Life Cycle Cost Analysis of Air Preheating Systems using Wastewater and Geothermal Energy

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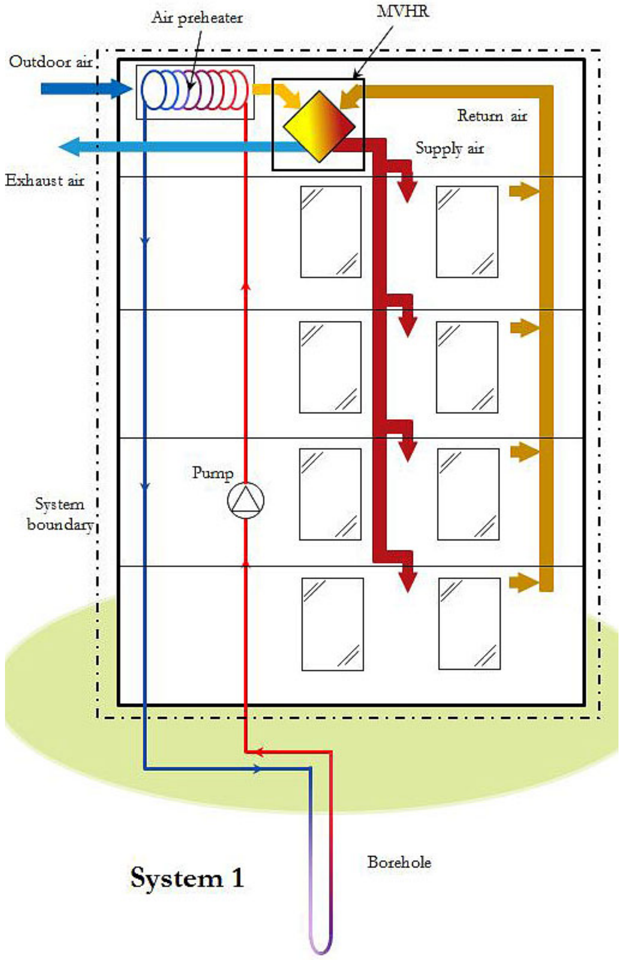
Frosting is a common problem in air handling units in buildings in cold climates. Tackling this problem is so far achieved by using considerable amount of energy while during this process, the indoor air quality is compromised. This article presents the Life Cycle Cost (LCC) assessment of a preventive solution for frosting using two renewable heat sources.

Keywords: wastewater heat recovery, geothermal heating, energy saving, balanced mechanical ventilation, Life Cycle Cost (LCC)

Heat recovery from the return air from buildings has long been carried out in Sweden [1]. Thanks to developments in building insulating materials, the heat losses from building façade have dropped significantly. Therefore, the share of wastewater heat losses has been doubled in modern low-energy buildings compared to the constructions erected between 1940s and 1990s [2]. The present research work explored the potential of residential wastewater as a renewable heat source to improve the performance of mechanical ventilation with heat recovery (MVHR) systems in Sweden. The performance of the suggested wastewater heat recovery system was compared with a passive geothermal system which is already installed and utilized for the same purpose. The air preheating systems were technically assessed and compared in details in previous publications by the authors [3]–[5]. The current study is based on the system presented in [5] which showed that the air preheating systems could reduce the frosting time to 25%. This would maintain the heat recovery efficiency of the MVHR system above 80% for almost 90% of the studied period. The wastewater/brine circulation pumps needed 2%-8% of the recovered heat energy from wastewater or borehole for own operation.



Yet, there is still a lack of knowledge about the financial side for the suggested solutions. To raise awareness for this heat recovery System and establish it in the market, potential customers also need to be familiar with the costs over the complete life-cycle.

Methodology

The simulated building is a multi-family house located in central Sweden and holds a total heated floor area of 876 m² [6]. The base (reference) ventilation system was a common MVHR system. Three outdoor air preheating systems combined with the existing MVHR were compared to the reference system. System 1 used the geothermal energy as the heating source. A vertical U-tube heat collector was inserted in a 250m deep borehole to absorb the heat from the soil. The collected heat was then used to preheat the incoming outdoor air in a heat exchanger placed in front of the MVHR. The other two systems used wastewater as a heat source. System 2 was equipped with a stratified storage tank to utilize a benefit of temperature stratification. System 3 was equipped with an unstratified tank. The studied systems are shown in **Figure 1**. The systems with air preheaters were compared to the reference MVHR system.

