Evaluating Carbon Dioxide Heat Pumps for Residential Use Utilizing a Building Energy Performance Simulation

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Introduction

Carbon dioxide heat pumps are an emerging heat pump technology that utilize carbon dioxide as a refrigerant instead of a traditional hydrofluorocarbon refrigerant. CO_2 heat pumps have several potential benefits.

- **Low Global Warming Potential**
  Traditional refrigerants can contribute to global warming at rates more than 1000x that of CO_2 if released into the environment. CO_2 heat pumps greatly decrease the environmental impact of refrigerant leakage or improper disposal.

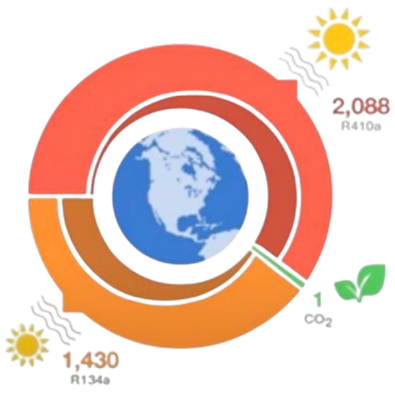

Fig. 1. Relative Global Warming Potential of CO_2 [1]

- **High Temperature System Compatibility**
  Many homes use high-temperature systems powered by oil or gas boilers. Most heat pumps can't reach these temperatures, requiring major system changes. CO_2 heat pumps, however, can deliver higher output temperatures, making them compatible with existing heating setups.

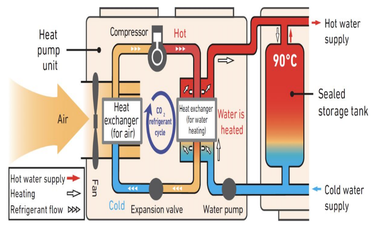

Fig. 2. Air to water CO_2 heat pump [2]

However, there are some challenges to CO_2 heat pump implementation.

- **Limited market availability**
  CO_2 heat pumps aren't widely available for purchase in Ireland.
- **Specialized Design**
  CO_2 heat pumps require specialized parts to support operation in a transcritical cycle, which csn increase cost.
- **General Heat Pump Limitations**
  Upfront installation costs and system compatibility challenges are main deterrents of heat pump installation.

Project goal: Analyze the impact of a CO_2 heat pump on the energy usage of an Irish home using a building energy performance simulation.

Methods

This project utilized a building energy performance simulation (BEPS) produced in a research project previously completed in the UCD Energy Institute (Egan et. al, 2018). This research used sensitivity analysis of input variables to create a simplified BEPS requiring only the most influential input variables. For this project, the simplified BEPS was used to analyze how changing heat pump COP affected overall energy performance. All other input variables were held constant while the COP input was varied between 2.5 and 4.5 at intervals of 0.5, in accordance with CO_2 heat pump COP values identified in literature review.

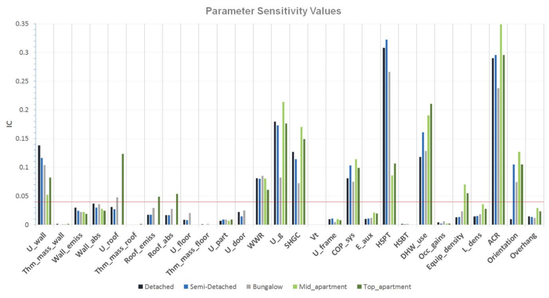

Fig. 3. Sensitivity analysis study results [3]

As shown in Fig. 3, the study tested 28 parameters over 5 different dwelling types for relative influence. Of those 28 parameters, 8 were identified to be included in the simplified model for a detached house, having an influence coefficient above 0.04.

