CHEMICAL ENGINEERING TRANSACTIONS
VOL. 89, 2021
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-87-7; **ISSN** 2283-9216
DOI: 10.3303/CET2189009

Solar Assisted Heat Pump Application in the Automotive Manufacturing Industry

Ku Mohamad Afiq Ku Arshad[a], Wai Shin Ho[b,*], Umi Aisah Asli[c], Zarina Ab Muis[b], Haslenda Hashim[b]

[a] School of Chemical and Energy Engineering (SCEE), Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[b] Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment, School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c] Innovation Center in Agritechnology for Advanced Bioprocessing, School of Chemical and Renewable Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.
hwshin@utm.my

In an automotive industry, high thermal energy demand is required mainly due to processes in the Paint Shop which leads to high energy utilization. In order to improve energy efficiency, automotive industry is now looking into the application of Solar Assisted Heat Pump (SAHP). SAHP is identified as a suitable technology and, as it produces energy from solar, can save up in energy cost to operate the heat pump in a long term. This research specifically looks into the painting section of the industry focusing on DIP Phosphating and Electrodeposition process as it consumed the most thermal energy compared to the other processes. The potential cost-saving and payback period are identified through scenario analysis involving Scenario 1 (Existing system), Scenario 2 (Heat Pump), Scenario 3 (Solar Thermal + Heat Pump), and Scenario 4 (Solar Photovoltaic + Heat Pump). Based on the analysis, it is concluded that Scenario 4 resulted in the highest potential cost-saving of MYR 73,988. As for the shortest payback period, it is achieved by Scenario 2 with a payback period of only 3.5 y.

1. Introduction

Automotive manufacturing processes requires thermal energy either in the low-temperature range (60 – 100 °C) or medium temperature range (100 – 200 °C). These are suitable for integration with solar thermal technologies to provide industrial heat (Uppal et al., 2016). By amassing heat from a cooler environment and relinquishing it to a warmer one, heat pumps are designated to convey thermal energy in the reverse direction of spontaneous heat flow. Heat pumps are extensively useful in heating and cooling systems and may considerably cut energy expenses. Because it requires some external energy such as electricity to run the mechanical compressor to operate the inverse Rankine cycle, "heat" is not saved in this operation (Gagneja and Pundhir, 2016). For automotive industries, cooling and washing are some of the identified thermal processes by which a series of heat pump integrations in that sector (Schlosser et al., 2020) may recover some low-grade waste heat from the cooling processes. By recovering waste heat, the heat pump can fulfil the targeted demand of the industrial heating process (Hoffman, 2018) and many studies were conducted on industrial waste heat utilization (Liew and Walmsley, 2016) in various industries using heat pumps (Deymi and Valipour, 2019). For the integration of solar energy and heat pump technology, it has been shown in recent decades that it is able to achieve continuous improvement in energy efficiency while lowering the cost of heat pumps. This technology is called Solar Assisted Heat Pump (SAHP)(Badiei et al., 2020). The solar integration has been carried out both with thermal and electrical technologies. For integration of heat pump with solar thermal technology, solar thermal collectors convert solar energy into thermal energy by heating up water turning it into hot water or even steam. The heated water is then used to warm the side of the circuit of the heat pump to act as cold side which enabling the heat pump to work efficiently with a lower temperature gap. Integration with solar photovoltaic is simpler in the sense that the solar panels will generate electricity using solar energy where the electricity will be directly utilize to operate mechanical compressor of the heat pump reducing electricity consumption from the power

Paper Received: 31 May 2021; Revised: 28 August 2021; Accepted: 16 November 2021
Please cite this article as: Ku Arshad K.M.A., Ho W.S., Asli U.A., Ab Muis Z., Hashim H., 2021, Solar Assisted Heat Pump Application in the Automotive Manufacturing Industry, Chemical Engineering Transactions, 89, 49-54 DOI:10.3303/CET2189009

grid. Solar technology has gained attention has gained attention through recent price reduction and is a viable option for use with heat pumps (Andersson et al., 2018). The currently available application of solar assisted heat pump in automotive industry is only for the electric vehicle segment, with low integration rate in the automotive manufacturing industry which usually meets their thermal demand from LPG-based boilers. This study aims to conduct a scenario analysis from the integration of the above-mentioned waste heat recovery heat pump along with solar thermal or solar photovoltaic system by comparing of their potential cost-saving towards the application in the automotive manufacturing industry. The associated research method and main results of these systems integration are subsequently analysed below.

