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Supplemental information

Coming in from the cold:
Heat pump efficiency
at low temperatures

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Supplemental Information to Gibb, D. et al, Coming in from the cold: Heat pump efficiency at low temperatures

References for mean January temperatures in Europe and percentage of households in temperature bands

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References for Figure 1

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2. IEA Weather for Energy Tracker – Data Tools. IEA. https://www.iea.org/data-and-statistics/data-tools/weather-for-energy-tracker.

Description of compiled datasets shown in Figure 2

In Switzerland [CH], field tests were carried out in 14 different buildings to evaluate air/water heat pump performance over a full heating season. All systems saw COPs well above 2, even between 3 and 4, around 0°C.

Field tests in southwestern Germany [DE] showed the performance of air/water heat pumps in residential applications. The heat pumps had COPs above 3 even hovering around 0°C and on the coldest day, a COP of 2.4 at -10°C.

In the United Kingdom in [UK], some of the country's coldest days with average temperatures reaching -6°C found only a marginal decline in air-source heat pump performance. Although these data contain some outlying datapoints with COPs less than 2 around 0°C, overall, the median COP was 2.4 during the coldest day of the monitoring period for all homes.

In the United States[i] [US1], 43 homes in the states of New York and Massachusetts were set up with monitoring equipment to evaluate the performance of cold-climate air-to-air heat pumps during real-world cold-weather conditions. Monitoring results showed average COPs around 2.5 when temperatures fell below freezing.

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[i] The authors of this study note that the data collected were not large enough to be statistically significant.

In-field performance testing of an air-source heat pump was carried out during the winter in a well-insulated house in Ontario, Canada [CA]. At the lowest outside air temperature of -19°C, COP was around 1.8, while it reached 5.0 at 9°C. Between -10°C and 0°C, COP averaged 2.75.

In China [CN], a three-month field test of an air-source heat pump system was conducted in one of the country's coldest regions. The system was able to meet the heating demand, even when the ambient temperature fell to -24°C. In mild cold climate conditions, between 5°C and -10°C, COP averaged 2.4.

Also in the United States [US2], field testing was conducted of cold-climate heat pumps in Connecticut which saw COPs above 2.5 below freezing and as high as 2.3 when daily average outside temperatures dropped to -15°C.

Due to their large sizes, the datasets CH and CN were downsampled to 500 measurements to make them more comparable to the other data. This reduced the weight of these samples in the aggregate, but their individual distributions remain the same.

Tables summarizing performance of heat pumps in mild and extreme cold climates

Table 1. Performance summary for heat pumps in mild cold climates

Study	**Average COP measured when outside temperature was between -10°C and 5°C**
[CH] – Switzerland	3.2
[DE] – Germany	3.7
[UK] – United Kingdom	2.5
[US1] – United States, NY and MA	2.5
[CA] – Canada	3.3
[CN] – China	2.4
[US2] – United States, Connecticut	2.7

Table 2. Performance summary for heat pumps in extreme cold climates

Study	**Minimum Temperature (°C)**	**COP at Minimum Temperature**
[FI] – Mitsubishi – MSZ-RW25VG	-30	1.5 – 2.0
[FI] – Toshiba – RAS-25N4KVPG	-30	1.0 – 1.5
[US3] – United States, Minnesota	-12	1.3
[US4] – United States, Alaska	-35	1.8

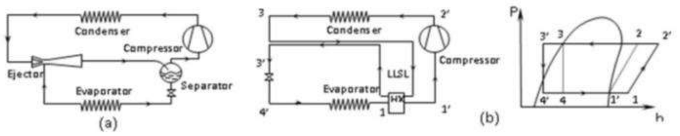
Clarifying note on heat pump performance

It is worth noting that there can be a significant range of performance across heat pumps models, due in part to the device design and in the software used to operate them. Analysing average efficiency can risk obscuring the extremes of performance and this should be considered when selecting a heat pump model that is appropriate for certain climate conditions and heating demands.

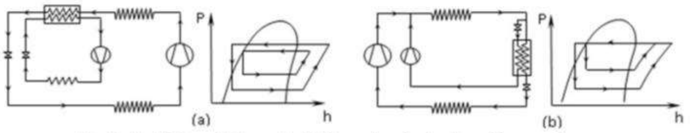
Additional information on performance enhancements for heat pumps

Strategies to enhance heat pump performance include avoiding low compressor speeds and periodically increasing speed to supply lubricant, as well as cycle enhancement, a process that increases evaporator capacity without compromising heat pump delivery temperature.

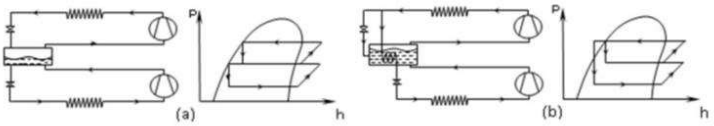
The following figures illustrate potential enhanced cycle options, whose benefits vary according to operating temperatures and refrigerant characteristics.



Cycles with ejector (a) and liquid-line/suction-line heat exchanger (b)



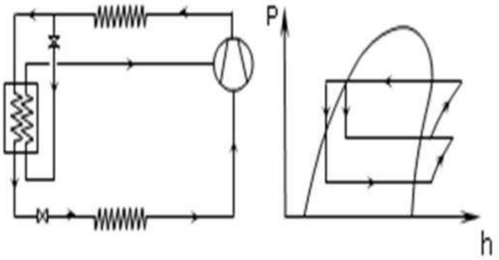
Dedicated (a) and Integrated (b) mechanical subcooling cycles



Two-stage cycles with flash tank economizer (a) and shell-and-coil economizer (b)

Figure 2: Heat Pump Cycle Enhancements

A popular approach is the use of vapour injection, where the refrigerant flow is split into two portions: the larger portion of flow works between the condensing and evaporating pressures as in a single-stage cycle, while the smaller portion of flow only works between the condensing and intermediate pressures. Thus, with not all the refrigerant flow across the whole temperature lift, performance is improved.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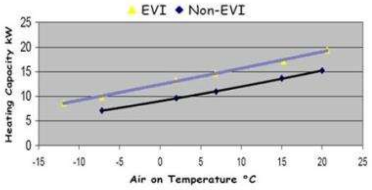
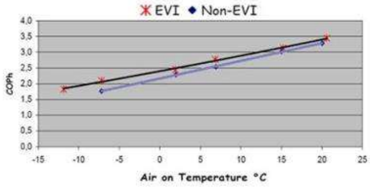

EVI
Non-EVI
Heating Capacity kW
25
20
15
10
5
0
-15
-10
-5
0
5
10
15
20
25
Air on Temperature °C


EVI
Non-EVI
COPh
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
-15
-10
-5
0
5
10
15
20
25
Air on Temperature °C

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