JOURNAL OF ENERGY TECHNOLOGY
Vol. 19, No. 1, pp. 55–68, July 2026

Original Scientific Article

USING A HIGH-TEMPERATURE HEAT PUMP FOR HEATING GREENHOUSES

Submitted
4. 6. 2026

Accepted
26. 6. 2026

Published
15. 7. 2026

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Abstract Greenhouse heating is associated with high energy consumption and operating costs, particularly during winter conditions. This study investigates the application of a geothermal high-temperature heat pump for greenhouse heating in northeastern Slovenia. A case study greenhouse used for rose cultivation was analysed, to determine heat losses, heating demand and economic feasibility. The heat loss calculations were performed using the greenhouse geometry, the thermal properties of double-wall polycarbonate panels, and the minimum outdoor temperatures recorded between October 2023 and April 2024. The results showed that the maximum heating demand reached 91.31 kW, exceeding the capacity of the existing 80 kW electric heater. Consequently, a Thermeco2 HHR180 high-temperature heat pump was selected, with a heating capacity of 130 kW and a coefficient of performance (COP) of 4.78. An economic analysis indicated annual savings of €29,143.07 and a payback period of 6.55 years. The findings confirm that high-temperature heat pumps represent a technically feasible and economically viable solution for improving energy efficiency and sustainability in greenhouse production.

Keywords
geothermal high-temperature heat pump, greenhouse heating, greenhouse, heat losses, renewable energy sources

https://doi.org/10.18690/jet.19.1.53-68.2026

1 Introducton

Agricultural production is challenged increasingly by rising energy costs and environmental requirements. Greenhouse cultivation enables year-round production of flowers, vegetables and other high-value crops by providing controlled environmental conditions. However, maintaining the required indoor temperature during colder periods results in substantial energy consumption and operational costs.

Conventional greenhouse heating systems are commonly based on direct electric heating, natural gas, fuel oil, or biomass. Although these systems are capable of maintaining the desired thermal conditions, they often exhibit low energy efficiency, or generate considerable greenhouse gas emissions. Consequently, there is a growing interest in alternative heating technologies, that can reduce energy consumption while maintaining stable climatic conditions.

High-temperature heat pumps have emerged as a promising solution for applications requiring elevated supply temperatures. Unlike conventional heat pumps, these systems can produce water temperatures exceeding 80 °C while maintaining relatively high efficiency. Recent developments in refrigerants, compressor technologies and system integration have expanded their applicability in industrial processes, district heating systems and agricultural facilities significantly (Cox & T. L. J., 2023; Sun et al., 2023).

Previous studies have demonstrated that heat pump systems can reduce energy consumption in greenhouse applications significantly. Improved energy performance and reduced operating costs were reported when geothermal heat pumps were implemented in greenhouse heating systems (Anifantis et al., 2016). Furthermore, the integration of renewable heat sources contributes to lower greenhouse gas emissions and the improved sustainability of agricultural production.

The objective of this study is to evaluate the technical and economic feasibility of implementing a geothermal high-temperature heat pump for greenhouse heating. A case study greenhouse was analysed, used for rose cultivation in northeastern Slovenia. The research includes the determination of thermal losses, calculation of the required heating capacity, selection of a suitable heat pump and assessment of the investment costs and payback period.

2 Materials and Methods

2.1 Case Study Description

The investigated greenhouse is located in the vicinity of Maribor, Slovenia, and is used for commercial rose cultivation, as shown in Figure 1. The greenhouse consists of a steel structure covered with 10 mm double-wall polycarbonate panels. Due to the relatively high thermal transmittance of greenhouse covering materials compared with conventional buildings, the heating demand remains substantial during winter conditions.

Figure 1: Greenhouse used for rose cultivation in the case study
Source: own

The greenhouse dimensions were determined according to published greenhouse design guidelines (Nemali, 2021). The greenhouse width is 11 m, the length is 36 m and the sidewall height is 2.3 m.

The total envelope area was determined according to the greenhouse geometry using Equation (1):

$$A = 2ac + 2bc + (\pi ab/2) + (\pi a^2/4) \quad (1)$$

where A represents the total greenhouse envelope area (m²), a is the greenhouse width (m), b is the greenhouse length (m), and c denotes the sidewall height (m). The calculated total envelope area equals 933 m².

The target indoor temperature during the heating season was set to 16 °C, which corresponds to the typical cultivation requirements for roses.

2.2 Climatic Data

The thermal calculations were based on meteorological data obtained from the Slovenian Environment Agency (Agencija Republike Slovenije za okolje [ARSO], 2024). The analysis considered the minimum recorded monthly temperatures between October 2023 and April 2024, representing the heating season relevant for greenhouse operation.