2. Methodology

The system evaluation is conducted as comparison study based on best market-available technologies. The technologies considered in this scenario analysis are the integration of waste-heat recovery heat pump and indirect use of solar energy through solar thermal or solar photovoltaic integration with the heat pump itself. The factors used to compare are potential cost saving and payback period. The generated heat from the heat pump is used for industrial hot water preparation in a local automotive manufacturing industry that will be explained in the case study.

2.1 Case study

In Paint Shop, there are multiple processes which are Pre-washing, Degreasing, Raw water rinsing, Dissolved Inorganic Phosphate (DIP) chemical treatment, Deionized (DI) Water Rinsing, Electrodeposition (ED), and Ultrafiltration (UF). Degreasing and DIP chemical treatment requires stable and continuous thermal energy supply in order to main the process in between 40 °C to 50 °C, at which the heat required for hot water is generated by LPG Fire tube boiler before exchanging at existing plate heat exchanger for the system. Figure 1 shows the process for the case study in Paint Shop. The current LPG consumption is at 31,065 kg/y or 1,689 kWh/d, at which contributes 130,473 MYR/y to the total energy bill specifically for this process. This is considering current energy price is at 4.2 MYR/kg (ST, 2014) for LPG. For the second process known as Electrodeposition (ED) process, it requires the temperature of the water to be maintain at 27 °C to 29 °C throughout the process. In order to fulfil this requirement, a set of chiller system is currently used to supply cool water with the electricity usage for this purpose is at 1,098 kWh/d, which contributes MYR 98,856/y to the total energy bill when the electrical tariff is at 0.36 MYR /kWh (TNB, 2014). The total utility cost to run these processes is about 216,903 MYR/y. The annual operating hour for both processes is at 6,000 h/y.

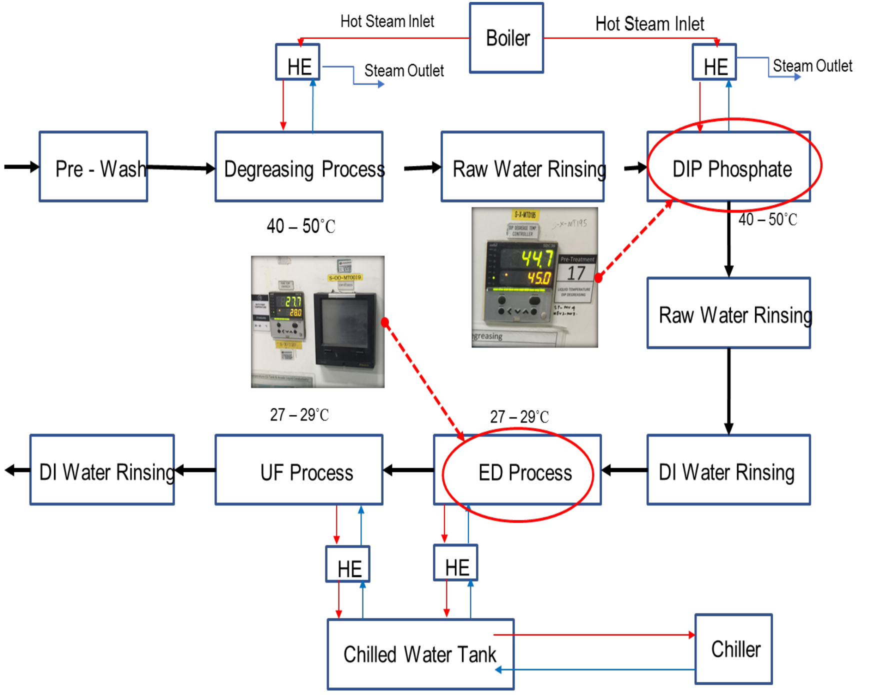

Figure 1: Targeted process in paint shop for integration of solar assisted heat pump.

