Hybrid energy system cost-optimal dimensioning for a Finnish kindergarten

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This study investigates cost-optimal dimensioning of a kindergarten hybrid energy system over a 25-year life cycle. Findings show high peak power demands make power fees dominate the total district heating costs. Consequently, varying district heat tariffs—considering waste heat integration—minimally impact the dimensioning, potentially undermining the waste heat utilization in district heating.

Due to the advantages of renewable sources for achieving carbon neutrality, their proportion in energy generation is rising. By 2030, the EU aims to create 20 million tons of hydrogen (European Commission, 2024). There is considerable opportunity of excess heat utilization. This study examines the cost-optimal dimensioning of a hybrid building energy system utilizing waste heat from hydrogen production, based on a 25-year life cycle cost (LCC) analysis. The hybrid energy system comprises a primary heating unit, a ground source heat pump (GSHP), and a district heating (DH) backup for a kindergarten. Two district heat tariffs: a commercial district heat pricing from a district heating company and a zero-emission district heat price derived from waste heat for hydrogen production were selected for comparative purposes.

Building parameters

The examined kindergarten locates in Lappeenranta, Finland. **Table 1** collects the building main parameters. This study assumed the connection of an existing district heating network with supply temperatures of 115/70°C.

Intermittent mechanical balanced ventilation with heat recovery is in operation. It operates for two hours at maximum capacity by a constant air volume system to remove pollutants, after that transitioning to utilizing CO_2-based variable air volume control throughout operational hours. Consequently, there are significant heating power peaks in the early morning.

Simulation tool and weather conditions

Software IDA Indoor Climate and Energy (IDA ICE) version 5.0 with embedded optimization tool AutoMOO were used for the building simulation and LCC minimization (Ju et al., 2025). This study used hourly weather data from the Finnish Meteorological Institute (2023) station of Lappeenranta. The minimum temperature was –19.8°C as shown in **Figure 1** with the annual average of 5.3°C.

Decision variables and objective function

Table 2 collects the continuous decision variables and constraints of the hybrid system for dimensioning. The aim of LCC optimization is to search the cost-optimal solution under different variables related cost data.

Table 1. *Properties of the simulated building.*

Parameters	Kindergarten	
	Old zone	New zone
Total heated floor area, m²	1124	
Indoor air temperature setpoints for living spaces,°C	21 for living space	
Roof, W/(m²K)	1.0	0.17
External walls, W/(m²K)	0.09	
External floor, W/(m²K)	0.16	
Windows' U-value, W/(m²K)	1.0	
External door, W/(m²K)	0.9	
Heating system	Floor heating	
Dimensioning temperatures of the heating system,°C	35/30	
Design outdoor temperature,°C	-29	
Dimensioning heating power at design conditions, kW	297	

Table 2. *Units and constraints of the system for LCC optimization.*

Unit	Minimum value, kW	Maximum value, kW
GSHP	10	297
DH	0	287
PV capacity	0	61

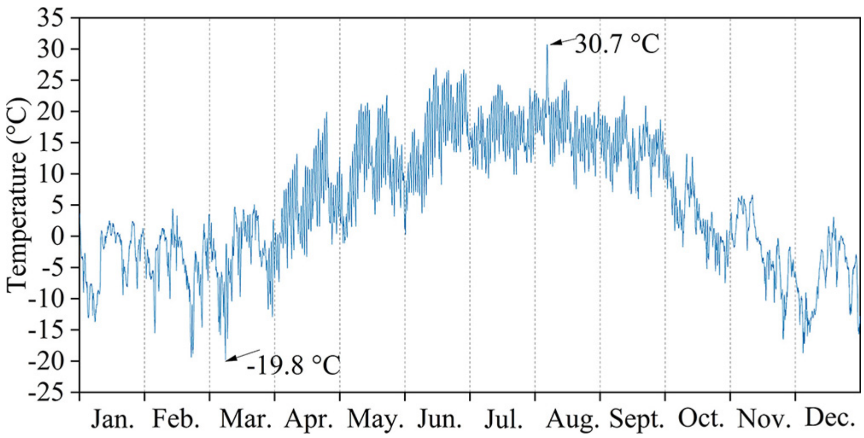

Figure 1. Lappeenranta outdoor temperatures for the year 2023.

The objective function for the optimization is the find the minimum net present value (NPV) of 25-year LCC which includes the investment, maintenance, and renewal cost data (Ju et al., 2025). The maximum constraint for GSHP and DH was defined based on the dimensioning heating demand (**Table 1**). Their design capacity relationship also follows the rule as shown in Eq. (1) during the simulation.

$$P_{dim.} = P_{HP} + P_{DH} \quad (1)$$

Where

$P_{dim.}$ is the dimensioning heating power, kW

P_{HP} is the heat pump design capacity for heating, kW

P_{DH} is the district heating design capacity, kW.

