Experimental testing of heat pump systems for domestic hot water use in a Future Homes Standard house under controlled environmental conditions

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Executive summary

Property developers require certainty of heating delivery based on heat pumps in mass produced homes. Whilst heat pump testing for space heating delivery has been carried out and reported elsewhere (Fitton et al., 2024), no rigorous tests have been carried out for domestic hot water delivery using heat pumps. The aim of this research is to investigate the ability of two heat pumps to deliver hot water to a required tapping profile according to British Standard (BS EN 16147:2017, 2017).

The testing was carried out in eHome2 by Saint-Gobain & Barratt Developments, located within Energy House 2.0 Environmental Chamber 1. This unique facility enables fully controlled conditions to be maintained as a simulation of external weather and provides stable conditions during the tests.

There are two DHW systems currently installed in eHome2: First, a 195-litre standalone unit generating hot water using an inbuilt ASHP (Curv system). Second, a 236-litre storage cylinder attached to the ASHP with a buffer vessel (Vaillant system). A standardised test protocol was developed by the research team to ensure a like for like comparison of the domestic hot water heating performance. Both the Vaillant and Curv DHW systems were tested for their ability to meet domestic hot water demands under varying conditions.

The Vaillant system, featuring a 236-litre Unistor cylinder and aroTHERM air source heat pump (ASHP), demonstrated stability and reliability. It maintained consistent hot water temperatures within the target range (25°C–55°C) across varying environmental temperatures (5°C, 7°C, and 14°C). The system's performance in high-demand scenarios, such as bath taps, showed steady flow rates. Energy consumption decreased with higher ambient temperatures, reflecting improved efficiency. At 5°C, it consumed an average of 8.58 kWh per day, whereas at 14°C, the consumption dropped to 6.62 kWh per day. Its hot water delivery efficiency ranged from 1.84 at 5°C to 2.38 at 14°C.

The Curv system, a compact 195-litre stand-alone cylinder with a smaller buffer tank, offered a more energy-efficient solution. It maintained similar temperature stability, though minor fluctuations occurred at lower temperatures due to the smaller buffer tank. Flow rates were consistent, meeting required volumes for both bath and kitchen taps. Its energy consumption was lower than the Vaillant system, dropping from 5.61 kWh/day at 5°C to 4.15 kWh/day at 14°C. Its hot water delivery efficiency ranged from 2.04 at 5°C to 2.56 at 14°C.

In summary, both systems met the British Standard (BS EN 16147:2017, 2017). The Vaillant system was more stable and reliable, while the Curv system provided a more compact, energy-efficient alternative.

Abstract

This paper reports on experimental testing of two different heat pump systems installed in eHome2, constructed in collaboration between Saint-Gobain and Barratt Developments within Energy House 2, which is part of Energy House Labs at the University of Salford. Whilst rigorous tests of the building space heating have been carried out and reported elsewhere, no systematic tests of domestic hot water delivery by the heat pumps have been performed to date. The paper introduces tests with a fully instrumented experimental setup consisting of two different heat pumps, the eHome2, and the Energy House 2 environmental chamber. The consistency of the standardised testing protocol between the heat pumps has provided the research team with a like for like comparison of the domestic hot water heating performance. The outcome of this work will be an increased understanding of how a standardised domestic hot water demand can be fulfilled with different heat pumps.

1 Introduction

Property developers require certainty of heating delivery based on heat pumps in mass produced homes. Whilst heat pump testing for space heating delivery has been carried out and reported elsewhere (Fitton et al., 2024), no rigorous tests have been carried out for domestic hot water delivery using heat pumps.

The aim of this research is to investigate the ability of two heat pumps to deliver hot water to a required tapping profile according to British Standard (BS EN 16147:2017, 2017).

The testing will be carried out in eHome2 by Saint-Gobain & Barratt Developments, located within Energy House 2.0 Environmental Chamber 1. This unique facility enables fully controlled conditions to be maintained as a simulation of external weather and provides stable conditions during the tests.

1.1 The environmental chambers

Energy House 2.0 is a globally unique building performance test facility. The building was constructed to allow for full-scale testing of structures under a controlled range of climatic conditions. The facility consists of two large chambers which can accommodate four family homes: two homes in each chamber. The chambers each contain a soil filled pit, 1200 mm deep which is isolated by insulation from the ground beneath and surrounding the pit. The walls and ceilings of the chamber are insulated, providing isolation from the external climate, with high levels of airtightness.

Both chambers are independently conditioned by a large heating, ventilation, and air conditioning (HVAC) system. In addition, there are weather rigs, which provide additional climatic effects. These control the climate in the chambers as follows:

- Temperature: (-20 °C to 40 °C)
- Relative Humidity (20% to 90%)
- Wind
- Rain
- Solar Radiation (up to 1200 W/m^2)
- Snow

Temperature and relative humidity can be held at constant steady state or varied in seasonal or daily patterns.

1.2 The test building – eHome2

eHome2, by Saint-Gobain & Barratt Developments, is a 3 bedroom detached home built using closed panel timber frame construction, insulated with mineral wool, this is cladded externally with a proprietary brick slip system and render (Fitton et al., 2024). The house has an insulated concrete floor structure, double glazed windows and patio doors and a roof insulated with 400mm of mineral wool insulation.

eHome2 has a design Whole House Heat loss (Heat Transfer Coefficient/HTC) of 73.8 W/K, which was extracted from the SAP energy model. This considers the total fabric heat loss and the infiltration heat loss. The measured HTC using the coheating method was 76.7 (±2.1) W/K thus giving a performance gap of 2.9 W/K or 3.9% (Figure 1). This is higher than the level of uncertainty so suggests a performance gap issues, although minor in extent.

The HTC can be disaggregated into plane element, thermal bridging and infiltration heat loss to understand the cause of any performance gap. shows this through the design values, and then also through the in-situ measurements made by the team at Energy House Labs.