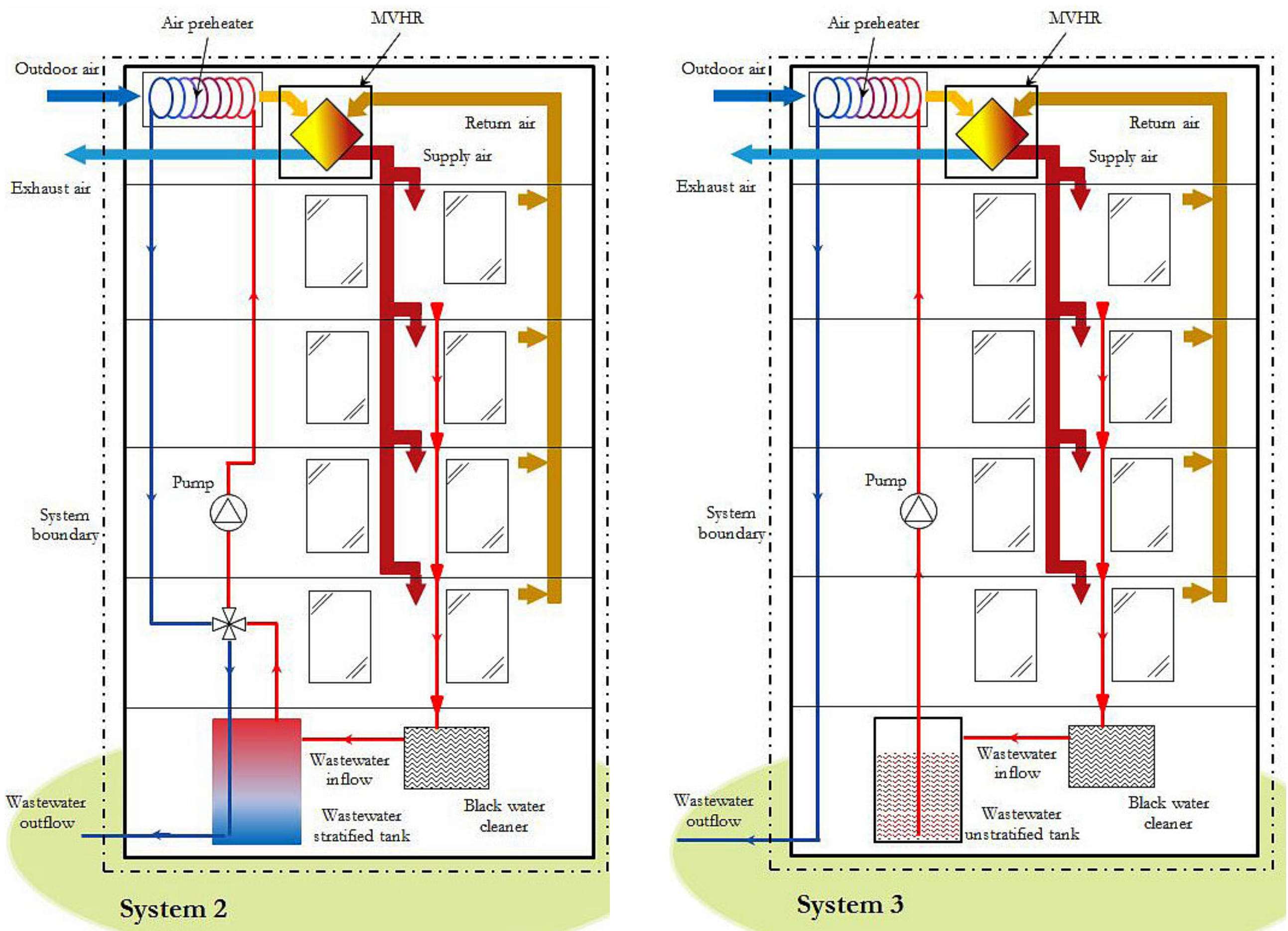


Figure 1. Schematic flow charts of the studied systems, air preheater served by (from left to right) a) borehole (System 1), b) wastewater from the stratified tank (System 2), c) wastewater from the unstratified tank (System 3). [5]

In order to evaluate the cost effectiveness of the studied systems, a Life Cycle Cost Analysis (LCCA) was carried out. The cost factors considered in the financial model are illustrated in **Figure 2**.

