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Waste Heat Recovery by Electric Heat Pump from Exhausted Ventilating Air for Domestic Hot Water in Multi-Family Residential Buildings

*Wojciech Cepiński, Piotr Kowalski, Paweł Szałański**

Wroclaw University of Science and Technology, Poland

**corresponding author's e-mail: pawel.szalanski@pwr.edu.pl*

1. Introduction

Research on waste heat recovery concerns many branches and is carried out in a wide range of subjects. Waste heat recovery is used, for example, in data centres (Luo et al. 2019) industrial installations (Hys & Wiak 2013) and in heating equipment from flue gases (Dudkiewicz & Fidorów-Kaprawy 2017, Dudkiewicz & Szałański 2019).

A specific type of waste heat recovery is the heat recovery from exhaust air in ventilation systems. This is a particularly important issue, because any building in which people occupy cannot be operated without ventilation, heating and increasingly often without cooling of the air. Air heating process requires a significant amount of energy and it is important to recover it as much as possible. Therefore, heat recovery in ventilation is the current subject of research (Jaber & Ezzat 2017, Jafarinejad et al. 2019, Kang et al. 2010, Mahajan et al. 2017, O'connor et al. 2016, Wang et al. 2016).

In Poland, heat recovery in ventilation systems has been the basis for changes in regulations and the method of reducing heating needs and operating costs of buildings for over a dozen years. Since 2002, heat recovery has been required by regulations in supply and exhaust ventilation systems with a capacity of at least 10 000 m^3/h (Dz.U. 2002 nr 75 poz. 690 2012). Then, by regulation (Dz.U. nr 201 poz. 1238 2008), of 2008, the regulation was made stricter and in mechanical supply and exhaust ventilation or comfort air conditioning systems with a capacity of 2,000 m^3/h and more, it became mandatory to use heat recovery devices for extract air (where possible – hygienic and air purity reasons) with an efficiency of at least 50%. Further changes were introduced by Regulation (Dz.U.

2013 poz. 926 2013) of 2013. The value of the above mentioned capacity was changed to 500 m^3/h.

It is worth emphasizing, that the requirements of the regulations do not apply to natural and mechanical exhaust ventilation systems. Similarly, most of the above mentioned publications on heat recovery in ventilation installations do not apply to such systems. In these systems, all the warm exhaust air is discharged into the atmosphere and is a significant residual of the waste heat potential.

Natural and mechanical exhaust ventilation systems are characteristic for multi-family residential buildings, which are a very important part of the Polish housing market. According to the National Census of Population and Housing 2011 (GUS 2011), there were over 530,000 multi-family buildings in Poland and 42.5% of all citizens living in them, of which almost 80% were located in buildings with 10 or more flats. In the European Union, about 42% of the population live in multi-family buildings, as reported by Eurostat (EUROSTAT 2019).

Waste heat recovery from exhaust air in extract air ventilation systems is technically difficult. In mechanical supply and extract ventilation systems, heat recovery is achieved by transferring heat from exhaust air to outdoor air in the heat exchanger in air handling unit through which both streams flow without the mixing of these streams. In exhaust ventilation systems, such a recovery of heat is not possible due to the multipoint inflow of outdoor air into the building through the supply air vents located in the building envelope. Because of the relatively low exhaust air temperature (about 20-24°C), direct use of this heat for building or domestic hot water heating is not is not technically feasible. In a building heating system, the water inlet temperature may range from 30°C to 80°C, and in a DHW system, the need for heating is from 10°C to 60°C.

A heat pump can be used to utilize low-temperature waste heat because it is a device which, with the cost of an additional portion of energy, allows to raise the temperature level of the recovered heat. Heat pumps have various applications. For example, to recover heat from extracted air from the kitchen, for heating of natural gas (Englart et al. 2019), in combined use with phase change materials (Pardiñas et al. 2017), in heat recovery systems from grey water (Liu et al. 2014), for water tempering in pools (Géczi et al. 2014), for thermal water preparation for fish technological processes (Suslov et al. 2015) and for additional heat recovery in a supply and extract mechanical ventilation systems (Pisarev et al. 2016).

