

Cost-effective exhaust air heat pump hybrid system for hospital

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JIAYI LIU

School of Civil Engineering Aalto University, Finland



YUCHEN JU

Postdoctoral researcher, Aalto University
yuchen.ju@aalto.fi



XIAOLEI YUAN

School of Civil Engineering Aalto University, Finland



RISTO KOSONEN

Professor, Aalto University



JUHA JOKISALO

D.Sc., Senior scientist, Aalto University

Hospital buildings experience substantial ventilation heating energy consumption, which can be effectively reduced by a hybrid system, where an exhaust air heat pump (EAHP) and run-around heat recovery are optimally merged together. With appropriate dimensioning, the hybrid system reduces purchased energy for heating and life-cycle cost by up to 34% and 17% compared with the building without EAHP.

To ensure the wellbeing of patients and staff, hospitals typically operate intensive, continuous ventilation, which results in considerable heating energy consumption of ventilation. To reduce energy usage, run-around heat recovery is widely used in hospital buildings, because it uses an isolated fluid loop as the heat-transfer medium, thereby minimizing cross-contamination risk. However, this separation generally limits heat recovery performance compared e.g. with rotary wheel type of solutions, with temperature efficiency typically much below 70% [1]. As a result, a large share of ventilation heat losses remains unrecovered.

Exhaust air heat pumps (EAHPs) can provide high-efficiency heat recovery by further extracting heat from exhaust air after heat recovery [2]. Their energy-saving potential has been demonstrated in previous studies [3,4]. Moreover, the physical separation between exhaust and supply air streams helps minimize contamination risk, making EAHPs suitable for hospitals. This study evaluates the energy performance and life-cycle cost of hybrid EAHP and run-around heat recovery systems under different dimensioning options, aiming to identify cost-effective dimension for hospital buildings.

Methodology

This study focuses on a newly built hospital building in Tampere, Finland. The building has a net heated floor area of 7080 m², consisting of three above-ground floors and two basement floors. It is served by a constant air volume (CAV) ventilation system with a total airflow rate of 13.3 m³/s, distributed across seven air handling units (AHUs). AHU 1–5 serve the main above-ground functional areas; their supply air temperature is controlled based on exhaust air temperature and typically varies between 18 and 22°C. AHU 6–7 serve technical and auxiliary spaces in the basements, with a constant supply air temperature of 18 and 19°C, respectively. All AHUs are equipped with run-around heat recovery systems with a temperature efficiency of 46%.

Figure 1 illustrates the scheme of building heating system. Space heating and domestic hot water are supplied by district heating. For ventilation heating, AHUs 1–5 are primarily served by the EAHP, with district heating as a backup heat source. For AHUs 6–7, district heating is the only heat source. The heating setpoints are 23°C for toilets, 22°C for patient rooms, and 21°C for other rooms. Space cooling is provided by district cooling, with cooling setpoint of 23°C for the

whole building. Based on measured operational data, average heat gains are set to 1.6 W/m² for occupants, and 8.7 W/m² for both lighting and equipment.

In this study, four dimensioning cases for a combined run-around heat recovery and EAHP system are investigated. In each case, the EAHP and run-around heat recovery system are sized to maximize the utilization of available ventilation waste heat while avoiding over-sizing. For each investigated case, three PV scenarios are considered: no PV (No-PV), PV panels covering 50% of the available roof area (PV-80kW), and PV panels covering 100% of the available roof area (PV-160kW), corresponding to installed capacities of 80 kW and 160 kW, respectively. All investigated cases are summarized in **Table 1**.

The energy performance is evaluated using detailed building energy simulations. The models are developed and simulated in IDA ICE with a customized ESBO module [5], enabling an accurate representation of the complex HVAC system. Hourly measured weather data from the nearest weather station for 2023 is used for simulations.

