15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Performance degradation of an air source heat pump in a dormer room enclosure

Andries van Wijhe*

*TNO, van Amsterpark 8, 2629JJ Delft, Netherlands

Abstract

In densely populated urban areas, installing the outdoor unit of an air-source heat pump can be challenging due to space and noise constraints. One available solution is integrating the unit into an inverted dormer roof, placing it within the attic space. While this approach offers aesthetic and practical benefits, it may restrict airflow and increase air recirculation, potentially reducing performance. To quantify these effects, a commercial air-to-water heat pump was tested in a climate-controlled chamber under two configurations: with and without the dormer enclosure. Key parameters measured included evaporator inlet air temperature, heating capacity, coefficient of performance (COP), and defrost cycle frequency. Results indicate a full-load capacity reduction of 6–10% when the enclosure is present and requiring approximately 6% higher compressor speed to maintain output in half-load conditions. Frost formation occurred at higher ambient temperatures with the dormer roof in place, so over a heating season the heat pump will have defrost more often. The measurements suggest recirculation as a contributing factor to the performance degradation. These findings highlight the need for careful airflow design in roof-integrated heat pump installations to avoid efficiency losses and increased defrosting.

Keywords: Air source heat pumps, outdoor unit positioning, efficiency, air reciruclation, heat pump frosting;

1. Introduction

The global transition towards low-carbon energy systems requires air source heat pumps to replace fossil fuel based domestic heating systems. Air source heat pumps extract heat from ambient air and make this heat available for home and domestic hot water heating. Air source heat pumps need to have access to large quantities of ambient air and are thus placed outdoors. The heat pump uses this ambient air to heat up the evaporator and the air is expelled at a lower temperature. The efficiency and capacity of the heat pump is reduced if the temperature of the evaporator is reduced. This means that if the air flow over the evaporator is reduced or if the outlet air is recycled to the evaporator inlet, the efficiency and capacity of the heat pump reduces. If the evaporator temperature drops below the dewpoint of the inlet air, condensation is occurring. If the temperature is below 0°C ice will form on the evaporator which then blocks the air flow. Modern heat pumps have an automatic reverse cycle defrosting function which removes ice by heating up the evaporator. Frosting and defrosting the evaporator reduces the heat pumps capacity and COP.

Domestic air to water heat pumps (and split air conditioning units) have a significant footprint and are not always perceived as an attractive addition to the outdoor space. In the Netherlands there are strict regulations on sound production of heat pumps which are defined at property borders [1]. In practice this means that heat pumps can be challenging to integrate in existing dwellings.

* Corresponding author. Tel.: +31-621441283
E-mail address: Andries.vanwijhe@tno.nl

15th IEA Heat Pump Conference 2026 - HDU4.5 - https://doi.org/10.23697/hpgf-5377

Currently there are several solutions on the market which integrate heat pumps in the house façade or roof. Since the heat pump is in an enclosed space, there are concerns on performance degradation due to restriction of the air flow via the enclosure or air recirculation. Restriction and recirculation cause a reduction in evaporator temperature and can accelerate ice formation.

In this paper a heat pump roof integration solution is investigated. The construction is similar to a dormer roof, but instead of extending the indoor space by moving the roof up, it creates a flat section for the heat pump to sit on by moving the roof down.. For aesthetics purposes a grille is placed on top of the dormer concealing the heat pump.

2. Approach

A mockup dormer roof with heat pump was tested entirely in the psychometric chambers of the Bouwinnovatielab in Delft. The chamber size is approximately 4 m wide, 8 m long and 4 m tall. On the right side is a slanted air distribution plenum with three layers of filter mesh providing a pressure drop of 3 Pa. This way the conditioned air can flow at 18,000 m^3/h, but the air velocity never exceeds 0.3 m/s. The chamber is conditioned by means of cooling, heating, drying and humidification.

The heat pump is tested with and without the dormer roof enclosure. Also, there is an access hatch which will be opened if the grill is removed. With the hatch and grill removed, the outdoor unit will operate as if standing in free air. This is verified by checking the temperature difference between the bulk air temperature at the room air inlet and before the evaporator.