In the literature, the topic of heat pumps is often discussed, developed and dealt with in various ways. The papers (Kowalski & Szałański 2019, Naldi, Dongellini, & Morini 2015, Dongellini, Naldi, & Morini 2015) present the influence of the climate of various cities on the results of calculations of seasonal energy performance of air heat pumps. The paper (Bohdal et al. 2015) concerns the technical, legislation and ecological aspects of the use of compressor heat pumps with particular consideration of the possibility of eliminating certain refrigerants. In (Dolna & Mikielewicz 2017) CFD analysis of the field type ground heat exchanger and its influence on the compressor heat pump performance was presented.

The authors propose the use of a heat pump to recover heat from the extract air as a potentially very beneficial option, as the lower heat source can be air with a constant and favourable high temperature value. The above was confirmed by examples from the literature review. If an air heat pump with exhaust air as the lower heat source is used, the efficiency of the air heat pump will be significantly higher than in the case of standard operation with outdoor air as the lower heat source (Cepiński & Szałański 2019). Therefore, the further part of the article presents an analysis of the use of air-to-water heat pump type to recover waste heat from the exhaust air from the exhaust ventilation system in a typical multi-family residential building and the use of this heat for the purposes of DHW and the impact of this solution on the energy performance of this building.

2. Requirements for buildings energy performance

On the basis of the EU Directive 2002/91/EC of 16 December 2002 on the energy performance of buildings (Directive 2002/91/EC 2002), in 2008, Polish legislation introduced the concept of energy performance and EP indicator for annual non-renewable primary energy demand for heating, ventilation, cooling, DHW preparation and lighting (Dz.U. 2007 nr 191 poz. 1373 2007; Dz.U. 2015 poz. 376 2015). Moreover, also in 2008, the regulation (Dz.U. nr 201 poz. 1238 2008) gave the method of determining the maximum permissible EP of a building. In May 2010, The European Parliament and The Council adopted the revised Directive "Energy Performance of Buildings" (Directive 2010/31/EU 2010), which further strengthened the requirements in this field. And in 2013, the Regulation (Dz.U. 2013 poz. 926 2013) introduced a gradual increase in EP requirements. The maximum EP limit values were stated as in force from the beginning of 2014, then from the beginning of 2017 and from the beginning of 2021. In 2017 (Dz.U. 2017 poz. 2285 2017), the date of application of the most strict future requirements was finally changed by one day - from the beginning of 2021 to the end of 2020.

The annual non-renewable primary energy demand EP [kWh/($m^2 \cdot a$)] is sum of the components for: heating and ventilation EP_H, domestic hot water (DHW) EP_W, cooling EP_C, lighting EP_L – except residential buildings.

The current values of components of maximum EP for different types of buildings are given in (Dz.U. 2017 poz. 2285 2017). Exemplary values for residential buildings are cited in Table 1. A specific type of waste heat recovery is the heat recovery from exhaust air in ventilation systems. This is a particularly important issue, because any building in which people occupy can not be operated without ventilation, heat

Table 1. Values of maximum EP components, kWh/(m^2·a) (Dz.U. 2017 poz. 2285 2017)

	from 1st January 2017			from 31st December 2020		
	EP_{H+W}	ΔEP_C	ΔEP_L	EP_{H+W}	ΔEP_C	ΔEP_L
Single-family residential building	95	$10 \cdot A_{f,C}/A_f$	–	75	$5 \cdot A_{f,C}/A_f$	–
Multi-family residential building	85			65		

A_f – floor area of rooms with controlled air temperature (heated or cooled), m^2
$A_{f,C}$ – floor area of rooms with controlled air temperature (cooled), m^2
If the building does not have a cooling system, then $\Delta EP_C = 0$ kWh/(m^2·a).