For the economic assessment, the net present value (NPV) of the life-cycle cost (LCC) is applied to all cases [6]. A 25-year analysis period is used, with a real discount rate of 3% and an annual energy price escalation rate of 2% [7]. Investment costs are based on market prices by consulter and contractor

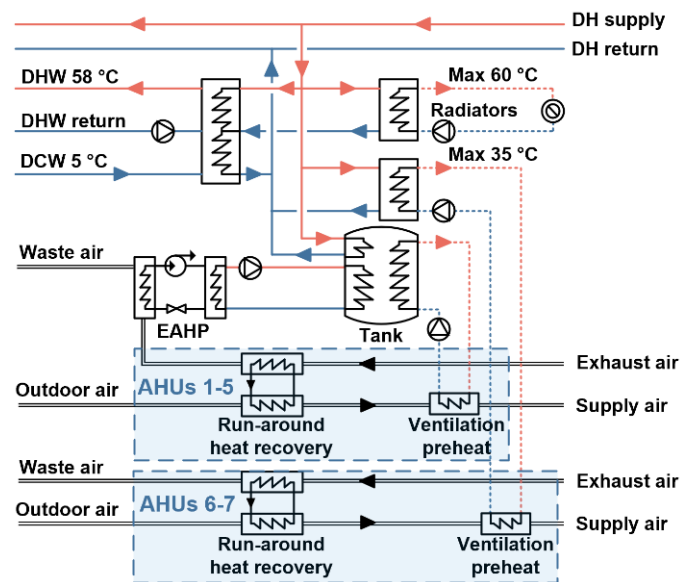


Figure 1. The general principle of the heating system.

recommendations, covering the EAHP, run-around heat recovery system, PV system, and all required auxiliary components and installation labor [6]. Energy costs are calculated using local energy companies' published hourly electricity prices and monthly district heating and district cooling tariffs for 2023 [6].

Results

How much energy can be reduced?

Table 2 summarizes the simulated annual energy demand under the No-PV scenario for the investigated dimensioning cases. Compared with the reference case

Table 1. Properties of systems alternatives.

Heating configurations	Run-around heat recovery temperature efficiency	District heat capacity, kW	EAHP capacity, kW	PV capacity, kW
HR46-No EAHP (Ref.)	46%	1063	None	0
HR40-EAHP260	40%	803	260	0
HR46-EAHP224	46%	859	224	0
HR60-EAHP125	60%	938	125	0
HR70-EAHP125	70%	938	125	0

* Each case is evaluated under three PV scenarios: no PV, 80 kW PV, and 160 kW PV.

Table 2. Simulated annual energy demand for heating of cases under No-PV scenario.

Cases	District heating		Electricity heating		Total purchased heating	
	Energy, MWh	Saving	Energy, MWh	Increase	Energy, MWh	Saving
HR46-No EAHP (Ref.)	919	–	362	–	1281	–
HR40-EAHP260	517	44%	550	52%	1067	17%
HR46-EAHP224	490	47%	530	46%	1020	20%
HR60-EAHP125	430	53%	486	34%	916	28%
HR70-EAHP125	393	57%	457	26%	850	34%

without EAHP, applying EAHP substantially reduces district heating demand, with savings of 44–57%, while electricity consumption increases due to heat pump operation. As run-around heat recovery efficiency increases and the corresponding EAHP capacity decreases, both district heating demand and electricity demand decrease. Overall, the total purchased energy for heating is reduced by up to 34% compared with the reference case.

How much energy cost can be saved?

Figure 2 compares the simulated annual energy costs for district heating and electricity. The EAHP reduces district heating costs by 41–49% relative to the reference case. The savings increase with higher EAHR efficiency. Simultaneously, while EAHP operation increases electricity costs. However, this penalty decreases substantially as EAHR efficiency increases and the EAHP capacity is reduced. PV integration further lowers purchased electricity. When high-efficiency EAHR is combined with a small-capacity EAHP and high PV capacity, the building can achieve lower electricity consumption than the reference case without PV and EAHP.

