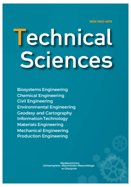
Technical Sciences, 2021, 24, 105–113

UNIWERSYTET
WARMIŃSKO-MAZURSKI
W OLSZTYNIE

Yearbook peer-reviewed scientific journal
ISSN 1505-4675
e-ISSN 2083-4527
TECHNICAL SCIENCES
Homepage: https://czasopisma.uwm.edu.pl/index.php/ts/



ISSN 1505-4675
Technical
Sciences

Biosystems Engineering
Chemical Engineering
Civil Engineering
Environmental Engineering
Geodesy and Cartography
Information Technology
Materials Engineering
Mechanical Engineering
Production Engineering

Wydawnictwo
Uniwersytetu Warmińsko-Mazurskiego
w Olsztynie

DOI: https://doi.org/10.31648/ts.6638

WASTE HEAT RECOVERY FROM SERVERS USING AN AIR TO WATER HEAT PUMP

***Seweryn Lipiński*[1], *Michał Duda*[2], *Dominik Górski*[3]**

[1]ORCID: 0000-0001-9771-6897
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn

[2]ORCID: 0000-0002-9174-3840
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn

[3]ORCID: 0000-0002-0812-9111
SKN EKO-ENERGIA
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn

Received 14 April 2021, accepted 31 August 2021, available online 1 September 2021.

Key words: air-water heat pump, server cooling, waste heat, heat recovery, domestic hot water.

Abstract

The analysis of advisability and profitability of using an air to water heat pump for the purpose of waste heat recovery from servers being used as cryptocurrency mining rigs, was performed. To carry out such an analysis, the cooling unit of the computing server was connected to the heat pump, and the entire system was adequately equipped with devices measuring parameters of the process. Performed experiments proves that the heat pump coefficient of performance (COP) reaches satisfactory values (i.e., an average of 4.21), what is the result of stable and high-temperature source of heat at the pump inlet (i.e., in the range of 29.9-34.1). Economic analysis shows a significant reduction in the cost of heating domestic hot water (by nearly 59-61%). The main conclusion which can be drawn from the paper, is that in a case of having a waste heat source in a form of a server or similar, it is advisable to consider the purchase of air-to-water heat pump for the purpose of domestic hot water heating.

Correspondence: Seweryn Lipiński, Katedra Elektrotechniki, Energetyki, Elektroniki i Automatyki, Wydział Nauk Technicznych, Uniwersytet Warmińsko-Mazurski, ul. Oczapowskiego 11, 10-719 Olsztyn, e-mail: seweryn.lipinski@uwm.edu.pl

Introduction

Currently, heat pumps are usually associated with the heating of single-family houses (Carroll et al. 2020, Martinopoulos et al. 2018), what is not surprising, considering both ecological (no harmful emissions given off locally in the process) and exploitation (almost maintenance-free, compared to other heat sources, and a small area of the boiler room) aspects (Lake et al. 2017, Ochsner 2012, Self et al. 2013). However, due to their high efficiency, as well as economical and ecological aspects, heat pumps are also increasingly used for other purposes, like e.g., supermarkets simultaneous heating and refrigeration (Salehi, Yari 2019) or assisting in distillation process (Yang et al. 2016). Schlosser et al. (2020) classifies 155 case studies of large-scale heat pumps to identify suitable characteristics that favour implementation. According to that review, utility water heating for cleaning purposes, process bath heating, drying, and thermal preservation processes, are identified as suitable processes that can be supplied with market-available heat pump technologies. Heat recovery, as stated above, is one of such applications, and quite big number of papers on the subject confirms that fact (Hu et al. 2017, Huang et al. 2017, Jouhara et al. 2018, Kosmadakis 2019, Singh et al. 2017, Xu et al. 2018). However, above cited papers on waste heat recovery technologies and applications focus mainly on big, particularly industrial use (Huang et al. 2017, Jouhara et al. 2018), like district heating (Hu et al. 2017, Xu et al. 2018), paper and pulp industry (Kosmadakis 2019) or dairy industry (Singh et al. 2017). Nevertheless, gradually falling prices of heat pumps, including low power ones, encourage attempts to use them also in non-standard and smaller-scale applications. For example, Adamkiewicz and Nikończuk (2019) analyse waste heat recovery from the air preparation room in a paint shop while Wang et al. (2017) propose kitchen exhaust air waste heat recovery.