In common residential buildings without cooling the energy performance depends on the non-renewable primary energy demand for heating, ventilation and for domestic hot water (DHW) preparation. According to (Dz.U. 2015 poz. 376 2015) the energy demand for heating and ventilation and the energy demand for DHW are calculated separately. To determine these values, the energy need is first calculated for the particular purpose. The efficiency of the particular installation is then taken into account to determine the final energy. Besides the final energy, the energy required to drive auxiliary devices such as fans, pumps and automatic control systems is also calculated. The results of final energy Q_k and auxiliary energy E_{pom} by the appropriate values of the non-renewable primary energy factor w_i. These values depend on the type of energy that covers the particular needs (for example: for grid electricity $w_i = 3.0$; for natural gas $w_i = 1.1$; for cogeneration district heating $w_i = 0.8$ (Dz.U. 2015 poz. 376 2015)). Finally, the non-renewable primary energy Q_p can be determined from the formula below:

$$Q_P = Q_k \cdot w_i + E_{pom} \cdot w_i \tag{1}$$

Non-renewable primary factor EP is calculated as:

$$\mathrm{EP} = \frac{Q_p}{A_f} \tag{2}$$

Final energy factor EK is calculated as:

$$\mathrm{EK} = \frac{Q_k}{A_f} \tag{3}$$

The final energy for heating and ventilation depends on the insulation of the building envelope, on glazing, on type and efficiency of heating system and on type of ventilation system. The final energy for DHW purposes depends on type of a building (residential, public, etc.) and on type and efficiency of DHW preparation system.

Current and future requirements presented in Table 1 are so high that when designing new multi-family residential buildings, despite proper insulation of the building envelope and application of energy-saving installation solutions, their fulfilment without the use of renewable energy sources (e.g. solar collectors for domestic hot water) or other unconventional solutions is often impossible.

The research on energy efficiency is still up to date. A study (Alzoubi & Malkawi 2019) showed that old vernacular buildings built in Jordan are better than modern traditional buildings in relation to energy performance. The paper (Stolarska 2019) describes the positive influence of a winter garden on the energy performance of a single-family building designed in a passive standard. There is also up to date topic of proper computation of energy performance of a building (Pasichnyi et al. 2019). Publication (Kowalski & Szałański 2018) presents the influence of the method of testing the airtightness of the whole building envelope and its particular zones on the result of energy performance calculations. Article (Kowalski & Szałański 2017) shows a comparison of the computational and actual energy performance of an exemplary single-family building.

Considering the high demand for new solutions improving the energy performance of buildings, this article shows the analysis of the heat recovery system of waste heat from exhaust air via a heat pump for DHW purposes.

3. Energy potential for heat recovery from exhaust air

The air exchange in the building is a must. According to the Polish standard (PN-B-03430:1983 1983), the minimum required exhaust air flow rates are, for example: for kitchens from 30 m^3/h to 70 m^3/h (depending on the number of occupants and type of oven), for bathrooms 50 m^3/h, for separate toilets 30 m^3/h, and for windowless auxiliary rooms 15 m^3/h. Consequently, for typical flats, the total minimum exhaust air flow rate may range from 80 m^3/h to 150 m^3/h. In exhaust systems, both natural stack ventilation and mechanical extract ventilation, the exhaust flow must be compensated for by external supply air. This air must be heated in the room to the indoor temperature required by the regulations and then is removed to the outside after assimilation of pollutants. Recovering waste heat from this air and using it for other heating purposes can improve the energy performance of the building. Table 2 shows the potential of heat recovery from extract air from dwellings with different total exhaust air flow rates and with different heat recovery rates from this air - different values of temperature drop of exhaust air on the evaporator of a heat pump. The given potential total heat recovery capacity values represent the potential capacity of the lower source of the heat pump. The higher temperature drop of exhaust air on evaporator and the higher relative humidity of this air, the higher potential total capacity of heat recovery is. Typical air-to-water heat pumps make the difference in temperature of the air flowing through the evaporator from about 5 K to about 10 K. Table 2 shows that a higher potential heat recovery rate can be achieved with heat pump designs that cool the exhaust air by approximately 10 K. Greater air cooling requires a larger evaporator heat exchange area, overcoming higher hydraulic resistances at the flow through the heat exchanger and additionally lower temperatures and evaporation pressures of the refrigerant. This results in a decrease of the energy efficiency COP of the heat pump.

