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EVALUATING THE ENERGY AND COST BENEFITS OF HEAT PUMPS IN MULTI-OCCUPANCY DWELLINGS

ANALIZA ENERGETYCZNYCH ORAZ KOSZTOWYCH KORZYŚCI STOSOWANIA POMP CIEPŁA W BUDOWNICTWIE WIELORODZINNYM

A b s t r a c t

This paper provides a tabular analysis of an "outdoor air-water" heat pump in heating and domestic hot water system inside a multi-occupancy dwelling house. The study set out to compare a conventional system using the city's district heat supply with one using an "outdoor air-water" heat pump. One part of the analysis is the energy performance of the renewable energy source. The study is also addressed the benefits of saving on conventional heat source and the period of financial return on the heat pump investment.

Keywords: *energy consumption*, *heat pump*, *savings*, *period of financial return*, *multi-occupancy domestic property/building/dwelling house*

S t r e s z c z e n i e

W artykule opracowano tabelaryczną analizę systemu ogrzewania i ciepłej wody użytkowej w domu wielorodzinnym, z zastosowaniem pompy ciepła „woda-powietrze". Badania przeprowadzono dla porównania konwencjonalnego miejskiego systemu ogrzewania z systemem pompy ciepła „woda-powietrze". Jedną z części analizy jest charakterystyka energetyczna źródła energii odnawialnej. Analizy przedstawiają korzyści z oszczędzania przy zastosowaniu konwencjonalnego źródła ciepła oraz okres zwrotu finansowego z inwestycji w pompę ciepła.

Słowa kluczowe: *zużycie energii*, *pompa ciepła*, *oszczędność*, *okres zwrotu*, *budynek wielorodzinny*

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1. Description of the selected multi-dwelling house

A multi-dwelling house (comprising 8 floors above ground) was selected for the study. It has a flat roof; the total heated floor area is 2.189 m^2. There are 32 flats in the building, with a total of 96 occupants. The building is supplied with thermal energy through the city's district heating system. This energy supply is used for heating and domestic hot water system within the property. The city's energy supply is fuelled by natural gas and black coal. The building's pre-renovation construction did not provide for sufficient heat transmittance values (*U*-values), when measured against the relevant standard requirements [1] (Table 1).

Table 1

***U*-values of the building constructions (before renovation)**

Building constructions	Current value	Standardized value
	U [W/(m^2·K)]	U_N [W/(m^2·K)]
External wall	0.46	0.32
Flat roof	0.52	0.20
Ceiling above the unheated floor	1.24	0.75
Old windows	2.40	1.70
New windows	1.45	1.70

The average consumption of domestic hot water in the selected house was calculated as 35 litres per person per day. Table 2 contains the actual thermal energy consumption figures for the heating and the domestic hot water system in the multi-occupancy dwelling house.

Table 2

Actual thermal energy consumption in multi-dwelling house (before renovation)

Period	Thermal energy consumption [kWh/year]	
	Heating system	Domestic hot water system
2010	216.778	129.159
2011	190.527	121.313
2012	185.250	117.172
Average value	197.518	122.548

2. Energy balance

The first task was to identify what energy savings could be achieved by improving the *U*-values of the building's construction in this property. The occupants had vacated the premises to enable a detailed survey to be conducted, with a view to the complete renovation of the building, including thermal insulation of the external walls (ETICS system), the flat roof and the ceiling above the unheated basement floor (Table 3).

On the basis of the results of this survey of the building's constructions, heating system energy savings of 32% are anticipated. Thermal energy consumption levels in the domestic hot water system are unchanged.

Table 3

U-values of building's constructions (after renovation)

Building constructions	Projected value U [W/(m^2·K)]	Standardized value U_N [W/(m^2·K)]
External wall	0.21	0.32
Flat roof	0.15	0.20
Ceiling above unheated floor	0.60	0.75
New windows	1.45	1.70

The occupants were invited to consider the advantages of using electric heat pumps (air--water) for their domestic hot water and general heating system needs in place of the existing source. These proposed alterations, forming part of the building renovation work are examined in the second stage of the energy balance. A new heating supply system was designed to meet this purpose (Fig. 1). The plans called for a set of 4 heat pumps (air-water) to act as the primary heat source with the city's district heating system serving as the back-up heating source.