The minimum temperatures were:

- October: –2.3 °C
- November: –6.5 °C
- December: –11.0 °C
- January: –15.2 °C
- February: –13.7 °C
- March: –7.8 °C
- April: –2.9 °C

These values were used to determine the maximum temperature difference between the indoor and outdoor conditions for each month.

2.3 Heat Loss Calculation

The heat losses through the greenhouse envelope were calculated using the standard heat transfer equation (2):

$$Q_{env} = U_{env} \times A_{env} \times \Delta T \quad (2)$$

where Q_{env} is the heat loss through the greenhouse envelope (W), U_{env} is the thermal transmittance coefficient of the envelope (W/m²K), A_{env} is the envelope area (m²), and ΔT represents the temperature difference between the indoor and outdoor environments (K). For the 10 mm double-wall polycarbonate panels, a thermal transmittance coefficient of 2.5 W/m²K was adopted according to manufacturer`s specifications (Akripol, 2014).

The ground heat losses were determined using Equation (3):

$$Q_g = U_g \times A_g \times \Delta T \quad (3)$$

where Q_g denotes the heat loss through the ground (W), U_g is the ground thermal transmittance coefficient (W/m²K), and A_g is the greenhouse floor area (m²). A ground thermal transmittance coefficient of 1.5 W/m²K was adopted, based on the published thermal property data (Engineering ToolBox, 2024).

The total required heating capacity was obtained as the sum of the envelope and ground heat losses, as shown in Equation (4):

$$Q = Q_{env} + Q_g \quad (4)$$

where (Q) represents the total heating capacity required to maintain the desired indoor temperature within the greenhouse.

2.4 Heat Pump Selection

A suitable high-temperature heat pump was selected following the determination of the peak heating load. The selection criteria included:

– the heating capacity,
– the coefficient of performance (COP),
– the operating temperature range,
– compatibility with the groundwater heat sources,
– economic feasibility.

A Thermeco2 HHR180 geothermal high-temperature heat pump was selected based on the calculated peak heating demand, (ENGIE, 2024) .

3 Results

3.1 Heat Loss Analysis

Table 1 presents the calculated heat losses and heating requirements during the analysed heating season.

Table 1: Monthly heat losses and required heating capacity

Month	Minimum temperature (°C)	Ground losses (kW)	Envelope losses (kW)	Heating demand (kW)
October	-2.3	10.87	42.68	53.55
November	-6.5	13.37	52.48	65.85
December	-11.0	16.04	62.98	79.02
January	-15.2	18.53	72.77	91.31
February	-13.7	17.64	69.28	86.92
March	-7.8	14.14	55.51	69.65
April	-2.9	11.23	44.08	55.31

The variation in the heating demand throughout the heating season is illustrated in Figure 2.

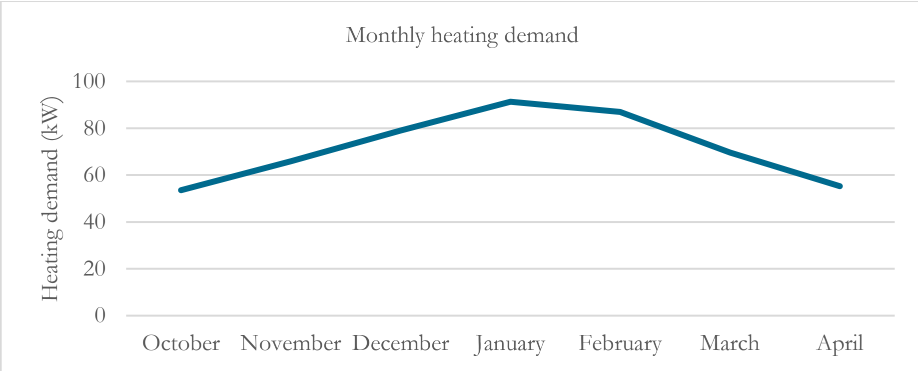

Figure 2: Monthly heating demand of the greenhouse during the heating season
Source: own

The results indicate that the heating demand depends strongly on outdoor temperature. The maximum heating load occurred during January and reached 91.31 kW. The existing electric heater installed in the greenhouse has a nominal capacity of 80 kW. Consequently, the existing system is unable to maintain the desired indoor temperature under the most demanding winter conditions.

3.2 Heat Pump Selection Results

Based on the calculated peak heating demand, The Thermeco2 HHR180 heat pump was selected based on the calculated peak heating demand. The main technical characteristics are summarised in Table 2.