The potential waste heat recovery capacity shown in Table 2 can be used for various purposes in a building. In order to determine the possibility of using this potential, the article analyses the possibility of using this heat in DHW system.

4. Description of an exemplary energy recovery system

With a heat pump it is possible to use the heat recovered from the exhaust ventilation system for both purposes:

- heating,
- preparation of DHW.

In both cases, it is possible to use heat pumps of the type:

- air-to-water,
- water-to-water,
- brine-to-water.

The heat pump can heat heating water or DHW:

- directly,
- indirectly using a medium and a heat exchanger or coil in the tank.

Table 2. Potential capacity for total heat recovery (potential capacity of the lower heat pump source) from exhaust ventilation air from typical dwellings

Description of the dwelling	Total exhaust air flow rate, m^3/h	Potential heat recovery capacity from exhaust ventilation air [1]					
		for 40% relative humidity of exhaust air		for 50% relative humidity of exhaust air		for 60% relative humidity of exhaust air	
		5 K [2]	10 K [2]	5 K [2]	10 K [2]	5 K [2]	10 K [2]
Apartment with bathroom, separate toilet and kitchen with gas cooker	150	0.25	0.50	0.25	0.57	0.25	0.73
apartment for more than 3 people, with bathroom, separate toilet and kitchen with an electric cooker	130	0.22	0.44	0.22	0.49	0.22	0.64
Apartment with bathroom and kitchen with gas cooker	120	0.20	0.40	0.20	0.45	0.20	0.59
Apartment for more than 3 people. with bathroom and kitchen with an electric cooker	100	0.17	0.33	0.17	0.38	0.17	0.49
Apartment for up to 3 persons. with bathroom and kitchen with an electric cooker	80	0.13	0.27	0.13	0.30	0.13	0.39

[1] for the exhaust air temperature from bathrooms of 24°C and the temperature of 20°C from other rooms, was determined assuming the heat exchanger wall temperature of 2 K lower than the temperature of air leaving the heat exchanger

[2] assumed decrease of exhaust air temperature on the evaporator of the heat pump

The paper presents an analysis of the possibilities and effects of heat recovery from exhaust air in a multi-family residential building via air-to-water heat pump and using this heat to indirectly heat (with a coil) the DHW stored in the tank. The diagram of the analysed system is shown in Figure 1. The exhaust air from kitchens, bathrooms and toilets is transported through ventilation ducts over the roof of the building. The heat pump evaporators are installed in the air stream. The heat is taken from the exhaust air by the evaporator of the heat pump. Then, it is transported to the condenser via the refrigerant of the heat pump. In the condenser, the heat is transferred to an intermediate fluid that heats up the water in the storage tank. In the storage tank, the domestic water is preheated in the lower coil. If the set point temperature in the tank is not reached, the domestic hot water is heated by an auxiliary heat source. The heat from the auxiliary heat source is transferred to DHW via the upper coil in the tank.