Price data of electricity and district heating

The optimization utilized Nord Pool (2024) day-ahead hourly electricity prices. The electricity generated by the photovoltaic panels was initially delivered to the building, with any surplus sold to the market.

Figure 2 presents the monthly commercial district heat prices (Fortum, 2024) and the zero-emission district heat prices (considered as CO_2 emission free) (Meriläinen et al., 2024). The zero-emission price is much lower than the commercial price in winter.

The total DH costs consist of the district heat energy cost (calculated by the commercial or zero-emission district heat price) and power fee defined in Eq.(2):

$$F_A = F_M \times 12 \times P_{DH\ max} \quad (2)$$

Where

F_A is the annual power fee (24%VAT), €;

F_M is the monthly power fee, 6.2 €/kW (24%VAT)

$P_{DH\ max}$ is the maximum district heating supply power for the year to the kindergarten, kW

Results

Figure 3 shows the cost-optimal solutions of LCC varying with heat pump design capacity for the kindergarten. It highlights that changing to the zero-emission district heat price reduces the heat pump design capacity and minimum LCC.

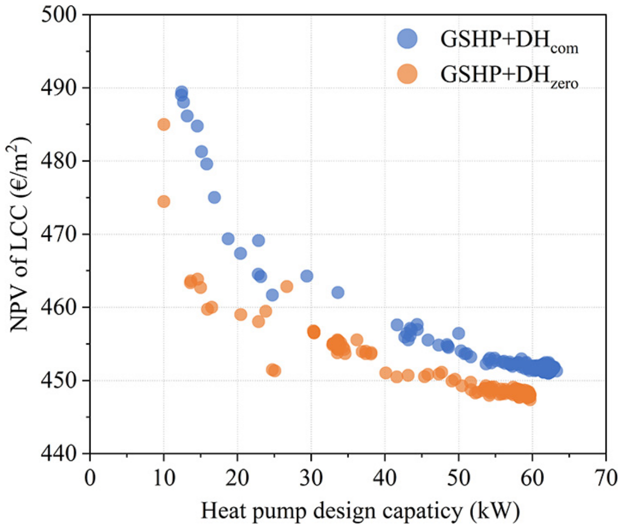

Figure 3. Cost-optimal solutions, net present value (NPV) of life cycle cost (LCC) varying with heat pump design capacity.

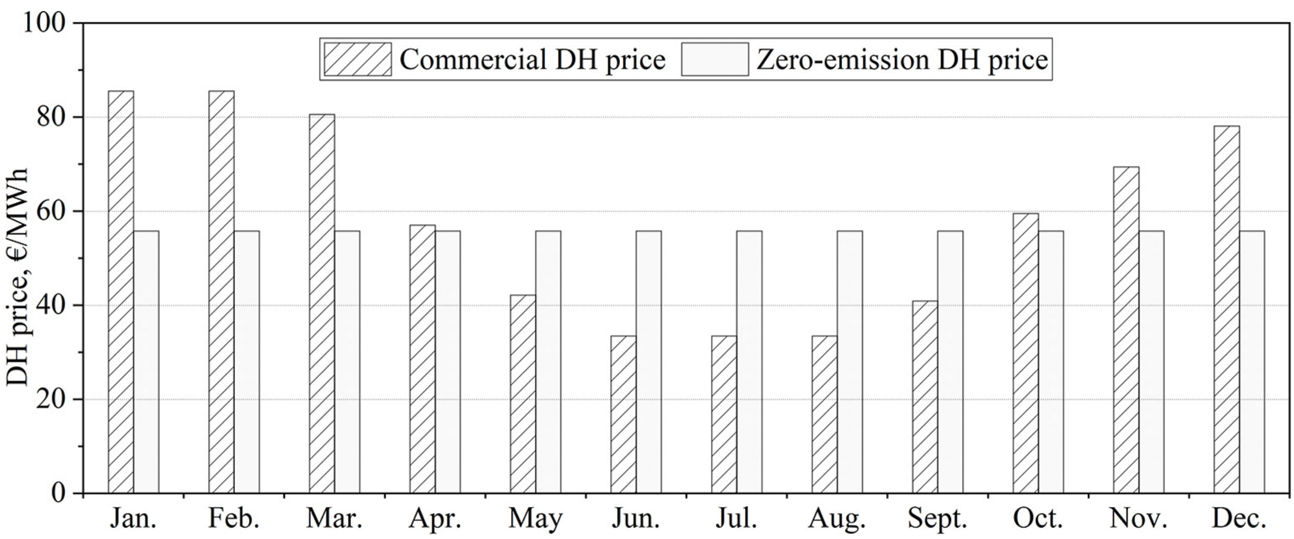

Figure 2. DH prices with 24% VAT.