Initial investment costs were based on local market prices in Sweden for year 2017. Based on the prices found, maintenance and repair costs were approximated as a percentage share of the initial investment cost. The average for this share was set at 2.4%. Expenditures for the replacement of components were added the year in which its official service life ended. The cost for electricity was predicated on the current market prices, and its development over the following years was estimated with an annual increase of 3%. Total energy usage was calculated using simulation software TRNSYS®. The Net Present Value (NPV) method was applied to compare the systems based on their value at present time. Future costs were therefore discounted with an interest rate of 2.4%, and the total lifespan of 20 years was considered for the suggested heat recovery systems.

The systems exclusively covered ventilation heating demand to reach thermal comfort. This was provided by maintaining a room temperature at 18°C. Since space heating was predominantly active in the cold months, the evaluation period was set from December to March when frosting inside the MVHR system was expected.

Results and Discussion

Figure 3 displays how the cost for each system accumulates over the evaluated lifespan. The base system has the lowest initial cost while its operational cost over 20 years was above the other systems. The operating cost of the reference system increased within three years by 90 000 SEK (≈ 8 800 €) on average, and after a period of 20 years, it had the second highest NPV.

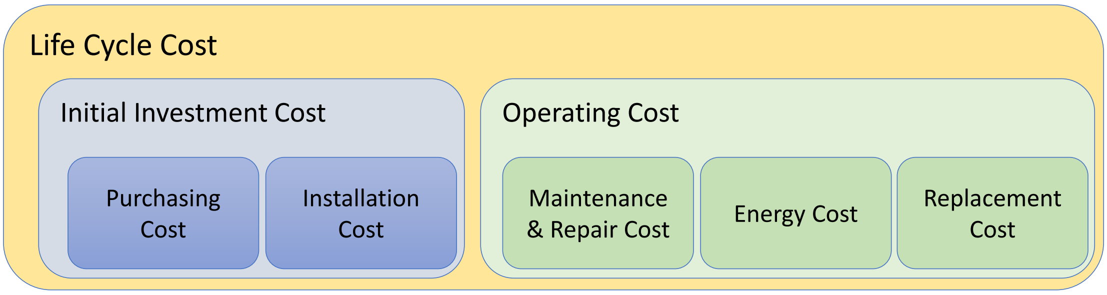


Figure 2. Overview on cost factors considered in the LCCA.

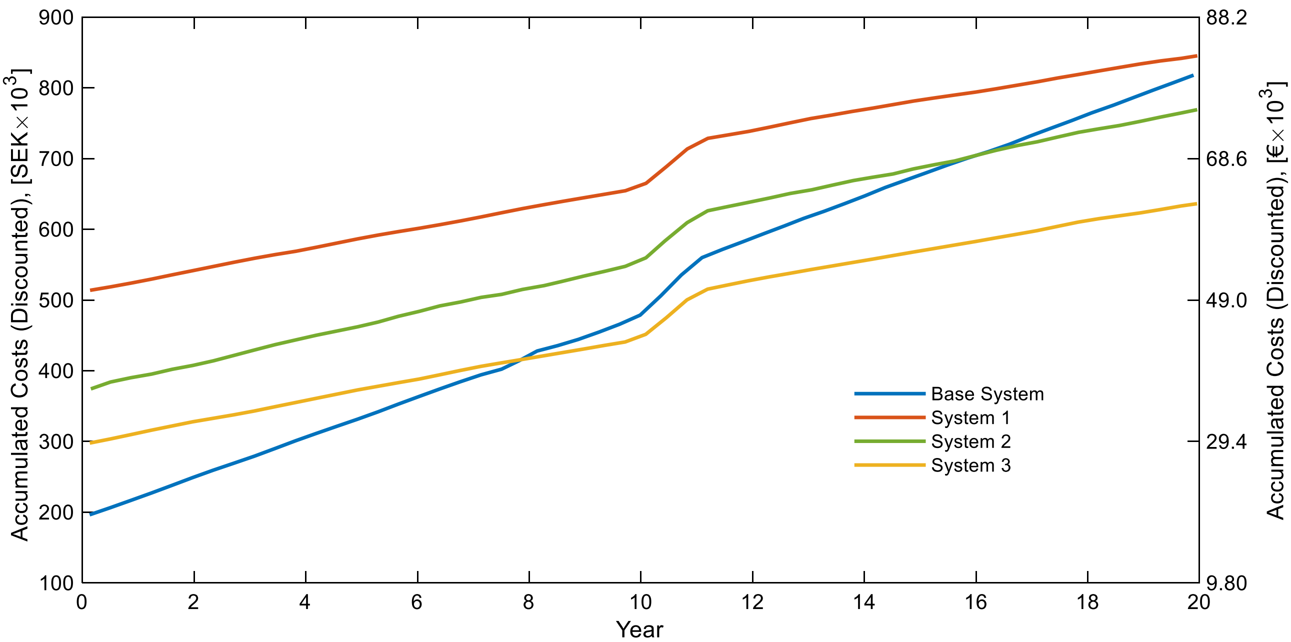


Figure 3. Accumulated cost and the discounted payback period of the studied systems.