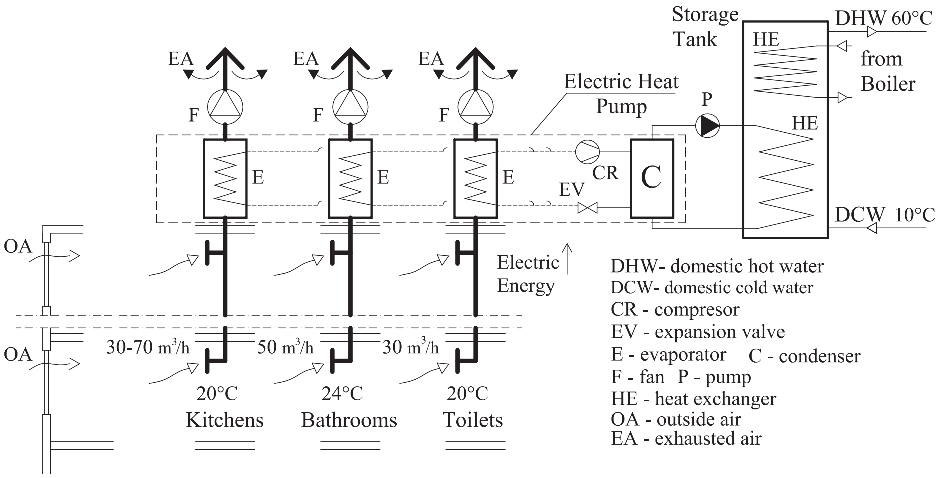

Fig. 1. Scheme of analysed solution

5. Simulation of an exemplary energy recovery system and its impact on the energy performance of a building

Computer simulations of the heat recovery system presented in Figure 1 were performed with the TRNSYS 17 software (Klein 2010) and using the TESSLibs 17 libraries (TESSLibs 17 2012). Table 3 shows the main modules used in the simulation.

Table 3. TRNSYS modules used in simulation

Type	Component name
938	Heat Pump Water Heater
534	Cylindrical Storage Tank with Immersed Heat Exchangers
1243	Water Draw Profile
742	Pump
911	On/Off Differential Controller
659	Auxiliary Fluid Heater With Proportional Control (Proportional Boiler)

The results of the simulation of heat recovery system operation were used to determine its impact on the energy performance of the building.

5.1. Assumptions for simulation

The system under consideration is automated. The heat pump operates in on/off mode. The flow temperature at the outlet of the heat pump is limited (to a value between 35°C and 50°C) by switching the heat pump on/off with a temperature hysteresis of 2 K. Additional heat source (boiler) operates with full capacity and binary control (ON/OFF) with hysteresis of 2 K.

The main assumptions for the simulations of the heat recovery system are presented below:

- simulations were carried out in the period similar to the heating season in Poland, i.e. from 1.10 to 30.04,
- separate hourly domestic hot water draw profiles for working days and weekends according to (Chmielewska 2017),
- value of the daily water draw 40 dm^3/(occupant·d),
- number of occupants 40,
- daily hot water draw of the building 1600 dm^3/d,
- the internal volume of the tank 700 dm^3,
- average coefficient of heat loss from the tank casing 0.51 W/(m^2 K),
- heat transfer area of the lower coil (supplied by the heat pump) 6.5 m^2,
- heating medium flow through the lower coil (from the heat pump) 1500 kg/h,
- heat transfer area of the upper coil (supplied by an additional heat source) 3.0 m^2,
- heating medium flow through the lower coil (from auxiliary heat source) 2000 kg/h,
- auxiliary heat source capacity 12 kW,
- supply medium temperature from the auxiliary heat source 65°C,
- temperature of the exhausted air entering the heat pump evaporators 22°C,

- relative humidity of the exhausted air entering the heat pump evaporators 50%,
- total air flow rate of exhausted air through evaporators 1500 m^3/h,
- the air-to-water heat pump with coefficient of performance COP = 4.0 at entering water temperature 10.0°C, entering air temperature 21.7°C and entering air relative humidity 50.0% (technical data of the heat pump was assumed from the Type 938 module of the TRNSYS (Klein 2010) and TESSlibs software (TESSLibs 17 2012)).

A multi-family residential building with a basement and a flat roof was assumed for analysis. It can be a new building or an existing one after thermal renovation. The building has 5 storey, each storey has 3 flats. There is a staircase in the central part of the building. The building is very well thermally insulated. Heat transfer coefficients of building envelope meet the current requirements of Polish regulations (Dz.U. 2017 poz. 2285 2017) and are as follows: external walls U = 0.23 W/(m^2 K), the flat roof U = 0.18 W/(m^2 K), the ceiling of the basement U = 0.25 W/(m^2 K), windows U = 1.10 W/(m^2 K). The floor area (A_f) of the building is 1001.5 m^2, the internal volume of the building is 2503.8 m^3. Indoor air temperatures are as follows: rooms and toilets 20°C, bathroom 24°C, staircase 8°C.

There is mechanical exhaust ventilation in the building. A gas condensing boiler is the heat source for building heating. Two heat source variants are considered for DHW preparation. I – gas condensing boiler, II – gas condensing boiler and air/water heat pump with lower source as exhaust air from mechanical ventilation system The II variant is a proposal of the authors presented in this paper (Figure 1).