Results

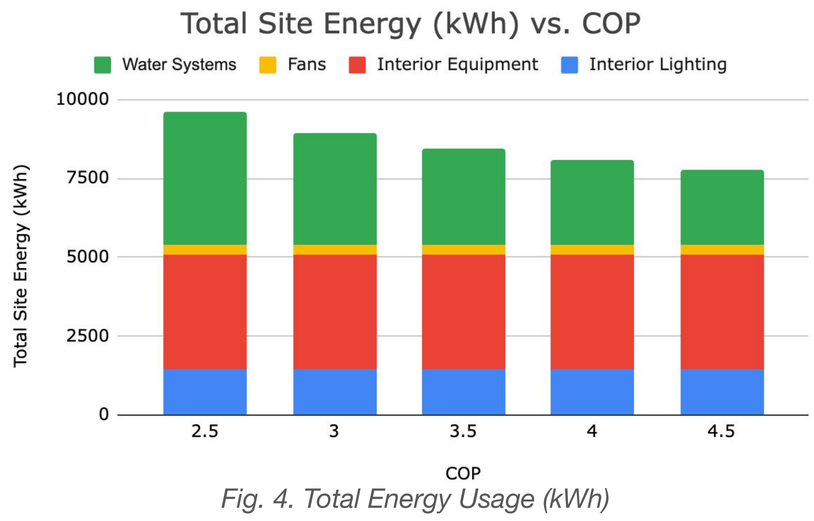

Fig. 4. Total Energy Usage (kWh)

Total Site Energy Usage

Total site energy usage, simulated over the course of a year, decreased as COP increased. COP only affected water systems energy usage, as the air to water heat pump only impacts the water system.

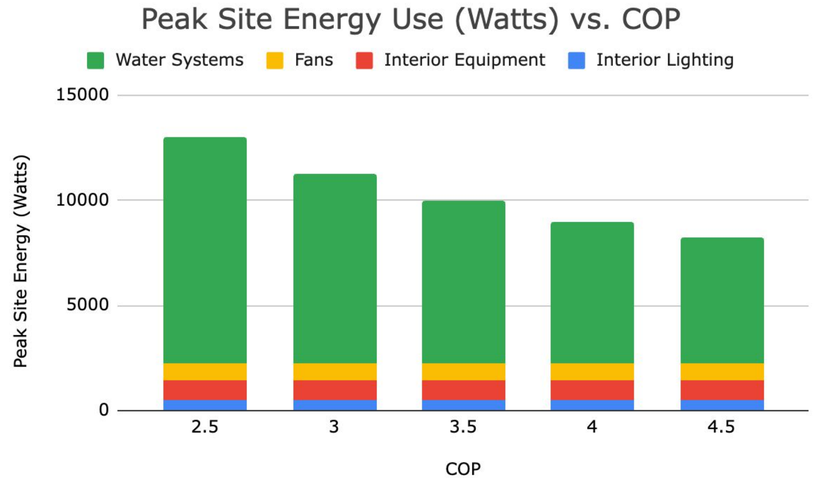

Fig. 5. Peak Energy Usage (Watts)

Peak Site Energy Usage

The peak site energy consumption was identified as occurring at night during winter climatic conditions, leading to lower energy use on interior equipment and lighting but higher use on the water heating system. Total energy use decreased with an increase in COP.

Conclusions

The results show that CO_2 heat pumps can improve the energy efficiency of Irish homes. Higher performance levels lead to lower water system energy use. Combined with the environmental and system compatibility benefits of using CO_2 as a refrigerant, these heat pumps offer a promising alternative to traditional refrigerants worth further study.

References

1. *All About C02 Domestic Hot Water Heat Pumps*. Directed by GreenHome Institute, https://www.youtube.com/watch?v=7RHtQAh8Ahc&t=1015s.
2. "CO2 Heat Pump Hot Water Heating Solutions." *Automatic Heating*, https://automaticheating.com.au/solutions/co2-heat-pump-hot-water-heating-solutions/.
3. Egan, James, et al. "Definition of a Useful Minimal-Set of Accurately-Specified Input Data for Building Energy Performance Simulation." *Elsevier*, 2018, https://www.sciencedirect.com/science/article/pii/S0378778818301804?via%3Dihub.