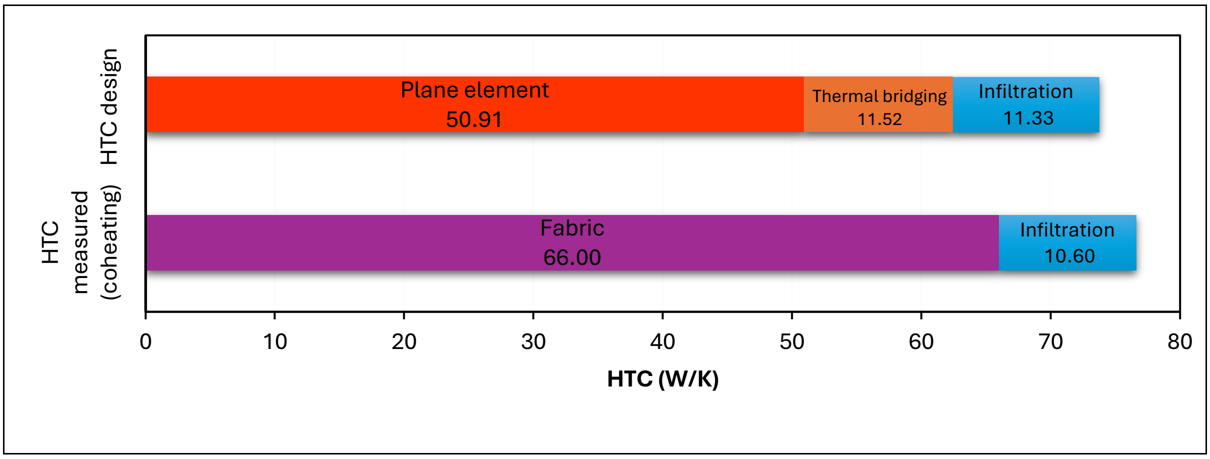

Figure 1. eHome2 HTC design vs measured (Fitton et al., 2024).

The plane element analysis can be broken down further into individual element through Plane element analysis disaggregates the, using both design and measured U-values. Figure 2 shows how the individual building elements of eHome2 performed, by comparing the in-situ measurement to the design.

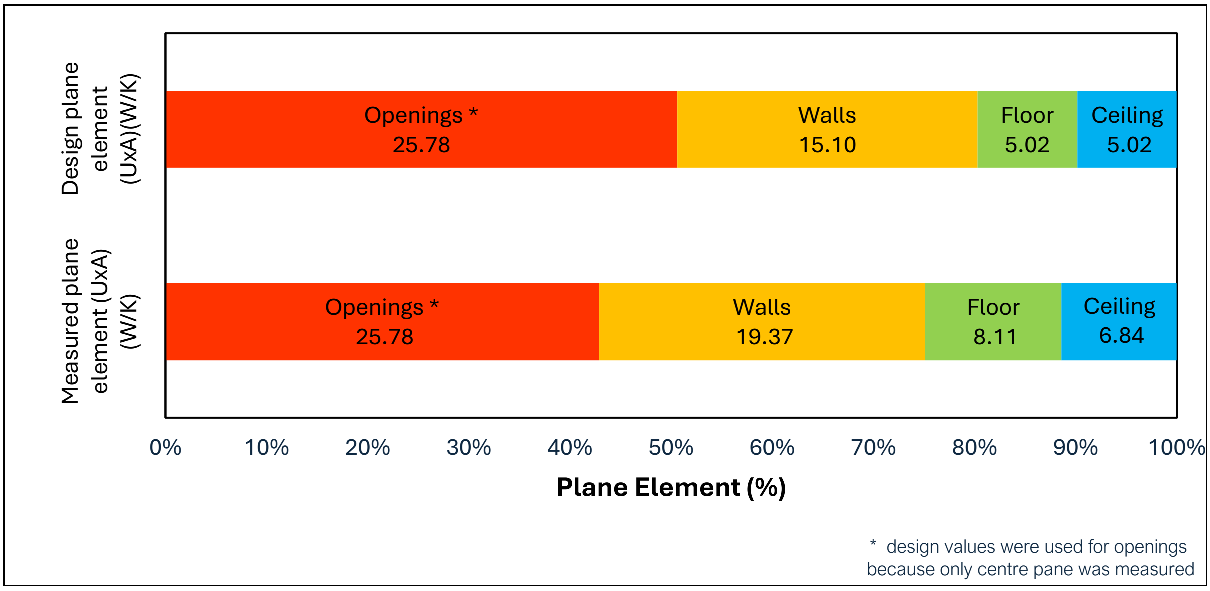

Figure 2. eHome2 Fabric Heat Loss by components (Fitton et al., 2024).

1.3 Hot Water Systems

There are two DHW systems currently installed in eHome2: First, a 195-litre standalone unit generating hot water using an inbuilt ASHP (Curv system). Second, a 236-litre storage cylinder attached to the ASHP with a buffer vessel (Vaillant system).

1.3.1 Curv ASHP Hot Water Cylinder

This is a stand-alone air source hot water cylinder, designed to work alongside an infrared heating system. The model is HP200M3, which has a capacity of 195 litres, with a quoted COP of 3.04 at 7 °C external temperature (Figure 3 left).

Figure 3. Curv hot water cylinder (left) and Vaillant ASHP cylinder (right)

1.3.2 Vaillant Unistor

This is a cylinder designed specifically to work with a Vaillant ASHP (Figure 3 right). It has a capacity of 200 litres and is supplied pre plumbed and is unvented. The installed version has an aroTHERM 45 litre buffer tank which can lead to less short cycling of the ASHP. The cylinder has been sized according to the Building Regulations Part L 2021 for a three-bedroom property with one bathroom and one shower room.