Table 2: Main technical characteristics of the selected heat pump

Parameter	Value
Heating capacity	130 kW
Cooling capacity	85 kW
Maximum electrical power consumption	60 kW
COP	4.78
Refrigerant	CO_2
Maximum outlet temperature	90 °C

The selected heat pump provides sufficient reserve capacity above the calculated peak demand, ensuring reliable operation during extreme weather conditions.

Although the calculated peak heating demand of the greenhouse was 91.31 kW, the selected heat pump has a nominal heating capacity of 130 kW. This difference is related primarily to the limited range of commercially available units offered by the manufacturer, as no intermediate model with a capacity closer to the calculated demand was available. Therefore, the next larger unit was selected, to ensure reliable operation under extreme weather conditions.

According to the manufacturer's technical documentation, the coefficient of performance (COP) of the selected heat pump depends on the operating conditions, particularly the heat source temperature and the heating water supply temperature. The reported COP value of 4.78 corresponds to the operating conditions specified by the manufacturer, and was therefore adopted for the purposes of this study (ENGIE, 2024).

In addition, the selected capacity provides opportunities for future expansion of the heating system. A residential building located in the immediate vicinity of the greenhouse could potentially be connected to the same heat pump system for space heating and domestic hot water preparation. Consequently, the additional capacity increases the flexibility of the installation, and may improve the overall utilisation of the heat pump throughout the year.

4 Economic Analysis

The estimated investment cost includes the heat pump unit, installation works and groundwater wells required for the water-to-water system configuration.

The total investment cost was estimated at €190,000. The investment costs for the groundwater wells were estimated according to the published market price data (Daibau International, 2024). The greenhouse is currently heated using electric resistance heating. Based on the annual heat demand and published electricity prices, the annual heating cost was estimated at €36,854.94 (GEN-I, 2023).

The annual heating cost of the existing electric resistance heater was calculated according to Equation (5):

$$C_{EH} = Q_{annual} \times c_e \tag{5}$$

Substituting the calculated values gives:

$$C_{EH} = 196{,}332 \times 0.18776 = 36{,}854.94\ €$$

where C_{EH} is the annual heating cost (€), Q_{annual} is the annual heating demand (196,332 kWh), and c_e is the electricity price (0.18776 €/kWh).

After the implementation of the heat pump the annual electricity consumption was reduced significantly due to the high COP value.

The annual electricity consumption of the heat pump was determined from the annual heating demand and the coefficient of performance (COP):

$$E_{HP} = \frac{Q_{annual}}{COP} \tag{6}$$

where E_{HP} is the annual electricity consumption of the heat pump (kWh).
Substituting the calculated values:

$$E_{HP} = \frac{196{,}332}{4.78} = 41{,}073\ \text{kWh/year}$$

The annual operating cost of the heat pump was then calculated as:

$$C_{HP} = E_{HP} \times c_e \tag{7}$$

which resulted in

$$C_{HP} = 41{,}073 \times 0.18776 = 7{,}711.87\ €$$

A comparison of the annual heating costs for the existing electric heater and the proposed heat pump system is presented in Figure 3.

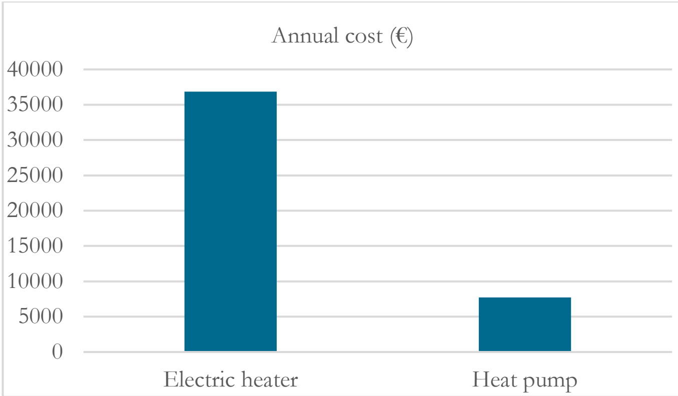

Figure 3: Comparison of the annual heating costs for the existing electric heater and the proposed heat pump system

Source: own

The annual savings were determined as the difference between the annual heating costs of the existing electric heater and the proposed heat pump system:

$$S = C_{EH} - C_{HP} \tag{8}$$

where S represents the annual savings (€).

Substituting the calculated values gives:

$$S = 36{,}854.94 - 7{,}711.87 = 29{,}143.07 \text{ €}$$

The simple payback period was calculated using Equation (9):

$$PB = \frac{I}{S} \tag{9}$$

where PB is the payback period (years), I is the investment cost (€190,000), and S is the annual savings.