Other example is using heat pumps for waste heat recovery from computing servers, which are being used in many applications, like e.g., calculations for scientific purposes (as a computing cluster), processing of large data packages, rendering graphic designs, working as a company server 24/7, and for cryptocurrency mining.

That is why the aim of this study is to check how the air-to-water heat pump will perform in the recovery of waste heat from server being used for the last of the above-listed purposes, i.e., as cryptocurrency excavator (mining rig), but it should be underlined that conclusions drawn from performed analysis are valid for each computing server, of course after considering its characteristics and parameters.

Literature review shows that however waste heat recovery for data centres and big computing servers is more and more popular on an industrial scale (Deymi-Dashtebayaz, Valipour-Namanlo 2019, Ebrahimi et al. 2014, ORÓ et al. 2017), awareness of this topic and possibilities resulting from it for the individual user is small. That is why we aim to contribute to this knowledge gap and to show new opportunities in the field of waste heat recovery on a small scale, i.e., by an individual, not an industrial user. For individual user, often the economic aspect is the most important, that is why we supplemented the study on heating efficiency with economic analysis of an investment in low-power heat pump for the investigated purpose.

Material and methods

As the waste heat source, the computing server Bitman Antminer D3 ver. 19.3 Gh with the cooling capacity of the server unit cooling system equal to 1.22 kW was used.

The analysis of the advisability of using a heat pump for waste heat recovery from server assumed that the heat is intended to be used for domestic hot water heating, because heating domestic hot water, unlike central heating systems, like computing servers, works all year round. That is why waste recovery was performed with the use of the heat pump intended for such purpose, i.e., 2 kW Basic 270 air-to-water heat pump, integrated with a 270-litre domestic hot water tank, produced by Galmet Sp. z o.o. This heat pump has total heating power (heat pump + 2 kW heater) equal to 4 kW and it allows to prepare domestic hot water for up to 4–5-person family (assuming the water consumption will amount to 50 l/person/day) with average power consumption equal to 0,49 kW and acoustic pressure at a distance of 2 meters equal to 46 dB.

The pump was installed according to the producer recommendations. Its air inlet was connected with the outlet of computing server cooling system using spiro pipe with the T-fitting allowing for compensating for the shortage of air for the heat pump resulting from the fact that the pump's air requirement is 313 m^3/h, while the excavator's cooling system delivers about 200 m^3/h. The second reason for using T-fitting is the fact that the heat input for heat pump should not and exceed 35°C, while the outlet temperature from the cooling system is about 40°C (value declared by the producer of the computing server, confirmed through measurement). Thanks to the use of a T-fitting, the temperature is reduced through mixing with cooler air from the room. It was confirmed experimentally that due to that mixing, the temperature supplied to the pump is within the operating temperature range specified by the manufacturer (i.e., it does not exceed 35°C).

Above-described configuration was equipped with measuring devices, allowing to measure temperatures on both air inlet and outlet (DS18B20 digital thermometers; ±0.5°C accuracy), as well as temperature and humidity inside the laboratory (DHT11 temperature and humidity sensor; resolution:

8-bit (±1% relative humidity), accuracy ±4 relative humidity (at 25°C)). Set up for the experiment and measurements is shown in Figure 1 while the scheme of the methodology used for the purpose of analysis presented in the article is shown in Figure 2.

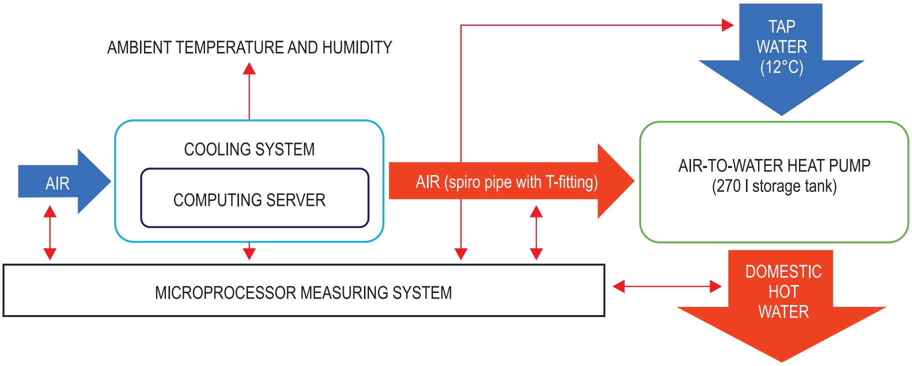
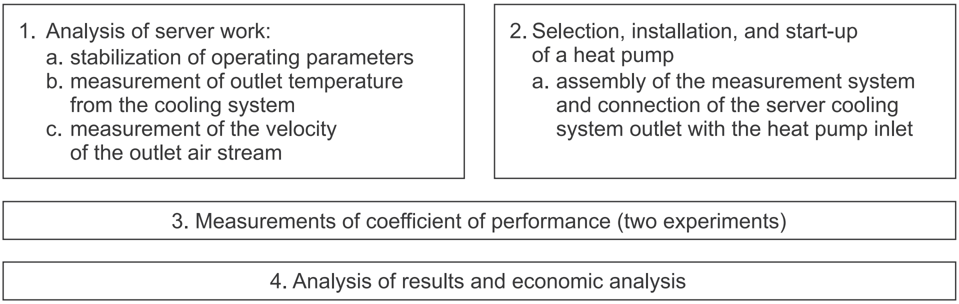


