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Ground-source Heat Pump Systems for Sustainable Greenhouse Facilities

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Summary

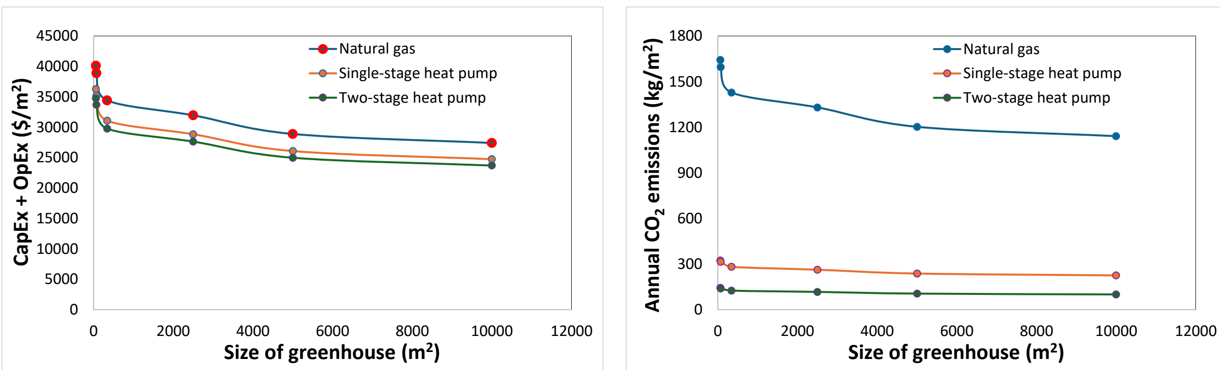
The greenhouse farming has gained popularity as the demand for agricultural products is increasing due to the population growth and adverse weather conditions. During its operation, the greenhouse heating plays a critical role in maintaining an ideal temperature for plant growth, yet the associated carbon footprint poses a challenge to the broader goals of environmental stewardship. As per the global initiatives and Canada's target of net-zero emissions by 2050, there is a pressing need for the energy transition towards low-carbon alternatives for greenhouse heating. Utilizing the geothermal energy with the help of heat pump systems could be a viable substitute for the traditional fossil fuel burning that would significantly lower carbon emissions and reduce energy requirements of the greenhouse heating. It is therefore our goal to evaluate the feasibility of employing ground-source heat pump technology to harvest shallow geothermal energy and convert it to usable heat for agricultural greenhouse facilities. Various heat pump cycles were analyzed for energy requirements so as to identify the high-efficiency heat pump configurations. A techno-economic model was developed specifically for an integrated ground-source heat pump and greenhouse system operated in a cold climate like the province of Saskatchewan. The system performance was evaluated in terms of energy consumption, cost and carbon emissions.

Method

The Aspen Plus process simulator was employed for assessing the performance of heat pump cycles as the Coefficient of Performance (COP), the ratio of the heat output from a condenser to the work input to a compressor. The agricultural greenhouse facilities of study were gable-shaped with various sizes (60 m^2, 72 m^2, 340 m^2, 2501 m^2, 5002 m^2 and 10 000 m^2), each with a single layer of polyethylene film covering. A number of factors was accounted for the analysis of greenhouse heat losses, including plant types, covering materials, greenhouse dimensions, meteorological data, HVAC ventilation standards, solar irradiation, soil properties, and ground conditions. The operating costs of both traditional natural gas furnace and heat pump systems included costs of natural gas/electricity, basic monthly charge, federal carbon tax, municipal surcharge tax, and GST. The capital cost estimate for the natural gas furnace incorporated unit cost, installation cost and equipment lifetime while that for the heat pump systems took into account: 1) unit cost, installation cost and lifetime of heat pumps, 2) excavation cost, and 3) unit cost, installation cost and lifetime of the ground-loops. The economic basis including interest rate, lifetimes of project, heat pump and furnace, was set for the Net Present Worth (NPW) analysis. The carbon footprint analysis considered SaskPower's electricity production by fuel usage, i.e. 40% natural gas, 36% renewable energy, and 24% coal.

Results

The ground-source heat pumps can achieve the COP in the range of 3.7 – 4.0 in Saskatchewan's climates. The two-stage vapor compression heat pump yields a higher COP than the single-stage vapor compression heat pump. The heat required for all sizes of greenhouse facilities is primarily used for compensating the conduction-convection heat loss through greenhouse's exterior walls and roofs (69%) followed by the ventilation heat loss via HVAC operation (23%) and the conduction heat loss through soil or building foundation (7%). Using the ground-source heat pumps for greenhouse heating can lead to 74 – 76% energy saving, 39 – 51% operating cost saving and 80 – 91% carbon emission reduction compared to the traditional heating using natural gas furnaces. However, the capital investment of a heat pump system is considerably high with the increment of 167 – 190% from the baseline cost derived from the natural gas furnace. By combining the capital and operating costs, the NPW of the heat pump systems is about 11 – 16% lower than that of the natural gas furnace.



(a) (b)

Figure 1: Performance comparison of heat pump and natural gas furnace; a) NPW and b) carbon footprint.

Conclusions

The ground-source heat pump system is an attractive alternative heating source for the traditional fuel-burning furnace. It provides clean and energy-efficient heating for greenhouse facilities in cold climates with lower operating cost and carbon emissions. The challenge of the heat pump deployment is the high capital investment.

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