Table 3 list the results of minimum LCC and cost-optimal dimensioning capacities for GSHP DH, and PV. The utilization of the zero-emission district heat tariff decreases the 25- year LCC about 7% for the reference cases. In the cost-optimal cases for the kindergarten, the GSHP design capacity just slightly reduces after changing to the zero-emission district heat price. The percentage values in the brackets are the ratio of GSHP or DH design capacity among the total dimensioning heating power.

There are the DH costs when the LCC is minimum as shown in **Figure 4**. The total district heating cost consists of the energy costs calculated for the two district heat tariffs and the power fee by Equation (2). The power fee primarily varies according to the highest DH supply power. In the reference cases, the power fee allocation for the kindergarten exceeds 60%. It is prevalent in the district heat cost analysis. The high peak heating demand arises from the early morning purging ventilation. The dominant effect of the power fee leads to a little decrease in GSHP design capacity when a lower district heat price is applied. It signifies a challenge in recovering waste heat from hydrogen production for use in DH.

Conclusion

The study examined the hybrid energy system (GSHP+DH) cost-optimal dimensioning for a kindergarten in Finland. The analysis contains a comparison of two district heat tariffs: the commercial district heat price and the zero-emission district heat price derived from the district heating production cost coupling with

Table 3. *Minimum life cycle cost and design capacity.*

Cases		Min. LCC, €/m²	HP design capacity, kW	DH design capacity, kW	Max PV capacity, kW
System	DH price				
Reference	Commercial	583	--	297	--
	Zero-emission	542	--	297	--
GSHP+DH	Commercial	451	62 (21%)	235 (79%)	11
	Zero-emission	447	60 (20%)	237 (80%)	10

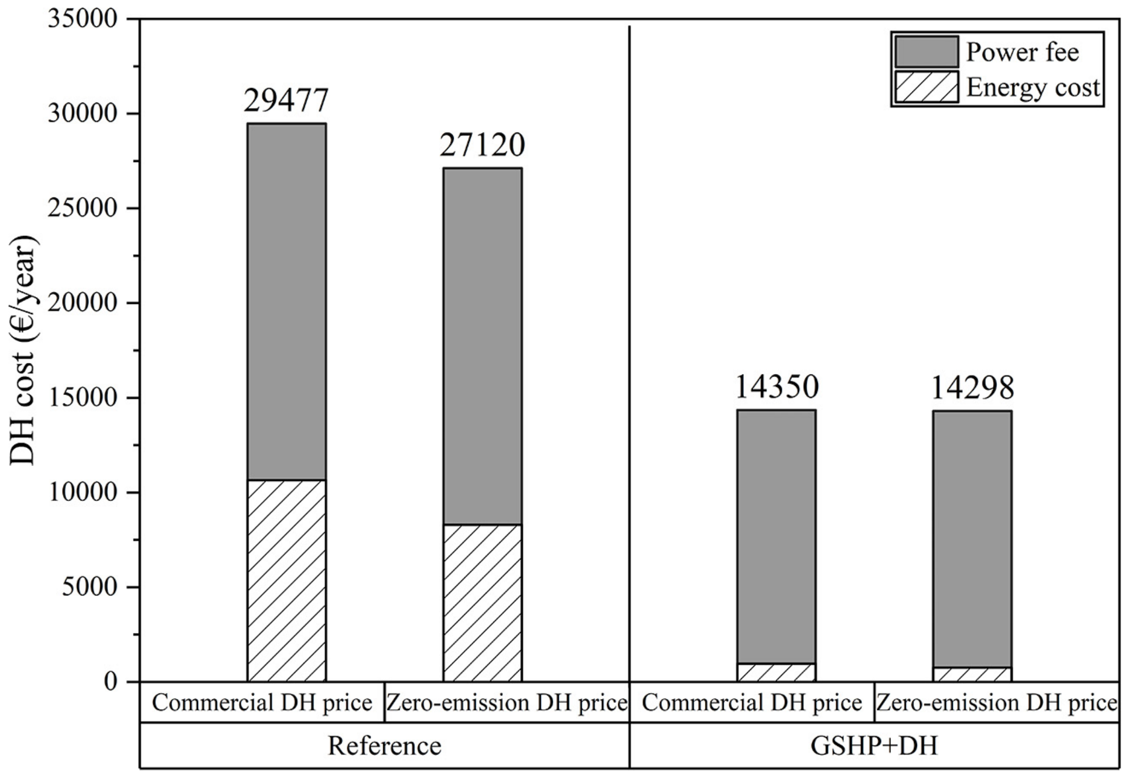

Figure 4. DH costs when the LCC is minimum.

the waste heat generated during hydrogen production. The cost-optimal dimensioning of ground source heat pump accounts for approximately 20% of the overall dimensioning power. The alteration of district heat tariffs has minimal impact on sizing, as the power fee accounts for over 90% of the total energy costs for the hybrid system. This highlights that the high peak heating power demand can undermine the waste heat utilization in district heating.

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