2 Methodology

2.1 Measurands

The following variables were monitored throughout each test at a one-minute time interval:

- House:
    - Air temperature in seven points in each room
    - Operative temperature in seven points in each room
    - Relative humidity in the geometric centre of each room
    - Electrical energy consumption

- Heat meter output on ASHP primary flow and return
- Electrical energy consumption by circuit (TFH & eHome2) and by individual power outlet (eHome2)

- Chamber:
  - Air temperature at 36 points
  - Relative humidity at 36 points
  - Sub soil temperature under the centre of each house

2.2 Sensor Schematic

Chamber Sensor Locations are shown in Figure 4

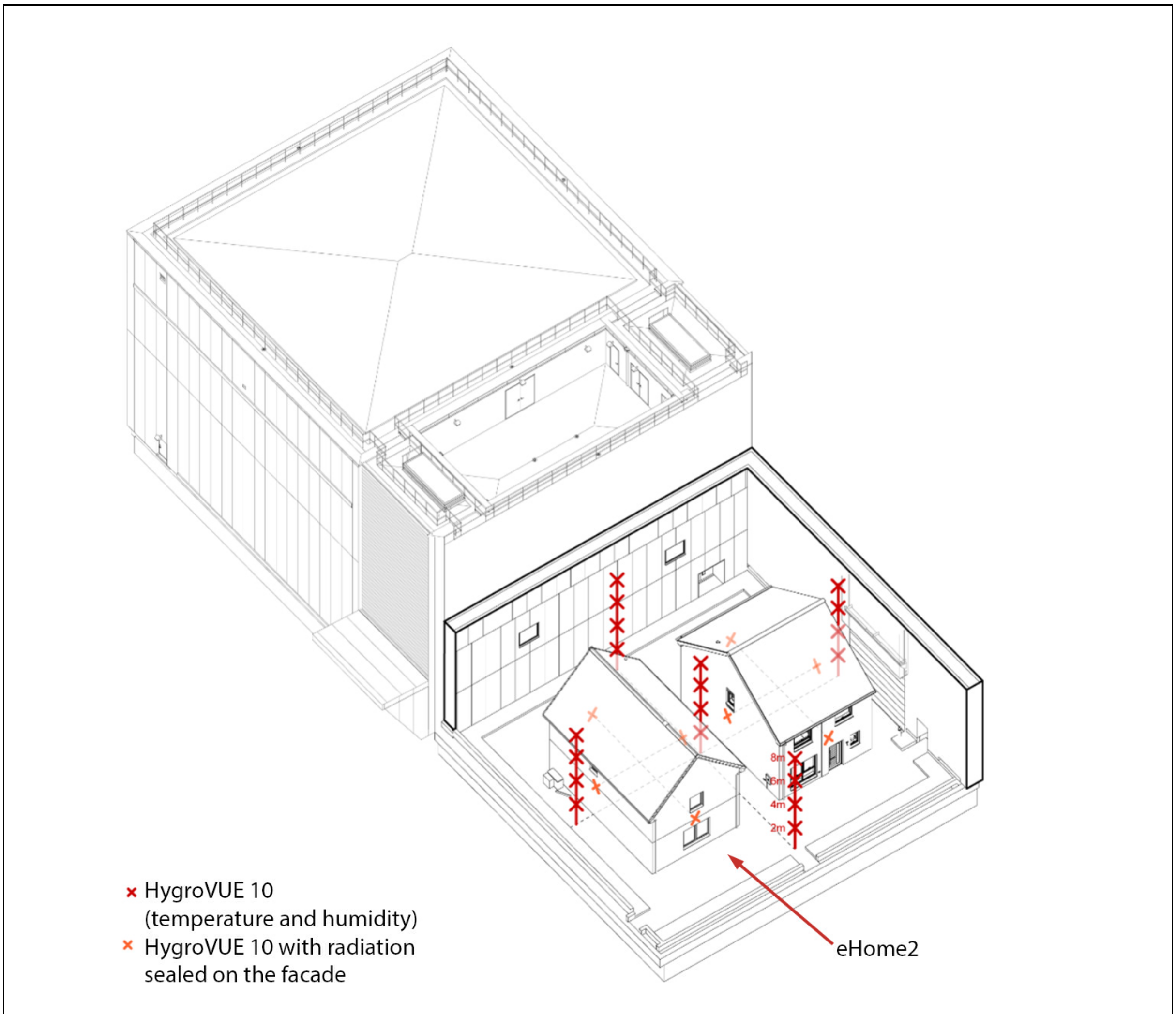

Figure 4. Diagram of air temperature and humidity sensor locations within the chambers

Whole House Sensor Locations in eHome2 are shown in Figure 5.

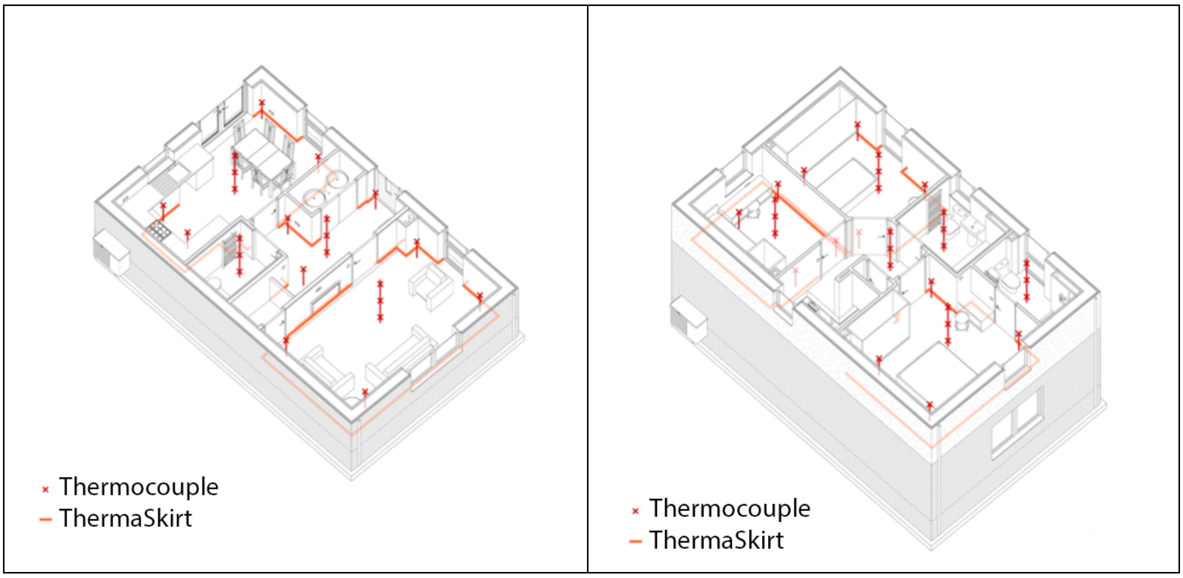

Figure 5. Heating emitters and sensors in eHome2 downstairs (left) and upstairs (right)