System 3 has the shortest payback period, which is about 7.5 years. System 2 pays off the initial investment cost for the outdoor air preheating system 9 years after System 3. This is mainly due to the higher cost for the stratified tank. At the end of the 20-year period, System 3 manages to save about 180 000 SEK (≈ 17 600 €) while the corresponding saving is around 50 000 SEK (≈ 4 900 €) for System 2. System 1 has a steady increase in costs like Systems 2 and 3 with about 40 000 SEK (≈ 3 900 €) every three years on average. Current market prices for borehole drilling are still high. Within the 20-year period, it is not breaking-even with the base system, even though the cost gap at the end of the period closes to about 25 000 SEK (≈ 2 400 €).

Figure 4 demonstrates the total NPV as well as the costs split-up into initial and operating costs at the end of year 20. The graph visualizes the relation between these two costs compared to each other. For the base case, the operating costs exceed the initial costs by around 300%. In other words, most of the costs do not occur in the purchase stage but in the later years during the operation. For System 1, the initial cost dominates over the operational cost with a ratio of about 1.4:1. For the two air preheating systems fed by wastewater, the two costs are roughly equally balanced. Compared to the base (reference) system, the operational costs for other systems were 35% – 45% lower.

Figure 5 depicts the total energy cost of the four systems. The costs in the graph are discounted to NPV. While the costs for the three systems using outdoor air, preheating are on a similar level, the energy cost for the reference system, without an air preheater, is more than three times higher. Therefore, the energy cost can be identified as the critical factor for cost cuts. It is hereby confirmed what was found in the previous studies. Beside the technical potential, frost-avoidance also has a great potential for reducing operational costs of MVHR-units in cold climates. Energy cost can be cut significantly with the suggested systems and eventually compensate for the higher initial investment cost.

Conclusion

In this case study, a multi-family house in central Sweden equipped with a MVHR system and an outdoor air preheating system was considered. Four alternatives were investigated from a financial perspective using the LCCA-method. The system with the lowest life-cycle costs was System 3, see **Figure 1**. According to the results, it saved on average about 180 000 SEK (≈ 17 600 €) after 20 years compared to the MVHR alone (reference system).

The avoidance of frost has proved itself as a significant factor for cutting energy cost. Outdoor air preheating is a practical solution to prevent frost formation inside the MVHR-unit and maintaining a high heat recovery efficiency from the ventilated air during the coldest periods