2.2 System configurations for comparison

Figure 2a represents the existing system of the case study at which conventional boiler and chiller is used to fulfil the Phosphate and ED processes' thermal requirement. The following figures shows four different system configurations that will be compared to assess cost saving potential in this study. In Figure 2b, only recovered waste heat from ED process. For Figure 2c and 2d, solar thermal and photovoltaic are used to reduce energy required by heat pump to recover the targeted amount of waste energy.

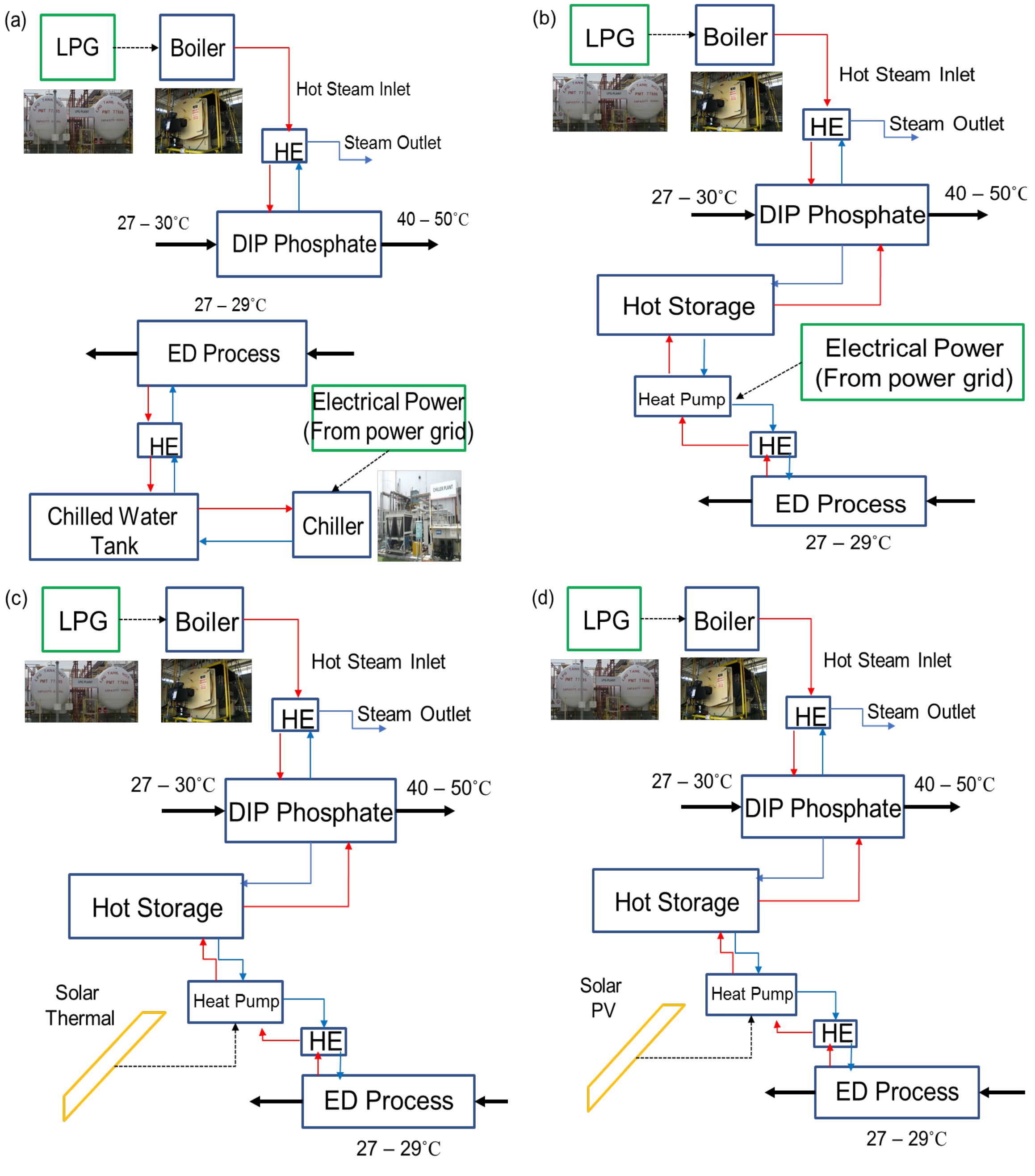

Figure 2: (a) Existing System, (b) Heat Pump, (c) ST + Heat Pump and (d) PV + Heat Pump