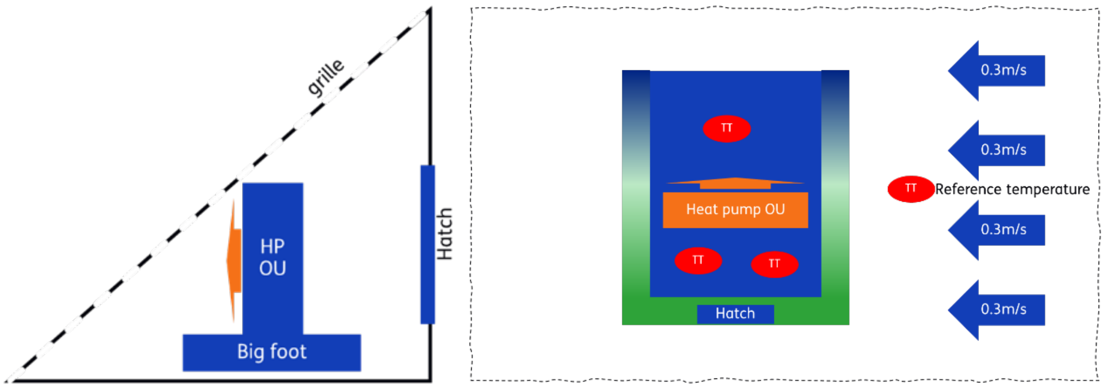

Figure 1. Left: schematic cross section of mock-up. Right: position of the setup in psychometric chamber. Abbreviations: HP: Heat Pump, OU: Outdoor Unit, TT: Temperature Transmitters

The heat pump is a relatively small domestic unit intended to be used in a hybrid configuration with a gas fired boiler. It is an R32 split with 4 kW rated capacity. The airflow through the evaporator is rated at 1,800 m^3/h. The outdoor unit size is just under 9 by 5 by 3 dm. In Fig. 1 a sketch is given of the heat pump inside the dormer and the placement of the dormer roof mock-up with heat pump inside the climate chamber, including temperature sensor positions.

Measurements on the unit are done by using 1/10th DIN PT100's, capacitive humidity transmitters, magnetic flowmeters and a high frequency power analyzer. The heat pump has pressure transmitters to the suction and discharge side of the heat pump and a Coriolis flowmeter in the liquid line. The various configurations are listed in Table 1 and the ambient air conditions are listed in Table 2. For the heat pump, the condenser flowrate is fixed at 720 l/h at 25 °C supply temperature for all measurements.

Table 1. Overview of the tested variants.

Test	configuration	Heat pump setting
1 Base case full speed	Roof and hatch removed	Max compressor speed
2 With roof full speed	With grille and hatch	Max compressor speed
3 Base case half speed	Roof and hatch removed	Compressor speed 50 %

4 With roof, half speed	With grille and hatch	Compressor speed 50 %
5 With roof, same capacity as 3	With grille and hatch	Compressor speed adjusted to match 3

Table 2. Overview of the tested conditions in the psychometric chamber.

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5
Dry bulb temperature	2 °C	4 °C	5.5 °C	7 °C	10 °C
Relative humidity	85 %	85 %	85 %	85 %	90 %
Dewpoint	-0.3 °C	1.7 °C	3.2 °C	4.7 °C	8.4 °C
Wet bulb temperature	1.1 °C	3.0 °C	4.4 °C	5.9 °C	9.2 °C

The test is executed until all the conditions are fully stabilized for at least 25 minutes. If freezing on the evaporator occurs, the test is extended over several complete cycles of frosting and defrosting. The performance is then evaluated over the entire cycle, an example of which is shown in Fig. 2.