For the building model, an annual energy needs calculation was carried out. Calculations of primary energy were performed in line with the Polish methodology for determining the energy performance (Dz.U. 2015 poz. 376 2015).

5.2. Simulation results

5.2.1. Effect of limiting the outlet temperature from the heat pump on the energy effect

In the discussed example, the heat source for DHW heating is both the heat pump and the boiler. The heat pump supplying the DHW system through the coil located in the lower part of the tank is the first DHW heating stage. The boiler is a source of heat, which through the coil located in the upper part of the tank is always able to provide the preset DHW temperature equal to 60°C. Therefore, the heat pump can operate in the range from DCW temperature equal to 10°C to DHW temperature equal to 60°C. The temperature of the upper heat source of the heat pump affects its efficiency. As the temperature of the upper heat source increases, the COP decreases. A heat pump can run longer heating DHW to a higher temperature or shorter to a lower temperature. In the first case it will reach a lower value of the seasonal coefficient of performance (SCOP) and in the second case higher. Therefore, it is important to consider what is more energy efficient. Table 4 shows the effect of limiting the maximum outlet temperature of a heat pump on the energy effect.

Table 4. Simulation and calculation results – the influence of limiting the maximum outlet temperature of a heat pump on the energy effect

Limit temperature of heat pump outflow	SCOP	$E_{HPT}/(E_{BT}+E_{HPT})$	Operating time		EK_W [1)]		EP_W [1)]
					kWh/(m² a)		
	–	%	Heat pump	Boiler	Heat pump	Boiler	kWh/(m² a)
t_{max} = 30°C	3.36	39.6%	43.6%	32.7%	23.13	4.06	39.97
t_{max} = 35°C	3.19	48.9%	53.7%	28.9%	19.56	5.29	39.68
t_{max} = 40°C	3.05	56.9%	62.3%	25.4%	16.52	6.42	39.71
t_{max} = 45°C	2.93	64.1%	70.0%	21.7%	13.76	7.55	40.00
t_{max} = 50°C	2.82	70.4%	77.0%	18.5%	11.32	8.59	40.42

[1)] for DHW
E_{HPT} – energy delivered to the storage tank from heat pump
E_{BT} – energy delivered to the storage tank from boiler (auxiliary heat source)

Operating time of the heat pump and the boiler change significantly. This means that a different amount of electricity is used to operate the heat pump and gas to operate the boiler. That's why final energy for DHW preparation (EK_W) decreases with increasing heat pump outlet temperature. But this does not mean the same impact on primary energy, because it also depends on the value of non-renewable primary energy factors. The energy effect indicator was assumed to be the non-renewable primary energy factor for DHW (EP_W). The lowest EP_W value is reached for a 35°C supply flow temperature. It is worth noting that for all analysed heat pump outlet temperatures the amount of non-renewable primary energy consumed by the system is close.

The amount of non-renewable primary energy in accordance with formula (1) depends on the non-renewable primary energy factor w_i and the amount of final energy (Q_k). Since for the heat pump $w_i = 3.0$, which is much more than for the gas for which $w_i = 1.1$, even a much smaller amount of final energy consumed by the heat pump does not significantly affect the total primary energy. It should be noted that PEF (Primary Energy Factor) values in the EU are below 3.0 and decrease over the years. (Esser & Sensfuss 2016; Uwe R. Fritsche 2015).

5.2.2. Effect of the exhaust air humidity on the heat pump capacity and the building energy effect

In the analysed system, the exhaust air from the apartments is the lower source of the heat pump. As shown in Section 3, the potential heat recovery capacity from the exhaust air, and thus the capacity of the heat pump, is significantly affected by the humidity of this air. This is the result of using the condensation of water vapour from the air in contact with the evaporator of the heat pump. Therefore, if the relative humidity of the air increases, the power of the lower heat source of the heat pump can increase. The higher the power of the lower heat source of the heat pump, the higher the efficiency of the heat pump. Thus, a higher seasonal coefficient of performance (SCOP) of the heat pump improves the energy efficiency of the building.