Because of the current situation, whereby heat released from the ED process cannot be effectively utilized, a waste heat recovery system that can utilize an absorption heat pump to recover waste heat from the ED process is proposed. The heat pump in the waste heat recovery system will absorb the low-grade waste heat from the ED process and heat the return water of the heating network from the hot storage. For hot storage, it is assumed to be constant at all available system configurations as this study focuses on the area before entering hot storage only.

Table 1: Proposed new system configurations

Figure	Descriptions
2a (Existing System)	Scenario 2a - LPG Based - Boiler is used to supply hot steam for Phosphate process and Chiller is used to supply chilled water for ED process
2b (Heat Pump)	Scenario 2b - Heat pump is integrated in the process at which the heat source is from ED process and heat sink is at Phosphate process. Electrical power from the grid is supplied to operate the heat. COP for heat pump is 2.5, with 439.2 kWh/d of electrical energy consumption (Mateu et al., 2019). Typical heat pump (non-heat recovery) consumes 490.2 kW/d, which equivalent to 2.22kWh saved for each 1°C increase.
2c (ST + Heat Pump)	Scenario 2c - Solar Thermal is integrated to assist the internal heating of the heat pump in 2(b) which targets to reduce the electricity consumption to operate the heat pump. COP for this SAHP is 2.9, with 378.6 kWh/d of electrical energy consumption (Wang et al., 2020).
2d (PV + Heat Pump)	Scenario 2d - Solar Photovoltaic is integrated to assist the heat pump by directly supplying electricity for heat pump operation which reduces the electricity consumption required from the power grid in 2(b). COP for this SAHP is 3.75, with 292.8 kWh/d of electricity consumption (Wang et al., 2020).

2.3 Applied equations and parameter data sets

In the case of heat pumps, a metric called the Heat Pump Co-efficient of Performance may be used to determine the connection between work input, temperature lift, and heat output (COP_{HP}) (US DOE, 2009).

$$\text{Co} - \text{efficient of Performance}\ ,\text{COP}_{\text{HP}} = \frac{Q_{out}}{W_{in}} \tag{1}$$

where Q_{out} represents the quantity of heat distributed by the heat pump and W_{in} represents the magnitude of energy or "effort" given to the driver. For cost saving of new system, total current energy cost is subtracted from total operating cost required as per Eq(2) :

$$\text{Cost Saving} = \text{Total Current Energy Cost} - \text{Total Operating Cost Required (New System)} \tag{2}$$

Total cost saving by new system are in MYR/y. By assuming the heat pump for Scenario 2b, 2c, and 2d is able to fully recover the waste heat from ED process, the work required, or electricity load are obtained. Solar thermal and solar photovoltaic panel are assumed to utilize the available rooftop area with collector field of 100 m². In term of identifying the payback period for the new system integrations, Eq(3) below is used.

$$\text{Payback Period (PP)} = \frac{\text{Capital cost of the project}}{\text{Cost Saving}} \tag{3}$$

Table 2 below is the estimated capital cost for waste-heat recovery heat pump (US DOE, 2009). Solar thermal or solar photovoltaic capital cost (Bany et al., 2019) are also listed below.