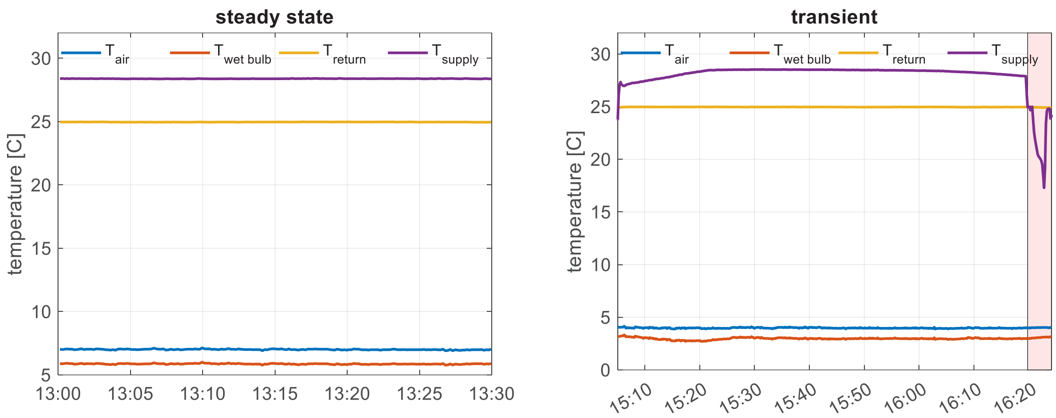

Figure 2. Example measurements of temperatures during a test. Left: steady state test at which the evaporator does not frost, Right: transient test at which the heat pump uses a reverse cycle defrost to clear the evaporator coil from ice. For transient tests the performance indicators are evaluated over an entire cycle of heating and defrosting as is shown in the graph. The defrosting period is marked red.

3. Results

The following Key Performance Indicators (KPI) are defined in Table 3. If the measurements are done according to EN14511:2022 [2], an additional heat and power gain is added to compensate for the circulation pump. However since the flowrate and pump speed remain unchanged for all the tests, the effect is considered not relevant for comparisons. The duration of a frost/defrost cycle is not evaluated in this paper.

Table 3. Overview of indicators to be used for the determining the impact of the heat pump enclosure.

KPI	Unit	relevancy
Heat pump capacity	kW	Capacity degradation might require an outdoor unit size increase, relevant for full load
Heat pump power consumption	kW	Increased electricity usage at the same capacity
Heat pump COP	-	Increased electricity usage at the same capacity
Temperature at evaporator inlet offset	°C	A difference between the evaporator inlet temperature and bulk ambient air temperature shows recycling of air.
Defrost cycle time	min	Enhanced frosting can cause a significant reduction of efficiency.

Result for heat pump running at full load

The heat pump is set to be controlled by the room thermostat. The compressor is then controlled by modifying a parameter which determines the maximum frequency of the compressor. It was verified that the compressor operates at the maximum set frequency. Note that the heat pump uses its own logic to control other actuators such as electronic expansion valve and fan speed. No special ‘test mode’ was used. The pump speed and flowrate are fixed throughout the tests.

The results for the capacity and COP are plotted in Fig. 3. There is a capacity reduction of 6-10 % for 2° C, 4 °C, 7 °C and 10 °C. However, the heat pump evaporator is frosting and thus needs to defrost at 5.5 °C or below with the dormer roof. Without the dormer roof this is at 4 °C and lower. This means the capacity and COP are significantly lower at 5.5 °C due the difference in frosting behavior of the evaporator.

