U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Office

Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies

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C.3.9 Vuilleumier Heat Pump

Brief Description	Similar to Stirling heat pumps, the Vuilleumier heat pump cyclically compresses and expands a gaseous working fluid between different volumes to produce a hot and cold side. With a high-temperature heat source, such as a gas burner, the system can provide space heating and cooling as well as service water heating.	
Unit Energy Savings	**Technical Maturity**	**Cost/Complexity**
Heating: 26% Cooling: 0%	Emerging	Moderate

Technology Characteristics	Value	Comments
Unit Energy Savings	Heating: 26% Cooling: 0% (fossil-fuel-fired)	• Estimated COPs for heating and cooling of 1.6 and 0.8, respectively (ThermoLift 2013). • Approx. 26% savings for heating
Fuel Type(s)	Natural gas	Some electricity for parasitic loads such as fans and pumps.
Working Fluid(s)	Helium	Long-term potential for other working fluids, including: hydrogen, and hydrogen-helium mixtures
Complexity/Size	Moderate	• Compact size estimated for products currently under development • Products would have relatively simple installation with self-contained systems that require water/glycol connections.
Projected Cost	N/A	Cost estimates for HVAC applications are unavailable.
Threshold Attributes	Moderate	Sealed design with few moving parts could offer long lifetimes and low maintenance requirements.
Excitement Attributes	Moderate	Gas-fired heat pump with heating COP over unity that utilizes non-toxic working fluid.
Ability to Utilize Low-Temperature Thermal Sources	Low	Requires high temperatures (500°C and higher).
Technical Maturity	Moderate	Performance has been demonstrated in laboratory, but market-ready prototypes have not been built.
Market Maturity	Low	Vuilleumier heat pumps are not yet commercialized.
Level of Stakeholder Support	Moderate-to-High	• Gas utilities are likely to support this technology as a gas-fired technology for cooling, and improved heating efficiency • Electric utilities will potentially oppose this technology because it requires a fuel switch from electricity to natural gas
Fit with BTO Mission	Moderate	Potentially an attractive thermally activated heat-pump technology that does not use toxic working fluids or require significant maintenance.

Background

Technology Description

Comprising of both a heat engine and a heat pump, the Vuilleumier cycle transfers heat from a high-temperature source, such as a gas burner, to a medium-temperature heat source for space heating, and a low-temperature heat sink for space cooling. Similar to the Stirling cycle, a sealed volume of gas, usually high-pressure helium, undergoes cyclic compression and expansion. Whereas the Stirling-cycle heat pump utilizes a common piston with separated working volumes, the Vuilleumier heat pump circulates the working fluid through three volumes[17] of different temperatures separated by two displacers, as outlined in Figure C-21.

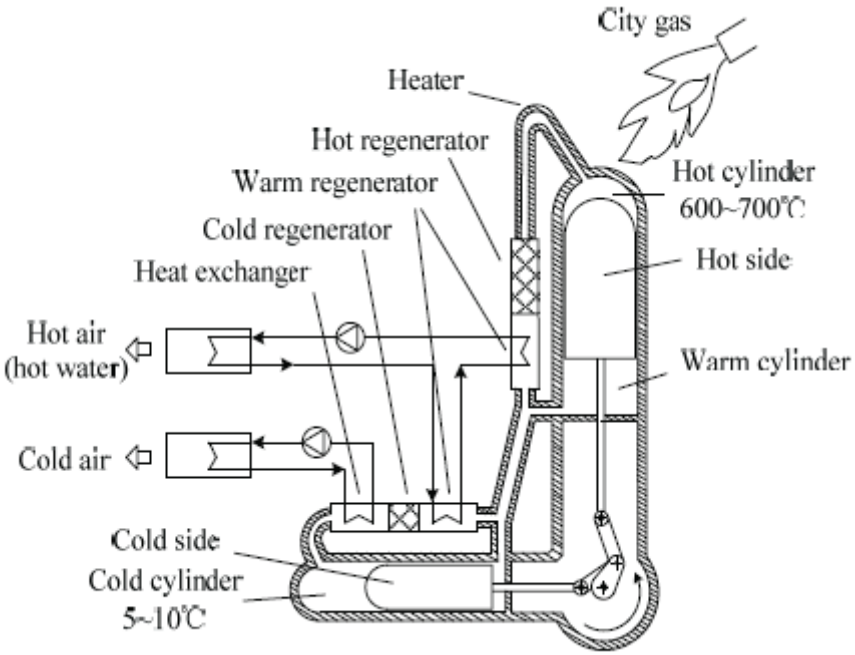

Figure C-21: Schematic of kinematic Vuilleumier heat pump

Source: Xie et al. (2008)