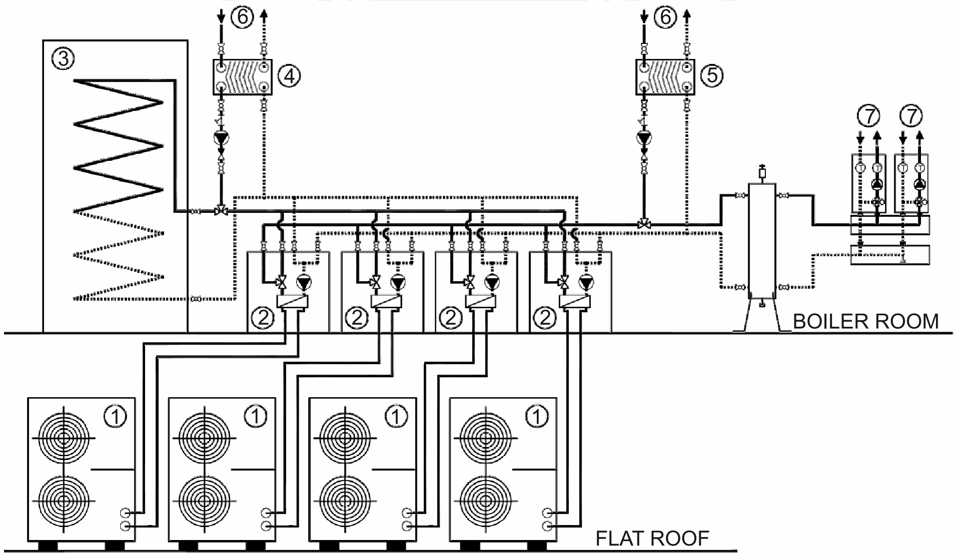

Fig. 1. New heating supply system for the selected multi-occupancy property. Legend: 1 – heat pump (outdoor units), 2 – heat pump (indoor units), 3 – domestic hot water storage, 4 – brazed plate heat exchanger (for the domestic hot water system), 5 – brazed plate heat exchanger (for the heating system), 6 – city's district heating system, 7 – heating system of the multi-dwelling house

Four sets of electric-powered high-temperature heat pumps were designed to act as the primary heating source, with a total heating capacity of 64 kW. The plan is to place the outdoor units on the flat roof of the building, and the indoor units in the boiler room (at the basement level). These heat pumps are capable of warming the water to a temperature of up to 80°C. Improving the thermal insulation of the building's constructions offered further reductions in the level of heat loss from the house. It is therefore possible to reduce the temperature of heating medium. For the purposes of this case study, a maximum output temperature of 65°C at from the heat pumps is considered to be appropriate. The number of heat pumps was set to a bivalent point of –5°C. The heat pumps were designed to work in combination with the city's district heating system, in order to provide the capacity for heating the property when outdoor temperatures fell to lower levels. Heat from the city's district heating system is delivered by designed brazed plate heat exchanger (Fig. 1, Item 5). A domestic hot water storage system was designed, to hold domestic hot water to a volume ratio of 1.500 liters, according to the ČSN 06 0320 standard [2]. Hot water consumption was set at 35 litres per person, per day. When required, the domestic hot water storage system can be supplemented with supplies from the proposed brazed plate heat exchanger connected to the city's district heating system (Fig. 1, Item 4). When these primary and secondary heating sources are combined, the heat provided through the city's district system accounts for only 5.9% of the building's total thermal energy demand. The electricity energy demand