2.3 Heat Meter Output

Heat meter energy output only increased per kWh, so was calculated for better resolution as follows:

- 1 minute flow temperature, return temperature, volume per min, and specific heat capacity value was obtained
- Specific heat capacity value was calculated using the following equation:

$$Q = \frac{(\dot{m} \cdot 1000) \cdot C \cdot (\mathrm{T_{Flow}} - T_{Return})}{3600000}$$

Where:

- Q is heat meter energy in Wh
- $\dot{m}$ is volume flow per minute in m3/min
- C is the measured specific heat capacity in J/(kg.K)
- $\mathrm{T_{Flow}}$ is the flow temperature in °C
- $\mathrm{T_{Return}}$ is the return temperature in °C

2.4 Monitoring Equipment

The findings provided in this report are based on measurements obtained using the equipment listed in Table 1. Measurements were recorded at one-minute intervals by the Energy House's monitoring system.

Table 1. Measurement equipment used in eHome2 heating system tests

Measurement	**Equipment**	**Uncertainty**
Electricity consumption	Siemens 7KT PAC1200 digital power meter	± 1%
Boiler & ASHP energy and power output	Sharkey 775 heat meter	± 1 %
ASHP flow rate	Sharkey 775 ultrasonic flow meter	± 1 %
ASHP flow and return temperature	PT-100 RTD	± 0.3 °C
Internal shielded air temperature	Type-T thermocouples (calibrated to ± 0.1 °C)	± 0.1 °C
Mid-room shielded air temperatures	Campbell Scientific hygroVUE10 (20 to 60 °C)[2]	±0.1 °C
Chamber air temperatures	Campbell Scientific hygroVUE10 (–40 to 70 °C)[2]	±0.2 °C
Element surface temperatures	Type-T thermocouples (calibrated to ± 0.1 °C)	± 0.1 °C
Relative humidity	Campbell Scientific HygroVUE10	± 1.5%
Black globe temperature	Type-T thermocouple in 40 mm diameter globe	± 0.1 °C

2.5 The testing protocol

2.5.1 Objectives

- **To measure the energy efficiency** of the heat pump-driven DHW system with hot water storage.
- **To validate** that the system can deliver the required amount of hot water within a specified time frame.

2.5.2 Scope

- This protocol applies to the Heat Pump-driven DHW system with hot water storage in the eHome2.0 test building, focusing on energy efficiency and hot water performance in the specific conditions of the test environment.

2.5.3 Test Environment and Conditions

- **Ambient Temperature and Relative Humidity**: Preset the ambient temperature at typical UK outside temperature with three constant temperature 5°C, 7°C & 14°C, and recording the outdoor temperatures while testing.
- **Indoor Infrared Heating Temperature**: Running constant 21 °C for living room, 18 °C for other zones
- **Hot Water Supply Temperature**: The required hot water supply temperature is listed in Table 1 within 24hours test range. Record the temperature of incoming water while testing.
- **Required Hot Water Volume, Flow Rate and Temperature**: The volume, flow rate and time frame for the hot water supply is listed in Table 2.
- **Heat Source**: Air source heat pump.

Table 2. Tapping profiles (BS EN 16147:2017 (2017) patterns-Large)

Start time	Qtap	Type of draw off	Water flow rate at the tap (f)	Minimum temperature for counting useful energy (Tm)	Water temperature achieved during taping (Tp)	Taping time	Total flow volume
h	kWh		L/min	°C	°C	Seconds	m^3
07:00	0.105	Small	3	25		120	0.006019
07:05	1.400	Shower	6	40		401	0.040126
07:30	0.105	Small	3	25		120	0.006019
07:45	0.105	Small	3	25		120	0.006019
08:05	3.605	Bath	8	10	40	775	0.103325
08:25	0.105	Small	3	25		120	0.006019
08:30	0.105	Small	3	25		120	0.006019
08:45	0.105	Small	3	25		120	0.006019
09:00	0.105	Small	3	25		120	0.006019
09:30	0.105	Small	3	25		120	0.006019
10:30	0.105	Floor cleaning	3	10	40	60	0.003009
11:30	0.105	Small	3	25		120	0.006019
11:45	0.105	Small	3	25		120	0.006019

12:45	0.315	Dish washing	4	10	55	90	0.006019
14:30	0.105	Small	3	25		120	0.006019
15:30	0.105	Small	3	25		120	0.006019
16:30	0.105	Small	3	25		120	0.006019
18:00	0.105	Small	3	25		120	0.006019
18:15	0.105	Household cleaning	3	40		60	0.003009
18:30	0.105	Household cleaning	3	40		60	0.003009
19:00	0.105	Small	3	25		120	0.006019
20:30	0.735	Dish washing	4	10	55	211	0.014044
21:00	3.605	Bath	8	10	40	775	0.103325
21:30	0.105	Small	3	25		120	0.006019
Qref	11.655						0.372170

2.5.4 Test Equipment

- **Energy meters**: To measure the electrical consumption of the heat pump and the circulation pumps.
- **PT100 temperature sensors**: For measuring tap outlet, and hot water cylinder inlet and outlet water temperatures.
- **Flow meters**: For recording the volume of hot water delivered.
- **Timer**: To measure response and delivery times.