Since the simulation is based on constant relative humidity of the exhaust air (50%), it was decided to check what influence the change of this relative humidity will have on the energy effect of the building. The operation of the system with relative humidity of the exhaust air equal to 40%, 50% and 60% was analysed (Table 5). The change of the relative humidity of the exhaust air from 40% to 60% results in a reduction of EP_W by 2.1%. Exhaust air humidity changes over time. This is a result of changes in the humidity of the outdoor air and the emission of water vapour inside the rooms. Therefore, the determination of changes in the humidity of the exhaust air requires detailed analyses and the formulation of many assumptions. In order to formulate conclusions in this article, they are not necessary, but they may be a stage of future research.

Table 5. Simulation and calculation – influence of the relative humidity of the exhaust air on the energy effect

Relative humidity of the exhaust air	SCOP	$E_{HPT}/(E_{BT}+E_{HPT})$	Operating time		EK_W [1)]		EP_W [1)]
					kWh/(m² a)		
	–	%	Heat pump	Boiler	Heat pump	Boiler	kWh/(m² a)
RH = 40%	3.11	48.6%	55.5%	29.0%	5.38	19.67	40.10
RH = 50%	3.19	48.9%	53.7%	28.9%	5.29	19.56	39.68
RH = 60%	3.28	49.2%	52.0%	28.9%	5.17	19.47	39.24

Temperature limitation of the heat pump outlet to 35°C.
[1)] for DHW
E_{HPT} – energy delivered to the storage tank from heat pump
E_{BT} – energy delivered to the storage tank from boiler (auxiliary heat source)

5.2.3. Impact of the proposed solution on the energy performance of the building

The use of a gas boiler as a heat source for building heating and DHW preparation is one of the typical solutions in heating technology in Poland. The type of heat source and the type of fuel from which the heat is produced significantly influences the value of non-renewable primary energy consumed by the building (see Section 2). Table 6 presents the results of energy performance calculations for the building in two variants, I – the source of heat for space heating and DHW preparation is a gas condensing boiler, II – the source of heat for space heating is a gas condensing boiler, the source of heat for DHW preparation is a gas condensing boiler and an air-to-water heat pump. In the II variant, the heat pump covers 48.9% of the DHW preparation needs (see Tables 5 and 6). The use of a heat pump allows to reduce the amount of final energy for DHW preparation (EK_W) by 35.1% in comparison with variant I. However, the difference in primary energy consumption (EP_W) is much smaller and amounts only 9.1%. This is due to the large difference between w_i values for electricity and gas (see 5.2.1).

In the analysed case, the application of the proposed solution made it possible to meet the Polish regulations on energy savings. The EP_{H+W} factor for variant II is lower than the maximum limit value for multi-family residential buildings. The comparison does not cover all possible cases. The similar result obtained for variant I and II calls for further research, which will determine in which cases the application of the proposed solution is energetically but also economically justified.

Table 5. Comparison of the energy effect of a boiler and a heat pump

Variant	Heat source for space heating	Heat source for DHW preparation	EK_W[1)] kWh/(m^2 a)		EP_W[1)]	EP_H[1)]	EP_{H+W}	$EP_{H+W(max)}$
			Heat pump	Boiler	kWh/(m^2 a)			
I	Boiler	Boiler	–	38.29	43.65	44.43	88.08	85.00
II	Boiler	Boiler/Heat pump[1)]	19.56	5.29	39.68	44.43	84.11	85.00

[1)] for DHW, [2)] for space heating
E_{HPT} – Energy delivered to storage tank from heat pump
E_{BT} – Energy delivered to storage tank from boiler (auxiliary heat source
Auxiliary energy calculated as for a boiler and distributed proportionally according to the share of two sources. Outlet temperature of the heat pump limited to 35°C, the exhaust air relative humidity is 50%

6. Conclusions

It was shown that using an air heat pump it is possible to recover waste heat from the exhaust air from the ventilation system of a multi-family residential building. This potential is high due to the large share of such buildings. By increasing the temperature level of the recovered heat with a heat pump, it can be used, for example, to preheat domestic hot water.