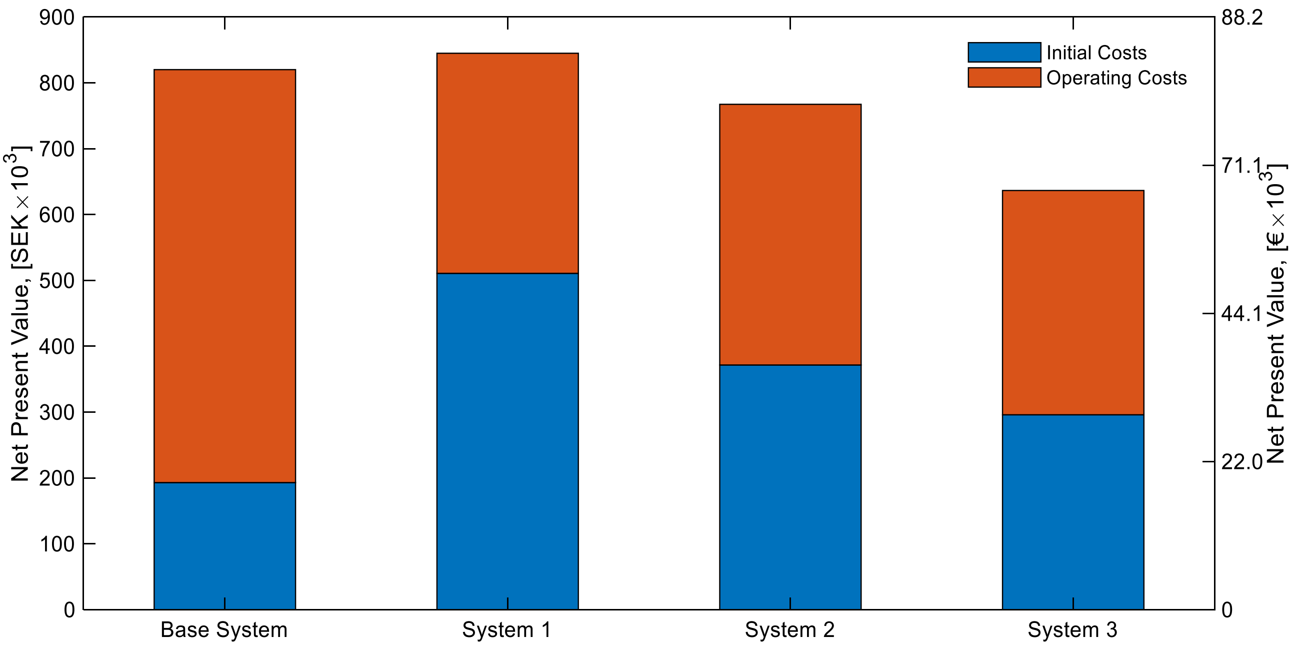


Figure 4. Total NPV of all studied systems.

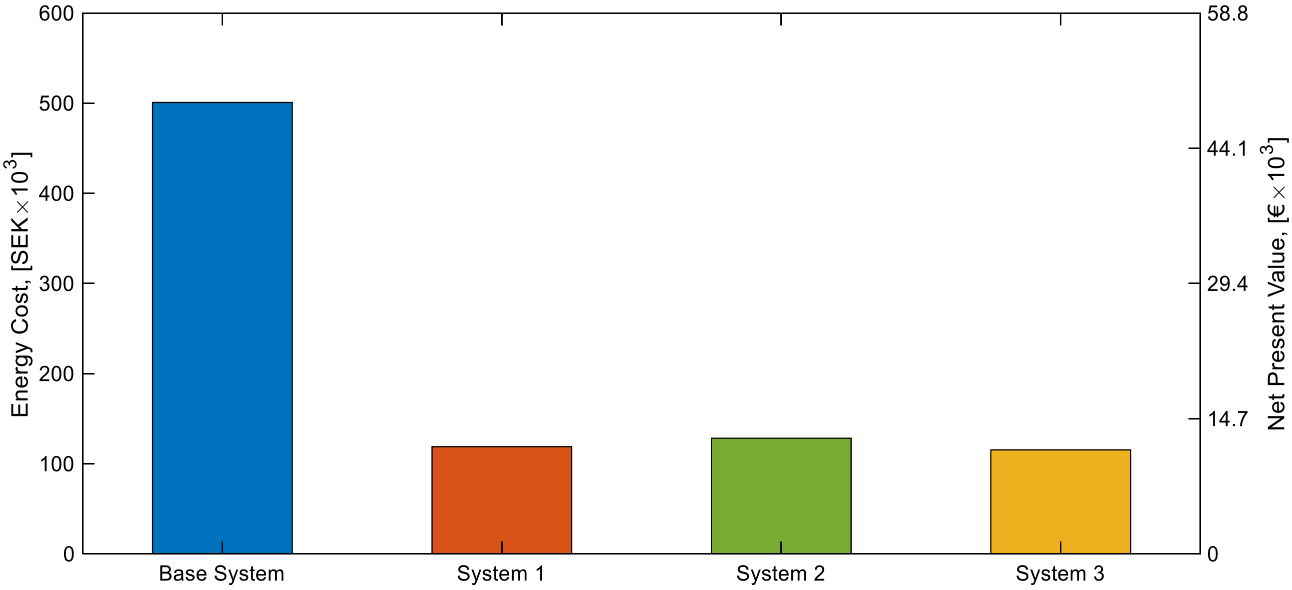


Figure 5. Energy cost per system (discounted).

of the year. While the wastewater system can already generate savings with the state-of-the-art technology, there is still need for improvement in the exploitation of geothermal energy.

Since the operational costs were saved by reducing defrosting time, the suggested outdoor air-preheating systems have even a bigger economic advantage in colder climates where defrosting need is higher. ■

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