Experience of air to water heat pumps for single family passivhaus dwellings

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Summary

We have monitored a number of air to water heat pumps in passivhaus dwellings and reviewed the design approach in light of our findings:

- CO_2 refrigerant gives good hot water heating performance but poor space heating
- Smallest air to water heat pumps available are over-sized for Passivhaus
- Heat emitter system should at least equal minimum heat pump output
- Zone controls should be minimised in order to maintain emitter output
- Very low hot water storage temperature is key to improve HFC heat pump performance

Introduction

The use of heat pumps is recognised as a key element in switching from fossil fuel heat sources to renewable energy. In the British Isles the normal heating system uses hot water radiators, with domestic hot water heated from the same source as the radiators. The same approach is used in other European countries with similar climates. Unlike in warmer countries there is little history of using air conditioning in houses. Therefore the heat pump systems favoured and promoted with subsidies use air to water heat pumps, with radiator or underfloor heating and domestic hot water systems.

Heat pump performance

Heat pumps transfer thermal energy from the outside air to the dwelling using a refrigeration cycle. A refrigerant liquid is evaporated at the lower temperature, absorbing ambient thermal energy, compressed using electric power to a higher pressure and temperature, and then condenses to release heat at higher temperature. The liquid then goes through an expansion valve where pressure and temperature reduce and the cycle repeats.

This process means that roughly 3 units of heat energy are delivered for each unit of electricity consumed by the heat pump. This ratio is called the coefficient of performance (COP) and summed over the year gives the seasonal performance factor (SPF). More electricity is required for a higher temperature difference between source and output, and less for a lower temperature difference. Therefore space heating systems are designed to run at low temperatures < 45 C, either using large radiators or underfloor heating.

Heat pumps usually use hydrofluorocarbon (HFC) refrigerants, which have very high global warming potential (GWP). Ideally they would never be released, but sometimes equipment fails and leaks occur. An alternative refrigerant is carbon dioxide, which is unusual in that

the heat release stage can take place over a wide temperature range. With careful design of the DHW store it is possible to use the incoming cold water to cool the refrigerant, and so achieve a higher COP than is possible for conventional refrigerants.

Passivhaus application

A Passivhaus has a high proportion of heat demand for DHW, often equal or more than for space heating, so a CO_2 heat pump looks like a good fit. PHPP analysis showed for single family houses that the overall SPF should be around 3, whereas with HFC heat pumps it would be lower, around 2.5.

We have monitored performance of both types in comparable situations, houses approx. 160 m^2, with the following results:

Type	Space heat SPF		DHW SPF		Overall SPF		Note
	PHPP	**Actual**	PHPP	**Actual**	PHPP	**Actual**	
HFC	2.4	**2.8**	2.5	**3.0**	2.5	**2.9**	DHW 50 C
CO2 #1	2.7	**2.0**	2.9	**2.7**	2.7	**2.2**	Low DHW use
CO2 #2	2.4	**2.0**	3.2	**3.2**	2.7	**2.5**	

PHPP model adjusted to actual occupancy and DHW temperature, using 15 test points for heat pumps, with CO_2 unit modelled as two heat pumps since DHW and heating performance is different.

Table 1: Modelled and monitored heat pump Seasonal performance factors

Observations

The CO_2 heat pump has particularly poor heating performance at low load, lower than anticipated though following this finding the manufacturer confirms the COP at minimum output is indeed poor. Re-adjustment of flow temperature settings was tried but no improvement was seen. Good SPF for hot water heating using CO_2 heat is confirmed.

The HFC heat pump performs better than anticipated. The use of a low DHW temperature appears worthwhile and can approach the DHW performance of a CO_2 heat pump.

The size problem

Initially we sized radiator systems for lower flow temperature 35 C to meet the design heat load, expecting to see high SPF. Typically this heat load is around 1.5 kW, however the minimum continuous output of the smallest air to water heat pumps was 2.5 kW. This means that the heat pump would run stop-start with frequent cycles which is inefficient, and reduces the lifespan of the compressor. At commissioning the controls were set for 45 C flow which means that the radiators have sufficient heat output to allow the heat pump to run continuously for longer periods.

Room temperature control was by sensor linked to the heat pump rather than on/off thermostat and no thermostatic radiator valves were used on living room radiators.

Conclusions

CO_2 heat pumps have not proved as beneficial as hoped and the example used did not work well with low heat loads. Conventional refrigerant types can perform well but require larger heat emitter systems than initially realised.