2.5.5 Test Procedure

Step 1: Initial Setup

- Install energy meters on the heat pump's power supply and other key electrical components.
- Set up temperature sensors at the inlet, outlet of the hot water storage tank and each tap outlet.
- Set up a constant ambient and indoor temperature and water supply temperatures before starting the test.
- Setup the default flow rates of both hot and cold tap water outlet to achieve a required value of the mixed temperature.

Five typical tap settings are listed in Table 3.

Table 3. Five typical tap settings

				Tap hot water outlet		Tap cold water outlet	
No.	Tap location	Tap mix water outlet flow rate	Tap mix water outlet temperature	Temperature	Flow rate	temperature	Flow rate
		L/min	°C	°C	L/min	°C	L/min
1	Bathroom basin	3	25	60	0.9	10	2.1
2	kitchen basin	3	40	60	1.8	10	1.2
3	kitchen basin	4	55	55	3.6	10	0.4
4	Kitchen basin	6	40	60	3.6	10	2.4
5	Bathroom bath	8	40	40	4.8	10	3.2

The PT100 temperature thermocouples were installed at the outlet of each tap as shown in Figure 6.

(a) Kitchen sink tap (b) Bathroom bath tap (c) Bathroom sink tap

Figure 6 Type-T thermocouple sensors installed at tap outlet

Energy balance was used to calculate the flow rates of hot and cold water required to mix and produce the desired mixed water temperature. The energy gained by the cold water must equal the energy lost by the hot water when they mix.

The formula used was as follows:

$$Q_{mix} = Q_{hot} + Q_{cold} \tag{1}$$

For the temperatures and flow rates, the equation becomes:

$$\begin{gathered}(T_{mix} - T_{cold}) \times F_{cold} = (T_{hot} - T_{mix}) \times F_{hot} \\ F_{mix} = F_{cold} + F_{hot}\end{gathered} \tag{2}$$

Where:

T_{mix}	is mixed water outlet temperature
T_{cold}	is cold water outlet temperature
T_{hot}	is hot water outlet temperature
F_{mix}	is total mixed flow rate
F_{hot}	is hot water flow rate
F_{cold}	is cold water flow rate

The pre-test was conducted before the 24-hour test to determine the actual achieved water flow rate and achieved temperature, with results shown in Table 4.

Table 4. Pre-test tap water flow rate and temperature

				Tap hot water outlet			Tap cold water outlet		
No.	Tap mix water outlet flow rate	Tap actual mixed water flow rate	Tap mix water outlet temperature	Temperature	Flow rate	Opening degree	temperature	Flow rate	Opening degree
	L/min	L/min	°C	°C	L/min	%	°C	L/min	%
1	3	2.784	25	60	0.956	4	10	1.828	3
2	3	2.535	40	60	1.772	5	10	0.763	2
3	4	3.969	55	60	3.969	8	10	0	0

4	6	5.952	40	60	3.826	8	10	2.126	3
5	8	7.845	40	60	4.8	100	10	0	0

To achieve the hot water energy consumption as required by (BS EN 16147:2017, 2017) Large pattern, the DHW tapping profile (Table 5) is scheduled for 24 hours at LOXONE control app (Loxone, 2024).

Table 5. DHW tapping profile schedule for 24 hours

Time schedule	Qtap	Type of draw-off	Test location	Expected mixed water flow rate	Actual mixed water flow rate	Tm	Tp	Test time interval	Start time	End time	Hot water tap set	Cold water tap set
h	kWh			l/min	l/min	°C	°C	min	h	h	%	%
07:00	0.105	Small	Bathroom Basin	3	2.784	25		2	07:00	07:02	4	3
07:05	1.400	Shower	kitchen basin	6	5.952	40		7	07:05	07:12	8	3
07:30	0.105	Small	Bathroom Basin	3	2.784	25		2	07:30	07:32	4	3
07:45	0.105	Small	Bathroom Basin	3	2.784	25		2	07:45	07:47	4	3
08:05	3.605	Bath	Bathroom Bath	8	7.845	10	40	13	08:05	08:18	100	0
08:25	0.105	Small	Bathroom Basin	3	2.784	25		2	08:25	08:27	4	3
08:30	0.105	Small	Bathroom Basin	3	2.784	25		2	08:30	08:32	4	3
08:45	0.105	Small	Bathroom Basin	3	2.784	25		2	08:45	08:47	4	3
09:00	0.105	Small	Bathroom Basin	3	2.784	25		2	09:00	09:02	4	3
09:30	0.105	Small	Bathroom Basin	3	2.784	25		2	09:30	09:32	4	3
10:30	0.105	Floor cleaning	kitchen basin	3	2.535	10	40	1	10:30	10:31	5	2
11:30	0.105	Small	Bathroom Basin	3	2.784	25		2	11:30	11:32	4	3

11:45	0.105	Small	Bathroom Basin	3	2.784	25		2	11:45	11:47	4	3
12:45	0.315	Dish washing	kitchen basin	4	3.969	10	55	2	12:45	12:47	8	0
14:30	0.105	Small	Bathroom Basin	3	2.784	25		2	14:30	14:32	4	3
15:30	0.105	Small	Bathroom Basin	3	2.784	25		2	15:30	15:32	4	3
16:30	0.105	Small	Bathroom Basin	3	2.784	25		2	16:30	16:32	4	3
18:00	0.105	Small	Bathroom Basin	3	2.784	25		2	18:00	18:02	4	3
18:15	0.105	Household cleaning	kitchen basin	3	2.535	40		1	18:15	18:16	5	2
18:30	0.105	Household cleaning	kitchen basin	3	2.535	40		1	18:30	18:31	5	2
19:00	0.105	Small	Bathroom Basin	3	2.784	25		2	19:00	19:02	4	3
20:30	0.735	Dish washing	kitchen basin	4	3.969	10	55	4	20:30	20:34	8	0
21:00	3.605	Bath	Bathroom Bath	8	7.845	10	40	13	21:00	21:13	100	0
21:30	0.105	Small	Bathroom Basin	3	2.784	25		2	21:30	21:32	4	3

Step 2: System Activation and Energy Measurement

- Turn on the heat pump and allow it to start heating water in the storage tank.
- Begin measuring energy consumption immediately and monitor the COP of the heat pump.
- Record how long it takes to reach the required water temperature (e.g., 60°C in the storage tank).