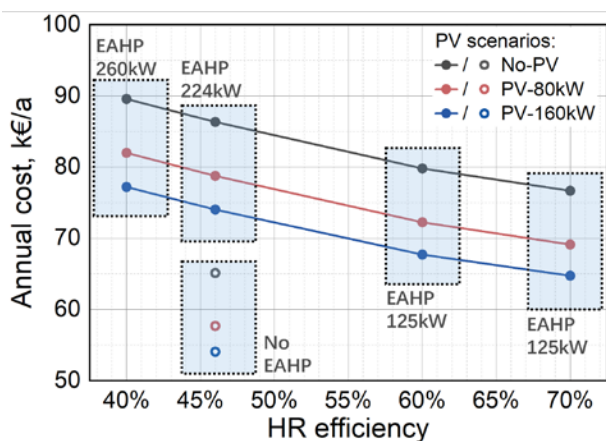
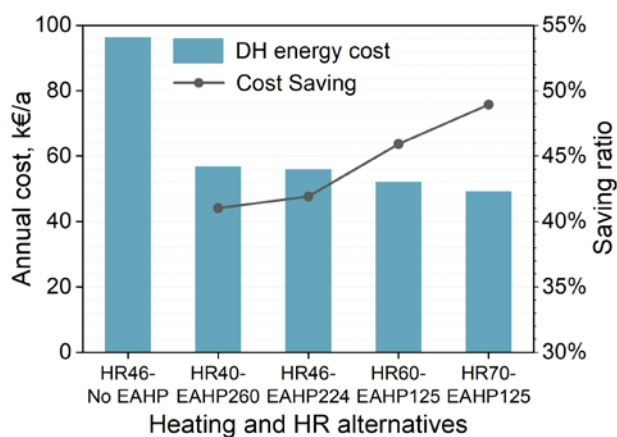


Figure 2. Annual energy costs for electricity and district heating.

What is the cost-optimal dimensioning?

Figure 3 shows the life-cycle costs of the investigated dimensioning cases under all PV scenarios. All EAHP cases show a lower LCC than the reference case. The lowest LCC is achieved by the configuration with the highest run-around heat recovery efficiency (70%) combined with a small-capacity EAHP (125 kW), indicating this as the cost-optimal dimensioning. In addition, LCC decreases as PV capacity increases. Compared with the reference case, the cost-optimal EAHP hybrid heating system dimensioning combined with the highest PV capacity achieves a maximum LCC saving of 16.6%.

Conclusion

Integrating an exhaust air heat pump (EAHP) with run-around heat recovery effectively reduces ventilation heating energy consumption in hospitals and lowering operating costs. Compared with the reference case using district heating and run-around heat recovery only, the EAHP hybrid system reduces district heating consumption by up to 57% and total purchased energy for heating by up to 34%. Among the investigated dimensioning options, a high-efficiency run-around heat recovery combined with a small-capacity EAHP achieves the greatest reductions in energy cost and life-cycle cost. PV integration can further decrease LCC, with larger PV capacities providing greater savings. With appropriate system dimensioning, the proposed hybrid solution can deliver up to 16.6% life-cycle cost savings for building owners.

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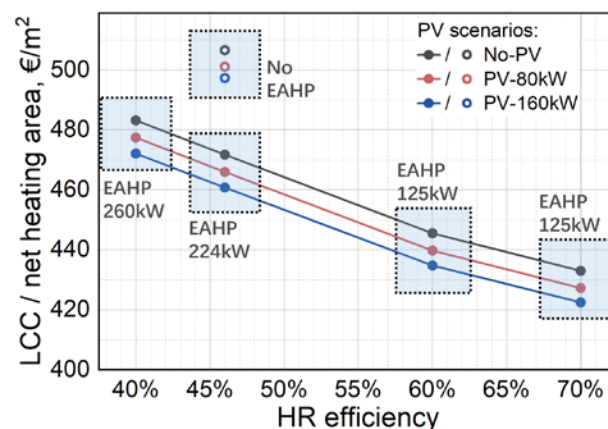


Figure 3. Net present value of life cycle cost of investigated dimensioning cases under all PV scenarios.

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