Energy*, vol. 35, no. 1, pp. 122–127, 2010, doi: 10.1016/j.renene.2009.03.034.

[15] I. Sarbu and C. Sebarchievici, "General review of ground-source heat pump systems for heating and cooling of buildings," *Energy Build.*, vol. 70, pp. 441–454, 2014, doi: 10.1016/j.enbuild.2013.11.068.

[16] "'https://www.solar.com/learn/what-is-the-carbon-footprint-of-solar-panels/.'"

[17] T. Schreurs, H. Madani, A. Zottl, N. Sommerfeldt, and G. Zucker, "Techno-economic analysis of combined heat pump and solar PV system for multi-family houses: An Austrian case study," *Energy Strateg. Rev.*, vol. 36, no. May, p. 100666, 2021, doi: 10.1016/j.esr.2021.100666.