Fig. 1. Experiment/measurement set up



1. Analysis of server work:
   a. stabilization of operating parameters
   b. measurement of outlet temperature from the cooling system
   c. measurement of the velocity of the outlet air stream

2. Selection, installation, and start-up of a heat pump
   a. assembly of the measurement system and connection of the server cooling system outlet with the heat pump inlet

3. Measurements of coefficient of performance (two experiments)

4. Analysis of results and economic analysis

Fig. 2. Schematic of the methodology used for the analysis

Results and discussion

Heating efficiency

Crucial parameter that allows to evaluate heating efficiency for broadly understood cooling and heating devices (e.g., refrigerators, air conditioners, and of course heat pumps), is so-called COP (i.e., coefficient of performance) (Hundy et al. 2016). COP is a ratio of useful heating or cooling provided to work (energy) required. To calculate heating efficiency, given as COP, we used measured air temperatures and velocities at the heat pump inlet/outlet to calculate power that is drawn out of the heat pump as heat Q [kW], and the amount of electricity consumed by the pump compressor P [kW], obtained with the use of a universal electricity meter. Using these two values, we obtain $\mathrm{COP} = \frac{Q}{P}[-]$. As it was mentioned above, the temperature of air obtained from server cooling thanks to the use of the T-fitting, was being decreased from about 40°C to the range of 29.9-34.1, i.e., proper temperature at the heat pump inlet. Based on that data, and on the assumption that domestic hot water is heated to the temperature of 50°C while its initial temperature (i.e., tap water temperature) is equal to 12°C, we performed an experiment of heating the tap water to the expected final temperature. The experiment was performed twice. All key input parameters in COP measurements are given in Table 1. Parameters of heat pump, as well as parameters of computing server, are given above, in "Material and methods" section.

Table 1

Key input parameters in COP measurements

Ambient temperature/humidity	22.3°C/54%
Air temperature/humidity at the heat pump inlet	29.9-34.1°C/18.7%
Air velocity at the heat pump inlet	4.9 $\mathrm{m{\cdot}s^{-1}}$
Air duct diameter	0.12 m
Initial/final temperature of heated water	12°C/50°C

The results are shown in Figure 3, where COP is shown in a function of water temperature. Average COP for the entire heating cycle was equal to 4.21 which value in our opinion can be considered as satisfactory and in accordance with expected COP for air-to-water heat pump.

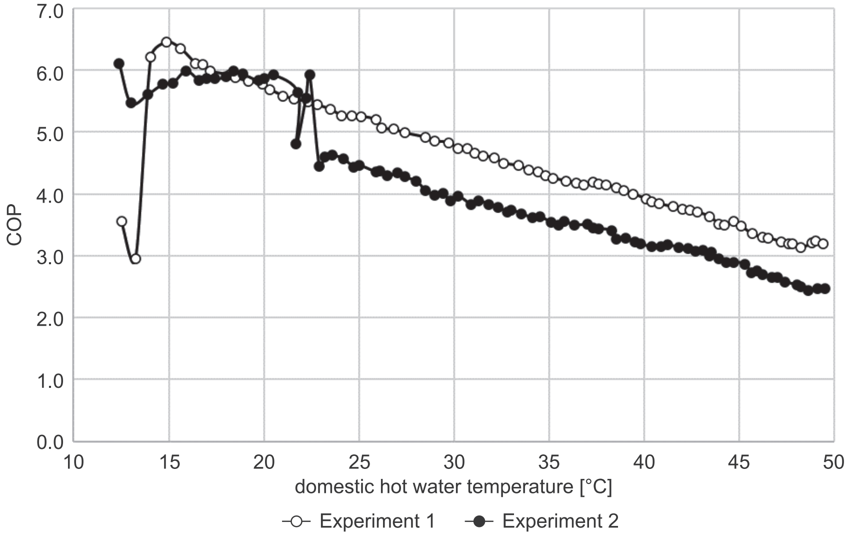


Fig. 3. The process of domestic hot water temperature heating obtained in two experiments shown as COP in a function of heated water temperature

Heating time obtained in both experiments was equal to 350 minutes, which is the result close to that given by the manufacturer of the pump (360 minutes).