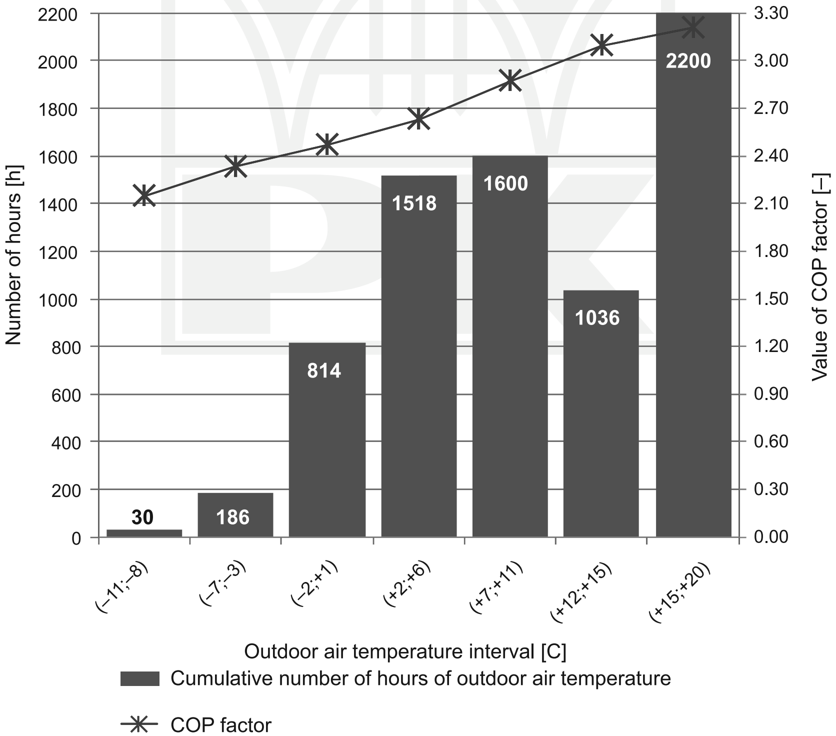

Fig. 2. Frequency of selected outdoor temperature readings and COP factor values

of the heat pumps was assessed on the basis of a COP factor set at 2.89. This value was calculated as the weighted average, based on outdoor temperature readings [3] for heating period (Fig. 2, Table 4).

Table 4

Capacity parameters of the heat pump with water at 65°C (Δθ = 10 K, 22.9 l/min)

Outdoor temperature [°C]	Heating capacity [kW]	Power input [kW]
–15	14.0	6.52
–7	15.8	6.78
–2	16.0	6.48
2	16.0	6.08
7	16.0	5.57
12	16.0	5.17
15	16.0	4.99

The graph below shows the energy consumption (current state) and energy demand (1st and 2nd variant) for the domestic hot water and heating system in the building (Fig. 3).

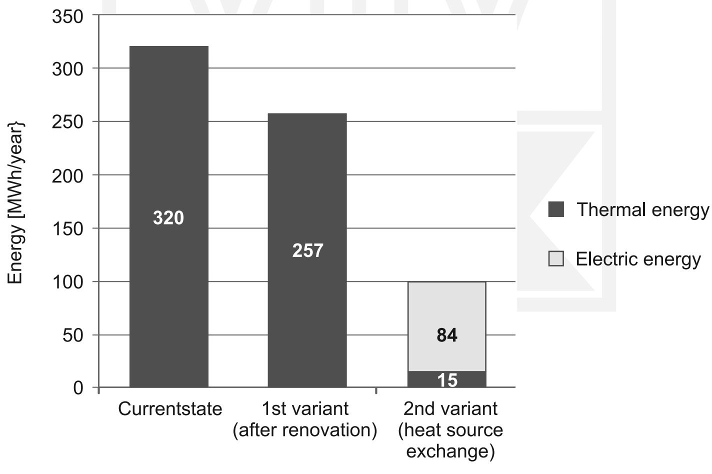

Fig. 3. Energy consumption (current state) and energy demand (1st and 2nd variant) for the domestic hot water and heating system in the building

Implementing the first (renovation) variant can bring energy savings of 20% in terms of the total energy consumption for the domestic hot water and heating system. Further improvements in terms of the heat pump technology can result in progressive energy savings of up to 69%.

3. Financial costs and benefits

It is necessary to conduct a full financial cost and benefits assessment in order to calculate the level of investment required to carry out the necessary renovation work in such a multi--occupancy property; to identify potential financial savings and to determine the financial return on the resources outlayed. In terms of the first variant, the proposed renovation work requires an investment of 186.264 Euros. This amount includes the necessary building materials and the price of the works. If the heat source exchange is included in the price, then the investment level rises by a further 63.403 Euros. This total sum covers the cost of the heat pumps, the domestic hot water storage, the brazed plate heat exchangers, the circulation pumps, piping, thermal insulation and installation of the above. The investment figure also includes VAT.