Step 3: Hot Water Delivery Test

- Once the tank reaches the target temperature, initiate hot water delivery to the test fixture (e.g., a bath, shower or tap).

- The scheduled Loxone (Loxone, 2024) app will automatically deliver the hot water at the target temperature (e.g., 3 litres at 40°C).
- Record the delivered water temperature and ensure consistent temperature during delivery.

Step 4: Energy Performance Analysis

- Throughout the test, continuously measure energy consumption and system COP.
- Monitor the temperature differential and calculate the total energy input required to heat the water.

3 Experiments and results

3.1 Valliant Heat Pump

3.1.1 A 24-hour pre-test

According to test procedure, a 24-hour test was conducted to test if the DHW system could provide the required hot water continuously. On 10th of October 2024, the first pre-test was conducted from 0:00 AM to 24:00PM, with water temperature, flow rate and time schedule set as listed in Table 5.

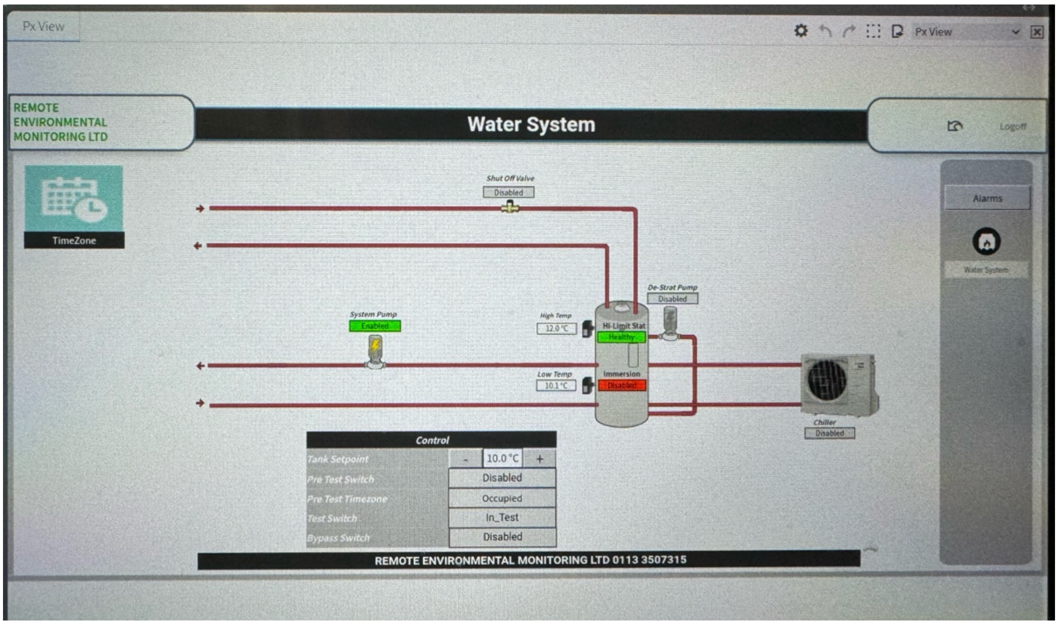

Figure 7. Cold water temperature setting

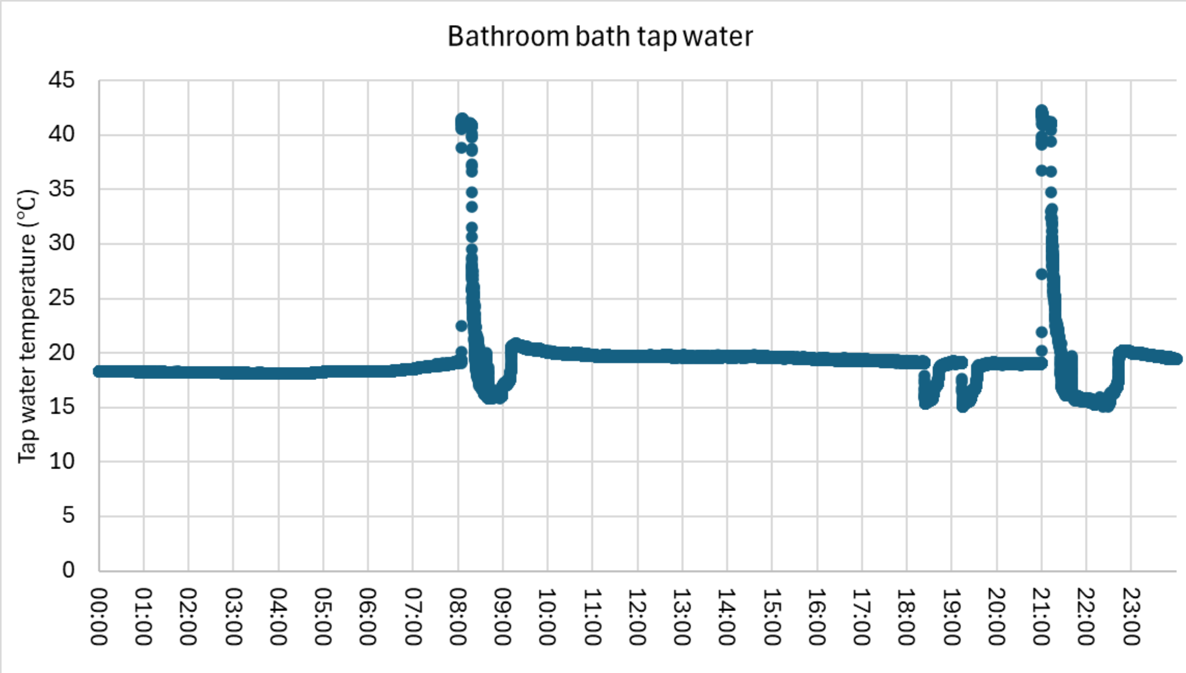

Figure 8. Bathroom bath tap temperature within a 24-hour pre-test

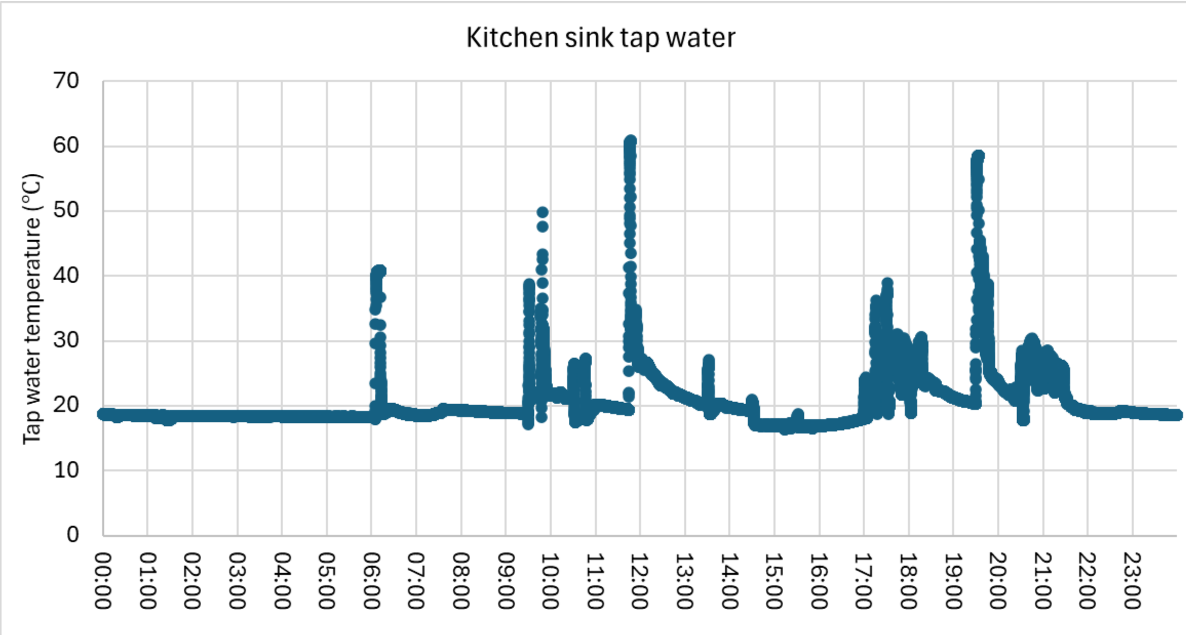

Figure 9. Kitchen sink tap water temperature during the 24-hour pre-test

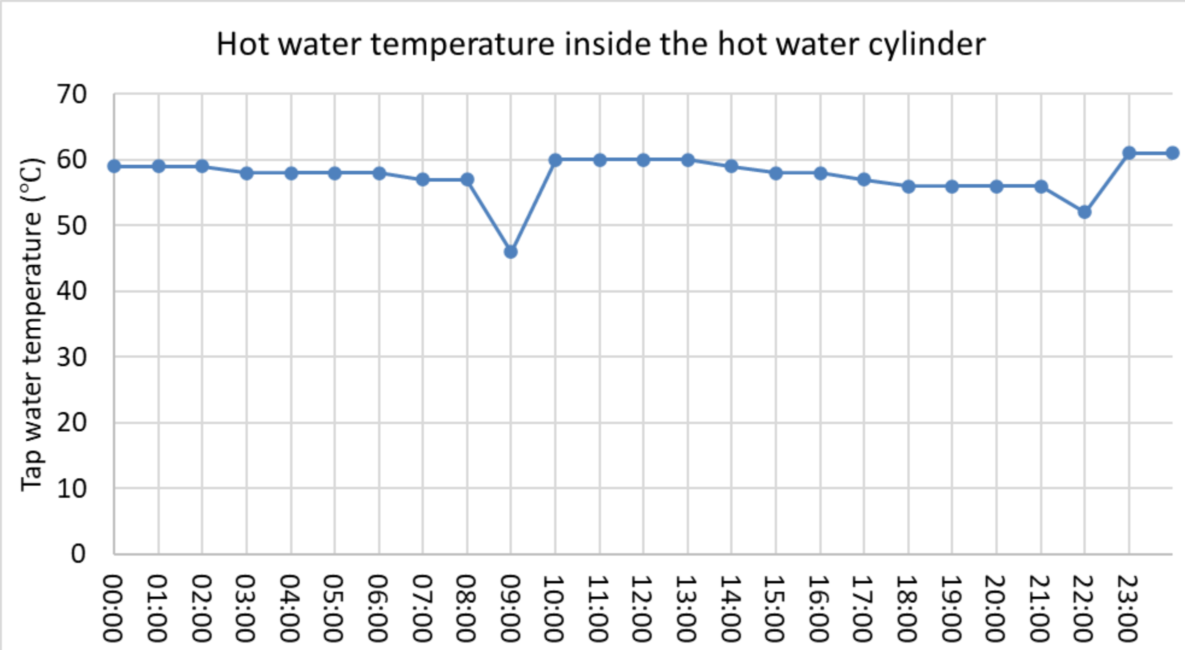

Figure 10. Hot water temperature inside the hot water cylinder during the 24-hour pre-test

3.1.2 A 72-hour pre-test

Following the 24-hour test, a 72-hour test was conducted between 16th – 18th October 2024 to evaluate the continuity of hot water delivery and its energy efficiency. Unlike the 24-hour test, the 72-hour test requires cold water refilling into the hot water cylinder and heat pump reheating twice daily. The first cold water refill occurs between 16:32 and 18:00, while the second refill takes place after 21:32, once the final tap schedule of the day has concluded.