The proposed heat recovery system of waste heat from exhaust air via an electric heat pump for DHW purposes was analysed by TRNSYS 17 software. Based on the analysis for an exemplary multi-family building, it was concluded that in order to obtain a minimum primary energy consumption for the analysed system, it may be justified (depending on the local values of the non-renewable primary energy coefficients) to limit the outlet flow temperature from the heat pump. In the analysed case, in Polish conditions, the temperature of 35°C was determined. In comparison with using only a gas condensing boiler, the final energy amount for DHW preparation (EK_w) by 35.1% and primary energy consumption (EP_w) by 9.1%. n Poland, electricity is produced mainly from fossil fuels, which results in high consumption of non-renewable primary energy for its production. When a larger share of cleaner sources (e.g. PV) is used to generate electricity, the proposed solution results in a much greater reduction in the demand for primary energy.

Moreover, an increase in the relative humidity of the exhaust air increases the efficiency of the heat pump, which in the analysed range (40-60%) resulted in a change in both EP_W and EK_W, but only by about 2%.

The discussed topic has a very wide range of future research possibilities. Further research is planned to determine how to recover available waste heat with less energy input and for which installations in the building it should be used. In the future, different heat recovery system and heat pump configurations, including gas, will be analysed, as well as the use of waste heat also for space heating and the cooperation of heat pumps with other heat sources.

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Abstract

The article discusses the possibility of recovering waste heat from the exhaust air from the ventilation system of multi-family residential buildings. A system of waste heat recovery from the extracted air with an electric heat pump was proposed for the preparation of domestic hot water (DHW). The proposed system has been analysed in TRNSYS 17 software for exemplary multi-family residential building. The influence of exhaust air humidity and heat pump outlet temperature on the energy effect was analysed. For the analysed case and the Polish conditions of electricity production, a possible reduction of the final energy amount for DHW preparation (EK_W) by 35.1% and primary energy consumption (EP_W) by 9.1% was determined in comparison with the use of a gas condensing boiler only.

The factors influencing the energy effect of the system for the recovery of waste heat from the exhaust air were indicated. The authors specified directions of further research aimed at determining how to recover available waste heat from the exhaust air with lower energy expenditure and for which installations in the building they should be used.

Keywords:
air-to-water electric heat pump, waste heat recovery, heat recovery in ventilation, domestic hot water, TRNSYS

Odzysk ciepła odpadowego za pomocą elektrycznej pompy ciepła z wywiewanego powietrza wentylacyjnego do systemu ciepłej wody użytkowej w wielorodzinnych budynkach mieszkalnych

Streszczenie

W artykule podjęto temat możliwości odzyskania ciepła odpadowego z powietrza wywiewanego z systemu wentylacyjnego budynków wielorodzinnych mieszkalnych. Zaproponowano system odzysku ciepła odpadowego z powietrza wywiewanego elektryczną pompą ciepła dla potrzeb przygotowania ciepłej wody. Zaproponowany system przeanalizowano w oprogramowaniu TRNSYS 17 dla przykładowego budynku wielorodzinnego. Przedstawiono wpływ wilgotności względnej powietrza wywiewanego i temperatury zasilania pompy ciepłej na efekt energetyczny. Dla analizowanego przypadku i polskich warunków produkcji energii elektrycznej, wyznaczono możliwe zmniejszenie zapotrzebowania energii końcowej na przygotowanie ciepłej wody użytkowej (EK_W) o 35,1% i energii pierwotnej (EP_W) o 9,1% w porównaniu z zastosowaniem tylko gazowego kotła kondensacyjnego.

Wskazano czynniki wpływające na efekt energetyczny systemu do odzysku ciepła odpadowego z powietrza wywiewanego. Autorzy podali kierunki dalszych badań zmierzających do określenia jak odzyskać dostępne ciepło odpadowe z wywiewu przy mniejszym nakładzie energetycznym i do jakich instalacji w budynku je wykorzystać.

Słowa kluczowe:
sprężarkowa pompa ciepła powietrze/woda, odzysk ciepła odpadowego,
odzysk ciepła w wentylacji, ciepła woda użytkowa, TRNSYS