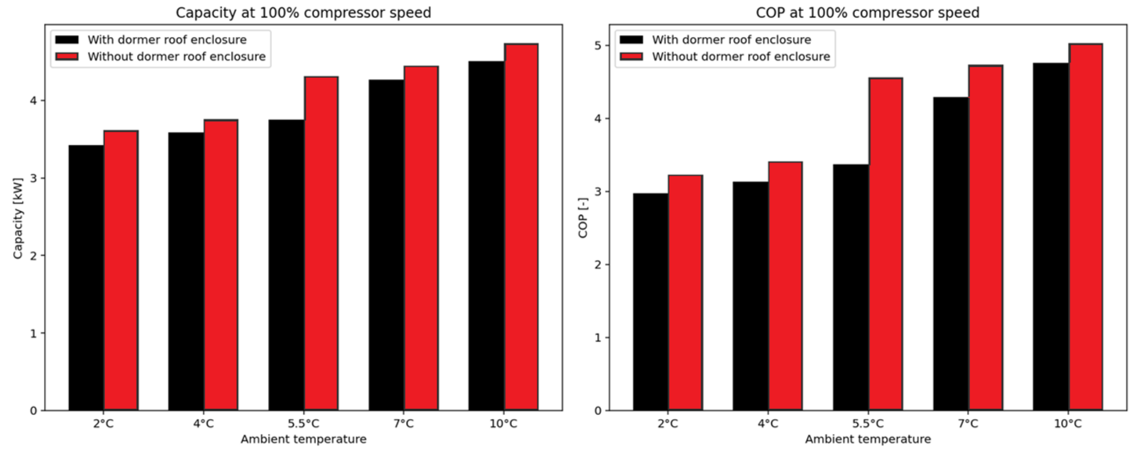

Figure 3. Results of the tests with and without the dormer roof at 100 % compressor speed. Left: the thermal capacity of the heat pump. Right: the heating COP for these conditions. Without the dormer roof the evaporator frosts at 2 °C and 4 °C. With the dormer roof the evaporator frosts at 2 °C, 4 °C and 5.5 °C.

Result for heat pump running at half load

In the second test, the heat pump is set at 50 % compressor speed for the base case (without dormer roof) before being repeated with the dormer roof installed. Finally, a test is performed where the compressor speed of the heat pump is set to match the capacity of the base case. This is a realistic scenario, since heat pumps are commonly controlled in a way to fulfill a heating demand or target supply water temperature. The comparison is also more suitable, because the supply temperature for both conditions are now equal.

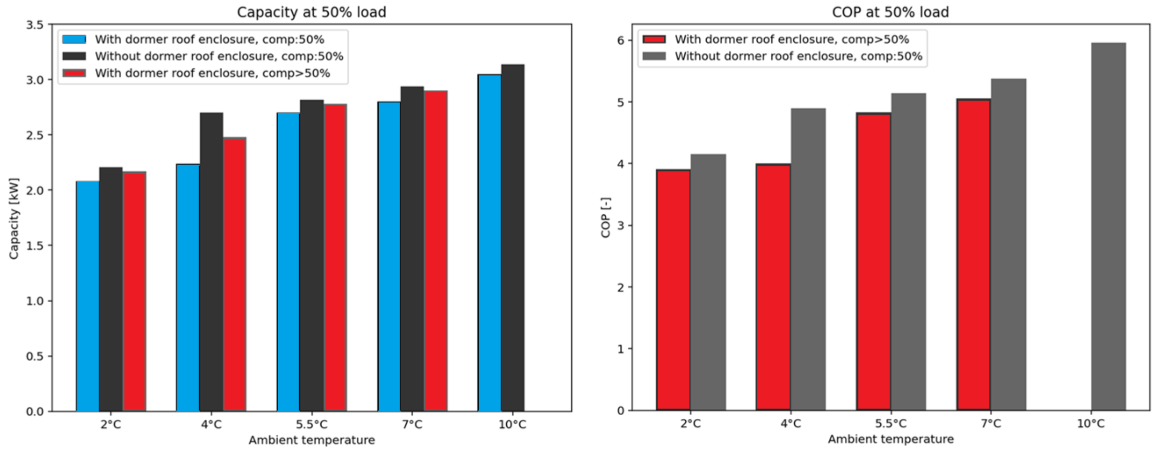

Figure 4. Results of the tests with and without the dormer roof at 50 % capacity. Left: the thermal capacity of the heat pump. Right: the heating COP for these conditions. Without the dormer roof the evaporator frosts only at 2 °C. With the dormer roof the evaporator frosts at 2 °C and 4 °C. To compensate for the capacity loss, the compressor speed was set to 54 % at 2 °C, 64 % at 4 °C 53 % at 5.5 °C and 7 °C. At 2 °C the compressor should have been set at a higher speed to match the capacity of the heat pump without the roof in place. The 10 °C test with dormer roof enclosure was omitted due to wrong set temperature on the psychometric chamber. The right graph does not show the 50 % compressor speed with roof to keep the comparison between with/without on the same thermal output of the heat pump.