In order to calculate the energy prices for the domestic hot water and general heating system in the building, energy suppliers's current prices were applied (Table 5) [4–5].

Table 5

The price of thermal and electricity energy including VAT

Thermal energy prices from the city's district heating supply		Electricity energy prices	
Variable price [Euro/kWh]	Fixed price [Euro/kW]	Variable price [Euro/kWh]	Fixed price [Euro/point of supply]
0.04992	262.9393	0.115	5.123

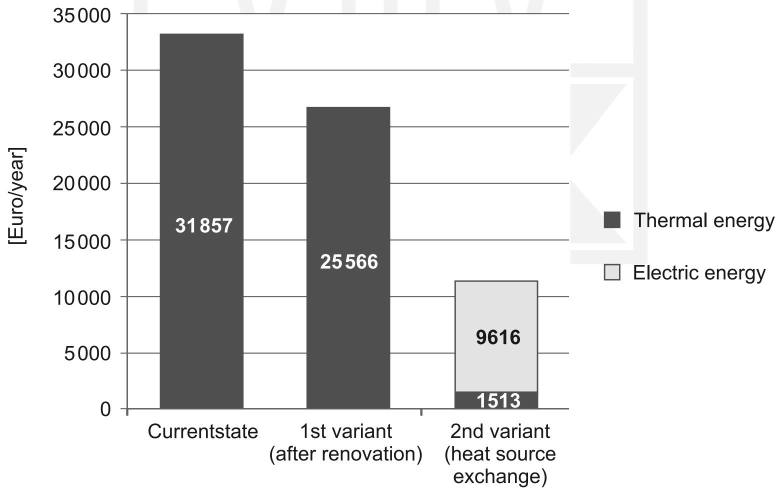

Fig. 4. Energy prices for the domestic hot water and heating system in the multi-occupancy building

Implementing the first (renovation) variant can bring about financial savings of 20% on the total operational costs of running the domestic hot water and heating system. Installing the heat pumps should reduce these operating costs by 65%, in relation to current amounts.

4. Conclusions

Implementing the first variant raises the prospect of achieving 30% energy savings – which is sufficient, but this requires a considerable commitment to invest in the necessary resources. Consequently the return on investment outlayed period is of the order of 29 years. If energy prices were to rise by 4% [6], then the investment return period is estimated to be 19 years.

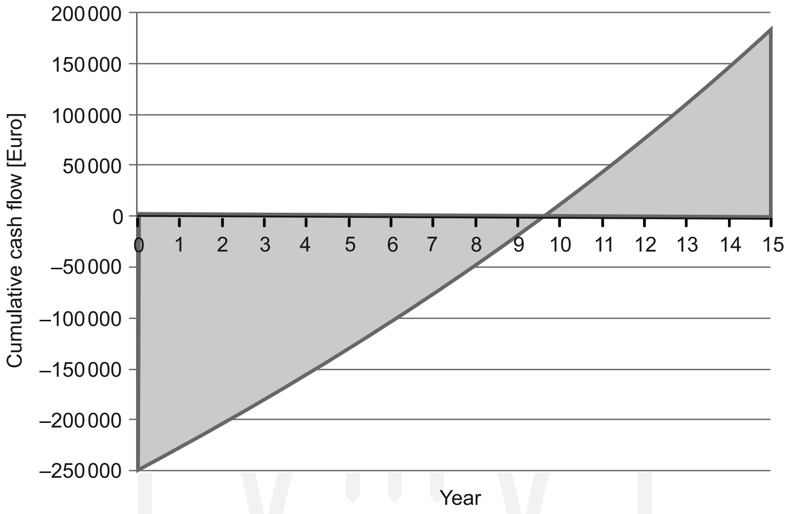

Fig. 5. The return on investments (building renovation work combined with the installation of heat pumps)

In the case of this particular property, a suitable solution is to combine the installation of heat pumps for the domestic hot water and heating system with renovation work on the building. It offers the potential to deliver clear energy and financial savings within a shorter investment return period of some 12 years. Should energy prices rise by 4% [6], then the investment return period reduces to 10 years (Fig. 5). The heat pumps are assumed to have operating lifespans of about 15 years.

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