Table 2: Estimated capital cost of solar technologies and heat pump system

System type	MYR/m²	MYR/kWh
Solar Thermal	2, 148.41	-
Solar Photovoltaic	1, 912.00	-
Heat Pump	-	188.90

Average daily yield for solar photovoltaic is at 0.163 kWh_{th}/m^2 and solar thermal is at 0.410 kWh_{el}/m^2 (Eva, 2017). In this study, the available rooftop area for solar collector installation is at 100 m² with 24 h and 250 working days. The chiller load at 1,098 kWh is assumed to be fully recovered for heat pump operation. The total electricity required is obtained after considering the electricity load required to operate solar thermal and solar photovoltaic and the price of electricity is 0.36 MYR/kWh (TNB, 2014). Electricity cost to operate the heat pump after solar thermal or photovoltaic integration is shown in Eq(4).

$$\begin{aligned}\text{Total Electricity load required (kWh)} &= \text{Electricity load required} - (100\ \text{m}^2 \times \text{Daily Solar Yield}) + \\ &\quad \text{Electricity load to operate solar technology}\end{aligned} \tag{4}$$

For the total annual operating cost of the new system, boiler load cost is added with the total electricity load cost to operate the heat pump, solar thermal system (for scenario 2c) and the chiller, as per in Eq(5) :

$$\text{Total Operating Cost Required} = \text{Boiler load cost (MYR/y)} + \text{Total electricity load cost (MYR/y)} \qquad (5)$$

3. Result and discussion

From an economic standpoint, comparisons of these various heat pump systems from Scenario 2a to 2d were made in this section. From the calculated data in Table 3, it is clearly shown that the highest total electricity load is from Scenario 2b, at which only Waste Heat Recovery-Heat pump is used to recovered waste heat for the system compare to other scenarios that has additional source of energy from renewable energy such as solar thermal or solar photovoltaic.

Table 3: Energy and cost saving from new system integration.

	Unit	Scenario 2a (Existing)	Scenario 2b (HP)	Scenario 2c (ST+HP)	Scenario 2d (PV+HP)
Boiler Load Required	kW	70.37	70.37	70.37	70.37
Boiler Load Cost Required	MYR/y	130,473	130,473	130,473	130,473
Chiller Load Required	kW	45.75	-	-	-
Chiller Load Recovered	kW	-	-45.75	-45.75	-45.75
Chiller Load Cost Recovered	MYR/y	-	94,867	94,867	94,867
Chiller Load Cost Required	MYR/y	94, 867	-	-	-
Electricity Load Required, W_{in}	kW	-	18.30	15.78	12.20
Electricity Load Cost Required	MYR/y	-	39,528	37,765	27,819
Total Electricity Load Cost	MYR/y	-	39,528	34,075	26,352
Total Current Energy Cost	MYR/y	229, 329	-	-	-
Total Operating Cost Required (New System)	MYR/y	-	168,419	160,853	155,340

As shown in Table 4, Scenario 2b achieved the lowest total project capital cost as heat pump is relatively cheaper than solar thermal system or solar photovoltaic system. This leads to a lower payback period as a payback period of 3.5 years is required for Scenario 2b. After integration with solar thermal system (Scenario 2c), the capital cost increases and the payback period increases to 6.5 y. This is due to fact that solar thermal technology is more expensive. In term of energy efficiency, integration of solar thermal reduces the electricity required to operate the heat pump and as solar thermal has a high efficiency it could reduce the energy requirement to operate the heat pump by 11 % of the electricity load. Solar photovoltaic (Scenario 2b) as it is cheaper, has a lower total capital cost compared to solar thermal assisted heat pump. The payback period for this Scenario 2d is 5.5 years and managed to reduce the electricity load of the heat pump by 6 %.

Table 4: Payback Period summary from new system integration.

	Unit	Scenario 2a (Existing)	Scenario 2b (HP)	Scenario 2c (ST+HP)	Scenario 2d (PV+HP)
Total Capital Cost	MYR	-	207,500	422,300	398,700
Cost Savings	MYR	-	59,328	68,780	72,504
Payback Period	y	-	3.5	6.5	5.5

4. Conclusions

The case study shows that solar photovoltaic assisted heat pump integration is the perspective of economy is more preferable to solar thermal assisted heat pump. However, in the case of maximize energy efficiency, solar thermal assisted heat pump would be a better option. Both Scenario when integrated with renewable energy will lead to a longer payback period compared to the stand-alone heat pump system without integration. As energy sustainability should be prioritized integration with solar technology should be considered by the industry. As a recommendation for future work, a more detailed optimization study will be conducted and an optimization model will be modelled to assist in identifying the optimal configuration and selection between solar thermal or solar photovoltaic assisted heat pump.