Average energy consumption obtained in the heating cycle of 270 l of water was equal to 2.817 kWh, this result differs from the result obtained from the theoretical calculations (2.356 kWh), i.e., the difference is close to 20%.

Economic analysis

To determine the profitability of the investment, which is the purchase of the heat pump, the key factor is the electricity costs. The calculations adopted the average price for electricity from 2020, which was equal to 0.62 PLN/kWh (cena-pradu.pl).

The analysis below is based on a comparison of two cases – the first case is a situation when the heat pump is used conventionally – using atmospheric air; the second case is the use of waste heat. In the case of conventional use of heat pump, following assumptions were made:

– the pump works only in periods when the air temperature outside the building is higher than 7°C;

– when the air temperature drops below 7°C, the heating role is then taken over by an electric heater built into the tank with a rated power of 2 kW;

– the analysis was carried out for Poland – average daily temperatures from the last four years were collected from the nationwide meteorological database (dane.imgw.pl). Based on that data, the average numbers of days of pump operation during the year in particular ranges were determined.

The results of the economic analysis are shown in Table 2 – it is clearly noticeable that the use of waste heat significantly improves the profitability of heat pump purchase. The annual electricity demand/cost drops by 59%-61.5%. Since annual savings are equal to about 1,000 PLN, while the cost of used heat pump is equal to about 7,500 PLN, an economic stimulus is easily noticeable for a potential heat pump buyer with a waste heat source in a form of a server or similar.

Table 2

The comparison of electricity demand/cost of heat pump with and without using waste heat

Specification	Electricity demand [kWh/year]	Electricity cost [PLN/year]
Heat pump using atmospheric air	2,644.21	1,639.41
Heat pump using waste heat	1,054.03	653.50
Difference	1,590.18	985.92

Discussion and conclusions

Comparing the achieved results with those known from the literature on the subject, it should be stated that they are at least satisfactory. Obtained COP value, equal to 4.21, is close to 4.8 value obtained by Hu et al. (2017) in the process of industrial waste heat recovery and much higher than value of 1.77 obtained by Xu et al. (2018) in the process of waste heat recovery in power plant. Kosmadakis (2019) shows that if COP value is higher than 2.5, waste heat recovery is starting to make economic sense (case study of typical large-sized paper and pulp industry in Sweden). Considering small-scale applications, Adamkiewicz and Nikończuk (2019) in the simulation study of waste heat recovery from the air preparation room in a paint shop obtained COP in the range of 3-3.5. The above examples, as well as the economic analysis performed, prove that the proposed solution for waste heat recovery from computing server at small scale makes practical and economic sense.

Summarizing, following conclusions can be drawn based on the performed experiment and analysis:

– the use of untypical heat sources for heat pumps, especially considering the declining prices of heat pumps, is advisable in terms of both economy and ecology;

– large and stable temperature difference between the heat source and tap water positively influences the value of the obtained COP – this difference results in the reduction of electricity consumption and so, quick return on investment in a heat pump (about 50% faster than in a case of using such pump in a conventional way);

– average COP in daily intended use would be obviously better in case of lowering expected domestic hot water temperature, which is a factor that can be influenced by the user;

– the recovered heat can also be used for other purposes (e.g., space heating), but the assumption of the analysis was to choose the method of its utilisation according to the source, i.e., as the computing server is assumed to operate all year round, then heat should also be used year-round as well;

– an additional positive aspect is the utilization of cooled air (pump outlet) at the inlet of the server cooling system – in this configuration, the temperature of the computing server is reduced by about 5°C, which is beneficial for the server's operation (Lall et al. 1997), and, thanks to the slower work of the fans, helps to reduce noise.

Acknowledgements

The authors acknowledge support from Galmet Sp. z o.o. – one of the elements of the agreement on teaching and research cooperation is making its products available for research conducted by students and scientists.
The authors also want to thank Michał Stryjewski and Dominik Zwierzychowski for their help and support for the project, i.a. by providing the computing servers used in the experiment.