The displacers may operate as a kinematic (as shown in Figure C-21) or free-piston machine (where the displacers share a common vertical shaft), and may require an electrical source to overcome minor frictional and pressure losses. Driven by the high-temperature heat source in the heat-engine portion, the displacers oscillate the working fluid among the hot, warm, and cold volumes. The system achieves high heating COPs by capturing waste heat from the engine portion in addition to the thermal energy generated by the heat pump. A regenerator, made of a porous metal mesh, stores a portion of the thermal energy to pre-heat or pre-cool the gas throughout the cycle for improved efficiency. To deliver the heating and cooling energy to the space, a secondary working fluid, usually water, circulates through the warm and cold heat exchangers.

[17] Three volumes refer to the hot volume, cold volume, and warm volume. Because the warm volume is split between both the hot and cold side of the cycle, some literature refers to four volumes, two of which are at the warm temperature. Because the working fluid is shared between each, it is a matter of preference.

Technical Maturity and Current Developmental Status
Although several groups have studied the Vuilleumier heat pump and its potential for gas-fired space conditioning, no products currently exist on the market. These past and current efforts include:

- Researchers in Germany and Denmark developed several prototypes for space heating and cooling in a residential home (7.5 kW) and fishing vessels (20 kW). Using a lower heating value (LHV) calculation, the units achieved approx. COPs of 1.6 for heating and 0.35 for cooling. (Carlsen 1989). Converting these values to the higher heating value (HHV) of natural gas results in COPs of approx. 1.4 for heating and 0.32 for cooling.
- Sanyo and several Japanese gas utilities investigated Vuilleumier heat pumps for residential space conditioning and service water heating, but the work did not continue (Bakker et al. 2010). Several prototypes were developed, which achieved COP values of 0.56 for cooling and 1.33 for heating (Toshikazu et al. 1999).
- ThermoLift, a start-up associated with Stony Book University, is currently developing a gas-fired Vuilleumier heat pump for residential and commercial space conditioning and service water heating. The company has received several grants from DOE and NYSERDA to build a demonstration prototype and expects heating COPs of 1.6–2.2 and cooling COPs of 0.8–1.2 (ThermoLift 2013). Their technology improves upon earlier mechanically controlled designs by utilizing a magnetic actuation system to precisely control the amplitude and timing of the oscillating displacers. This control mechanism allows the system to optimize efficiency and performance for different operating modes and ambient conditions.

Barriers to Market Adoption
Currently no products on the market utilize Vuilleumier heat pumps. Because cooling COPs are low, energy savings are not expected during the cooling season. For heating-dominated climates, the higher heating efficiency and cost savings may offset the lower cooling efficiency.

Energy Savings Potential
Potential Market and Replacement Applications
The Vuilleumier heat pump would be technically suitable for most residential and commercial applications once developed. The heat pump operates as a sealed system with water heat exchangers that could condition the space directly through a radiant system, or operate through an air-side heat exchanger for ducted systems. The gas burner would require an exhaust vent, similar to other gas-heating equipment.

Energy Savings
At current performance estimates, a fossil-fuel-fired Vuilleumier heat pump would only offer potential source energy savings for space- and service-water-heating applications compared to conventional vapor-compression equipment. Estimating heating COPs of 1.6 (ThermoLift 2013) and parasitic electric consumption (kW) of 0.023 per heating capacity (kW) for distribution systems, fossil-fuel-fired Vuilleumier heat pumps could provide source energy savings for heating of 26% over vapor-compression heat pumps.

Cost, Size, and Complexity

We found only limited cost and operating information for Vuilleumier heat pumps. By utilizing natural gas as the energy source, Vuilleumier heat pumps would have lower operating costs in space- and service-water-heating mode, and potentially in cooling mode. The sealed design could allow for easy installation, requiring only water connections and exhaust vents in the field.

Peak-Demand Reduction and Other Non-Energy Benefits

As a gas-fired technology, the Vuilleumier heat pump would offer peak-demand savings during the cooling season, although the exact benefit will depend on the parasitic loads. Helium is a non-toxic and environmentally benign refrigerant. With minimal moving parts, systems could have long lifetimes and low maintenance requirements.

Next Steps for Technology Development

Table C-22 presents the potential next steps to advance Vuilleumier heat pumps.

Table C-22: Next Steps for the Development of Vuilleumier Heat Pumps

Initiatives
Continue development of demonstration prototypes to benchmark space-heating, space-cooling, and service-water-heating COPs and understand the parasitic energy consumption

References

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