Acknowledgments

The authors would like to thank Universiti Teknologi Malaysia (UTM) for financial support under the grants Q.J130000.3051.02M03 and Q.J130000.2851.00L51.

References

Andersson M., 2018, Comparison of solar thermal and photovoltaic assisted heat pumps for multi-family houses in Sweden: Dissertation, KTH Royal Institute of Technology, Stockholm, Sweden.

Badiei A., Golizadeh A., Zhao Y., Shittu X., Xiao S., Li X., Fan Y., Li G., 2020, A Chronological review of advances in solar assisted heat pump technology in 21st century, Renewable and Sustainable Energy Reviews, 132, 110132.

Bany O., Taylor R., Shirazi A., 2019, Multi-objective optimization of solar photovoltaic and solar thermal collectors for industrial rooftop applications, Energy Conversion and Management, 195, 392-408.

Deymi M., Valipour 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.

Gagneja A., Pundhir S., 2016, Heat pump and its applications, International Journal of Advances in Chemical Engineering and Biological Sciences, 3, 117–120.

Hoffman K., 2018, Large Scale Heat Pumps for High Efficiency District Heating Projects, Institute of Refrigeration (IOR), Manchester, UK.

Liew P., Walmsley T., 2016, Heat pump integration for total site waste heat recovery, Chemical Engineering Transactions, 52, 817-822.

Mateu C., Mota A., Navarro J., Peris B., Molés F., Amat M., 2019, Multi-objective optimization of a novel reversible high-temperature heat pump-organic rankine cycle for industrial low-grade waste heat recovery, Energy Conversion and Management, 197, 111908.

Poppi S., 2017, Solar heat pump systems for heating applications: Analysis of system performance and possible solutions for improving system performance: Dissertation, KTH Royal Institute of Technology, Stockholm, Sweden.

Qu M., Abdelaziz O., Yin H., 2014, New configurations of a heat recovery absorption heat pump integrated with a natural gas boiler for boiler efficiency improvement, Energy Conversion and Management, 87**,** 175-184.

Schlosser F., Jesper M., Vogelsang J., Walmsley G., Arpagaus C., Hesselbach J., 2020, Large-scale heat pumps: applications, performance, economic feasibility and industrial integration, Renewable and Sustainable Energy Reviews, 133, 110219.

Eva A., 2017, SolarThermalWorld.org <www.solarthermalworld.org/news/solar-thermal-shows-highest-energy-yield-square-metre > accessed 21.10.2021.

ST (Suruhanjaya Tenaga), 2014, Pipe Gas Distribution Industry Statistics - LPG Prices in the Peninsula for the year 2014, <www.st.gov.my/en/contents/publications/statistic_gas/2014> accessed 10.06.2021.

TNB (Tenaga Nasional Berhad), 2014, Tariff E2 - Medium Voltage Peak/Off-Peak Industrial Tariff (For all kWh during the peak period), <www.tnb.com.my/commercial-industrial/pricing-tariffs1> accessed 10.06.2021.

Uppal A., Kesari P., Zunaid M., 2016, Designing of solar process heating system for Indian automobile industry, International Journal of Renewable Energy Research, 6, 1627-1636.

US DoE, 2009, US Department of Energy, Industrial Heat Pumps for Steam and Fuel Savings, <www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf> accessed 10.06.2021.

US DoE, 2020, US Department of Energy, Solar Energies Technology Offices, Sunshot2030 <www.energy.gov/eere/solar/sunshot-2030> accessed 23.10.2021.

Wang X., Xia L., Bales C., Zhang X., Copertaro B., Pan S., Wu J., 2020, A systematic review of recent air source heat pump systems assisted by solar thermal, photovoltaic and photovoltaic/thermal sources, Renewable Energy, 146, 2472-2487.