Discussion

The measurements show a drop in COP and Capacity due to a restriction of the air flow by the grille or due to recirculation of heat pump discharge air. Air recirculation can be shown by a negative offset between the bulk air temperature and at the inlet of the evaporator coil. This offset in temperatures is plotted in Fig. 5, and increases at an increase of heat pump capacity and at an increase of ambient temperature. The offset between the two sensors caused by dormer room is plotted in Fig. 5. It shows that this offset increases if the capacity of the heat pump increases and also if the ambient temperature increases. Both of these effects will cause an increase in evaporator duty and an enhancement of the effects related to air recirculation. The effect of fan speed on temperature offset is not investigated, as it was controlled by the heat pumps internal logic and not measured. With this, the effect of recirculation is shown. However, it is unclear what the role of a possible restriction of air flow is on the performance degradation and accelerated frosting.

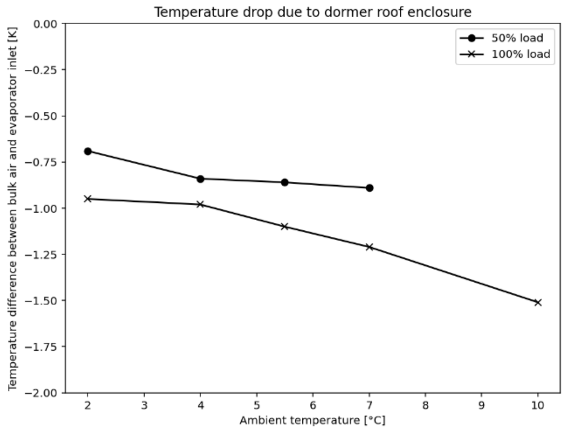

Figure 5. Graph of negative temperature offset between the bulk air temperature and the evaporator inlet air temperature if the dormer roof is in place. A negative value means that the air temperature at the inlet of the evaporator is lower than the bulk air temperature. If the dormer roof is not in place, no temperature difference between evaporator air inlet and the bulk air temperature is measured.

4. Conclusion

The reduction of capacity due to the placement of the heat pump in the dormer roof is around 6-10 % at full compressor speed. This is more relevant for hybrid heat pumps; a reduction of capacity means an increase of dependency of natural gas for the fossil fuel boiler. At 50 % partial load condition a consistent 6 % of extra electricity consumption has been observed.

The enhanced frosting means that there is a temperature limit above which the heat pump would be able to run without defrosting if installed conventionally (outside), but will start frosting if the heat pump is confined in the inverted dormer roof. In the latter case a COP/capacity drop in excess of 20 % has been measured at partial and full load. It is unclear where exactly this limit is, due to 1.5-2 K measurement increments in the measurement matrix. Also, the measurements have been done for a humidity of 85 %.

Accelerated frosting has been observed in the 2-5.5 °C ambient temperature range. If a heating season can be divided into integer temperature bins, the frequency per bin for this range is around 250-350 hours/a according to the current Dutch reference climate year [3]. According to the EN14825:2022 [4] this would correspond to a heating load [kW] of 40-54 % of the nominal heating load of a dwelling with respect to its nominal value defined at -10 °C for an *average* European climate.

The measurement set gives a general idea about the performance impact of a typical heat pump enclosure. Similar measurements would be helpful for other enclosure types, especially when looking at what aspects of the design impact the performance. A monitoring campaign would be useful to identify designs which affect performance. Limited design variables such as a more strict segregation between suction and discharge of the evaporator and different grill designs were tried in this study, but the effects were found to be limited.

5. Aknowledgements

The project was carried out with Topsector Energy funding from the Ministry of Economic Affairs and Climate Policy (EZK), implemented by the Netherlands Enterprise Agency (RVO). The specific subsidy for this project concerns the MOOI subsidy round 2022.

6. References

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