Substituting the calculated values yields:

$$PB = \frac{190\,000}{29\,143.07} = 6.55 \text{ years}$$

The calculated payback period should be interpreted as an approximate value, as the analysis was performed under simplified assumptions and ideal operating conditions. Future changes in electricity prices, maintenance requirements and actual system performance may affect the economic viability of the proposed solution.

The economic analysis was based on the investment costs, electricity consumption and current electricity prices. The maintenance and servicing costs of the heat pump system were not included in the calculation, and therefore represent a limitation of the presented economic assessment. However, these costs are generally considerably lower than the achieved annual energy savings, and are not expected to affect the overall economic feasibility of the proposed solution significantly.

5 Discussion

The obtained results demonstrate that high-temperature heat pumps represent a technically feasible solution for greenhouse heating applications. The calculated peak heating demand of 91.31 kW confirms that the existing 80 kW electric heater is insufficient under extreme winter conditions, highlighting the need for a more efficient heating system.

The selected Thermeco2 HHR180 heat pump provides a substantial safety margin, while maintaining a high coefficient of performance. Similar findings have been reported, identifying high-temperature heat pumps as an effective technology for replacing conventional electric and fossil-fuel-based heating systems (Cox & T. L. J., 2023). The achieved COP value of 4.78 is consistent with the performance range reported for modern high-temperature heat pump systems (Sun et al., 2023). Such efficiency enables significant reductions in the electricity consumption and operating costs.

From an economic perspective, the calculated payback period of 6.55 years can be considered favourable given the expected service life of the equipment, which typically exceeds 20 years. After the payback period, the system continues generating considerable annual savings.

In addition to the economic benefits, the proposed solution contributes to environmental sustainability. The reduced electricity consumption lowers greenhouse gas emissions indirectly and supports the transition towards low-carbon agricultural production.

6 Conclusions

This study investigated the application of a geothermal high-temperature heat pump for greenhouse heating in northeastern Slovenia.

The heat loss calculations revealed that the greenhouse requires a maximum heating capacity of 91.31 kW during the coldest winter period. Replacement with a more efficient heating technology was considered, since the existing 80 kW electric heater cannot satisfy this demand.

A Thermeco2 HHR180 high-temperature heat pump was selected with a heating capacity of 130 kW and a COP of 4.78. The economic analysis demonstrated annual savings of €29,143.07 and a payback period of 6.55 years.

The results confirm that high-temperature heat pumps can provide reliable greenhouse heating while reducing operating costs and improving energy efficiency significantly. The technology therefore represents a promising solution for sustainable greenhouse production and broader agricultural decarbonisation efforts.

Future research could focus on a more detailed analysis of the seasonal performance of high-temperature heat pumps under varying operating conditions. Additionally, further studies could investigate the integration of greenhouse heating systems with nearby residential buildings and domestic hot water preparation, in order to improve the overall utilisation of the installed heating capacity and enhance the economic performance of the system.

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Povzetek v slovenskem jeziku

Uporaba visokotemperaturne toplotne črpalke za ogrevanje rastlinjakov. Ogrevanje rastlinjakov je povezano z visoko porabo energije in visokimi obratovalnimi stroški, zlasti v zimskem obdobju. Prispevek obravnava uporabo geotermalne visokotemperaturne toplotne črpalke za ogrevanje rastlinjaka v severovzhodni Sloveniji. Analiziran je bil rastlinjak za gojenje vrtnic z namenom določitve toplotnih izgub, potreb po ogrevanju in ekonomske upravičenosti investicije. Izračuni toplotnih izgub so bili izvedeni na podlagi geometrije rastlinjaka, toplotnih lastnosti dvojnostenskih polikarbonatnih plošč ter najnižjih zunanjih temperatur, zabeleženih v obdobju od oktobra 2023 do aprila 2024. Rezultati so pokazali, da največja potrebna moč za ogrevanje znaša 91,31 kW, kar presega zmogljivost obstoječega električnega grelnika moči 80 kW. Zato je bila izbrana visokotemperaturna toplotna črpalka Thermeco2 HHR180 z grelno močjo 130 kW in grelnim številom (COP) 4,78. Ekonomska analiza je pokazala letni prihranek v višini 29.143,07 € in vračilno dobo investicije 6,55 leta. Ugotovitve potrjujejo, da visokotemperaturne toplotne črpalke predstavljajo tehnično izvedljivo in ekonomsko upravičeno rešitev za izboljšanje energetske učinkovitosti in trajnosti pri pridelavi v rastlinjakih.