References

Adamkiewicz A., Nikończuk P. 2019. *Waste heat recovery from the air preparation room in a paint shop*. Archives of Thermodynamics, 40(3): 229-241.

Carroll P., Chesser M., Lyons P. 2020. *Air Source Heat Pumps field studies: A systematic literature review*. Renewable and Sustainable Energy Reviews, 134: 110275.

Cena prądu. http://www.cena-pradu.pl/ (access: 31.12.2020).

Deymi-Dashtebayaz M., Valipour-Namanlo S. 2019. *Thermoeconomic and environmental feasibility of waste heat recovery of a data center using air source heat pump*. Journal of Cleaner Production, 219: 117-126.

Ebrahimi K., Jones G.F., Fleischer A.S. 2014. *A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities*. Renewable and Sustainable Energy Reviews, 31: 622-638.

Hu B., Liu H., Wang R.Z., Li H., Zhang Z., Wang S. 2017. *A high-efficient centrifugal heat pump with industrial waste heat recovery for district heating*. Applied Thermal Engineering, 125: 359-365.

Huang F., Zheng J., Baleynaud J.M., Lu J. 2017. *Heat recovery potentials and technologies in industrial zones*. Journal of the Energy Institute, 90(6): 951-961.

Hundy G.F., Trott A.R., Welch T.C. 2016. *Refrigeration, Air Conditioning and Heat Pumps*. Butterworth-Heinemann, Oxford.

Instytut Meteorologii i Gospodarki Wodnej. Dane publiczne IMGW-PIB. https://dane.imgw.pl/ (access: 15.01.2021).

Jouhara H., Khordehgah N., Almahmoud S., Delpech B., Chauhan A., Tassou S.A. 2018. *Waste heat recovery technologies and applications*. Thermal Science and Engineering Progress, 6: 268-289.

Kosmadakis G. 2019. *Estimating the potential of industrial (high-temperature) heat pumps for exploiting waste heat in EU industries*. Applied Thermal Engineering, 156: 287-298.

Lake A., Rezaie B., Beyerlein S. 2017. *Review of district heating and cooling systems for a sustainable future*. Renewable and Sustainable Energy Reviews, 67: 417-425.

Lall P., Pecht M., Hakim E.B. 1997. *Influence of Temperature on Microelectronics and System Reliability: A Physics of Failure Approach*. CRC Press, New York.

Martinopoulos G., Papakostas K.T., Papadopoulos A.M. 2018. *A comparative review of heating systems in EU countries, based on efficiency and fuel cost*. Renewable and Sustainable Energy Reviews, 90: 687-699.

Ochsner K. 2012. *Geothermal heat pumps: a guide for planning and installing*. Routledge, London.

Oró E., Taddeo P., Salom J. 2019. *Waste heat recovery from urban air cooled data centres to increase energy efficiency of district heating networks*. Sustainable Cities and Society, 45: 522-542.

Salehi S., Yari M. 2019. *Exergoeconomic assessment of two novel absorption-ejection heat pumps for the purposes of supermarkets simultaneous heating and refrigeration using* $NaSCN/NH_3$, $LiNO_3/NH_3$ *and* H_2O/NH_3 *as working pairs*. International Journal of Refrigeration, 101: 178-195.

SCHLOSSER F., JESPER M., VOGELSANG J., WALMSLEY T.G., ARPAGAUS C., HESSELBACH J. 2020. *Large-scale heat pumps: Applications, performance, economic feasibility and industrial integration*. Renewable and Sustainable Energy Reviews, 133: 110219.

SELF S.J., REDDY B.V., ROSEN M.A. 2013. *Geothermal heat pump systems: Status review and comparison with other heating options*. Applied Energy, 101: 341-348.

SINGH S., DASGUPTA M.S. 2017. *CO_2 heat pump for waste heat recovery and utilization in dairy industry with ammonia based refrigeration*. International Journal of Refrigeration, 78: 108-120.

WANG K., LI N., PENG J., WANG X., WANG C., WANG M. 2017. *A highly efficient solution for thermal compensation of ground-coupled heat pump systems and waste heat recovery of kitchen exhaust air*. Energy and Buildings, 138: 499-513.

XU Z.Y., MAO H.C., LIU D.S., WANG R.Z. 2018. *Waste heat recovery of power plant with large scale serial absorption heat pumps*. Energy, 165: 1097-1105.

YANG M., XIAO F., GUILIAN L. 2016. *Heat integration of heat pump assisted distillation into the overall process*. Applied Energy, 162: 1-10.