The significance of this process lies in its ability to simulate real-world usage conditions over an extended period, ensuring that the system can consistently maintain hot water delivery under varying demand levels. By incorporating cold water refilling and reheating cycles, the test evaluates both the performance and energy consumption of the heat pump in managing fluctuating loads. This approach ensures a more comprehensive assessment of the system's efficiency and reliability in long-term operation, simulating typical daily usage patterns.

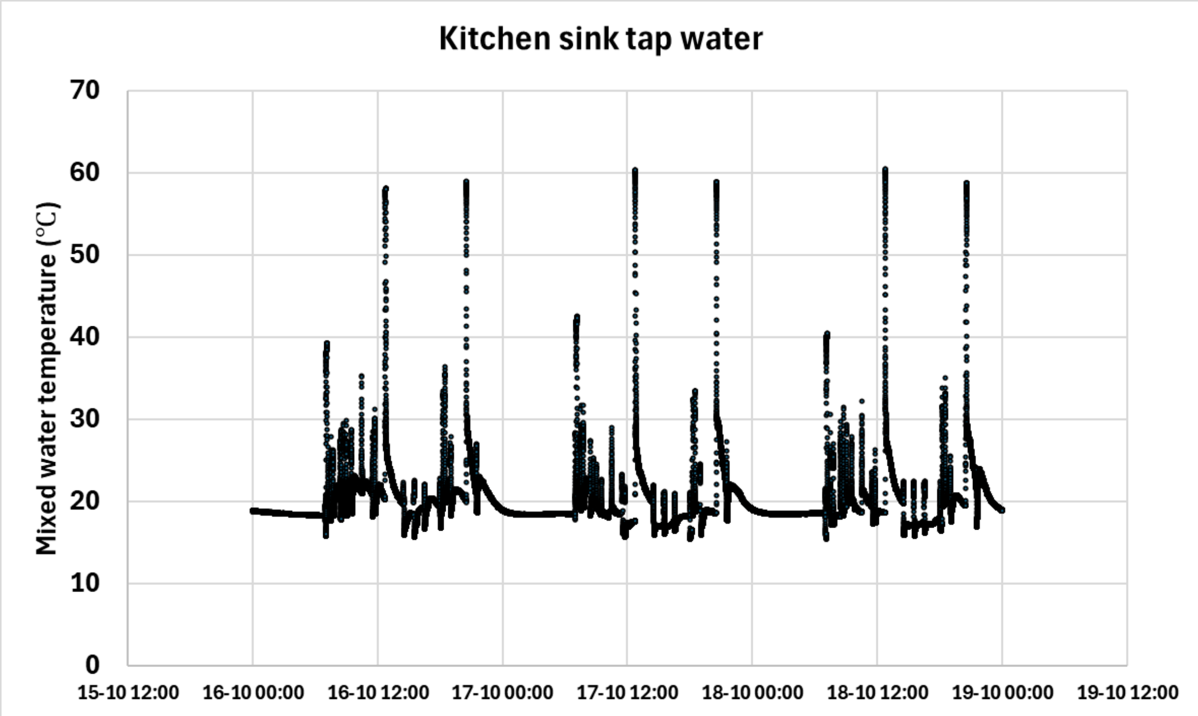

Figure 11. Kitchen sink tap water temperature during the 72-hour pre-test

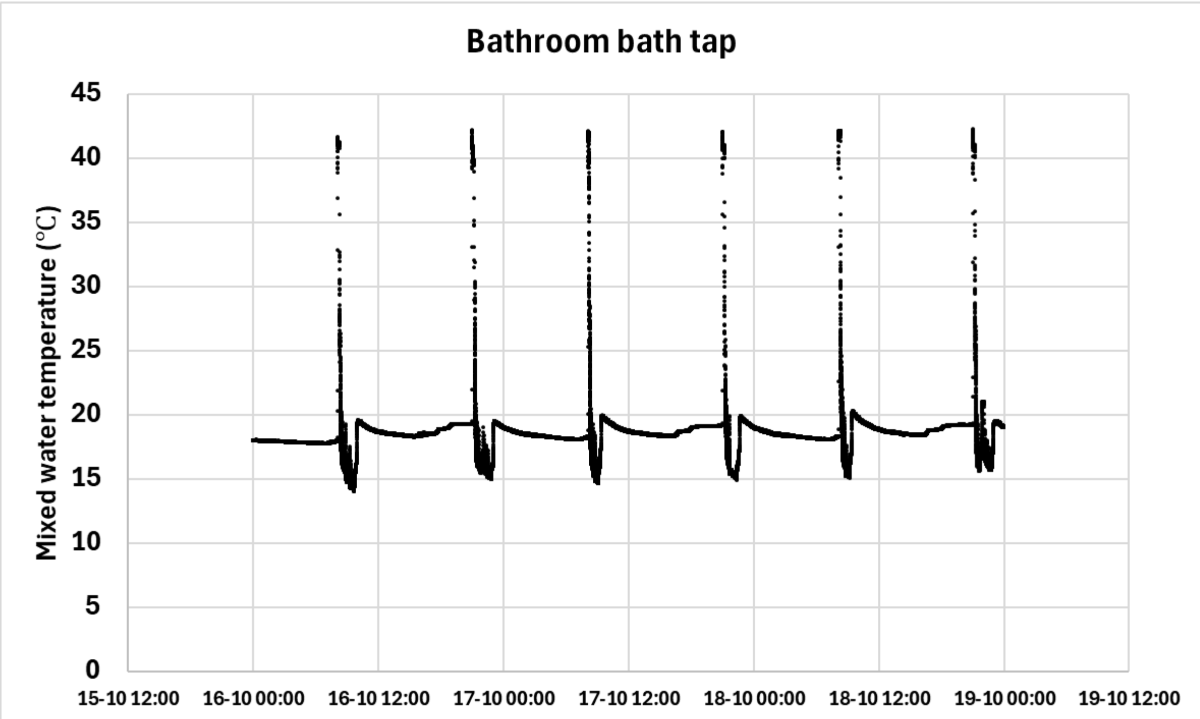

Figure 12. Bathroom bath tap temperature during the 72-hour pre-test

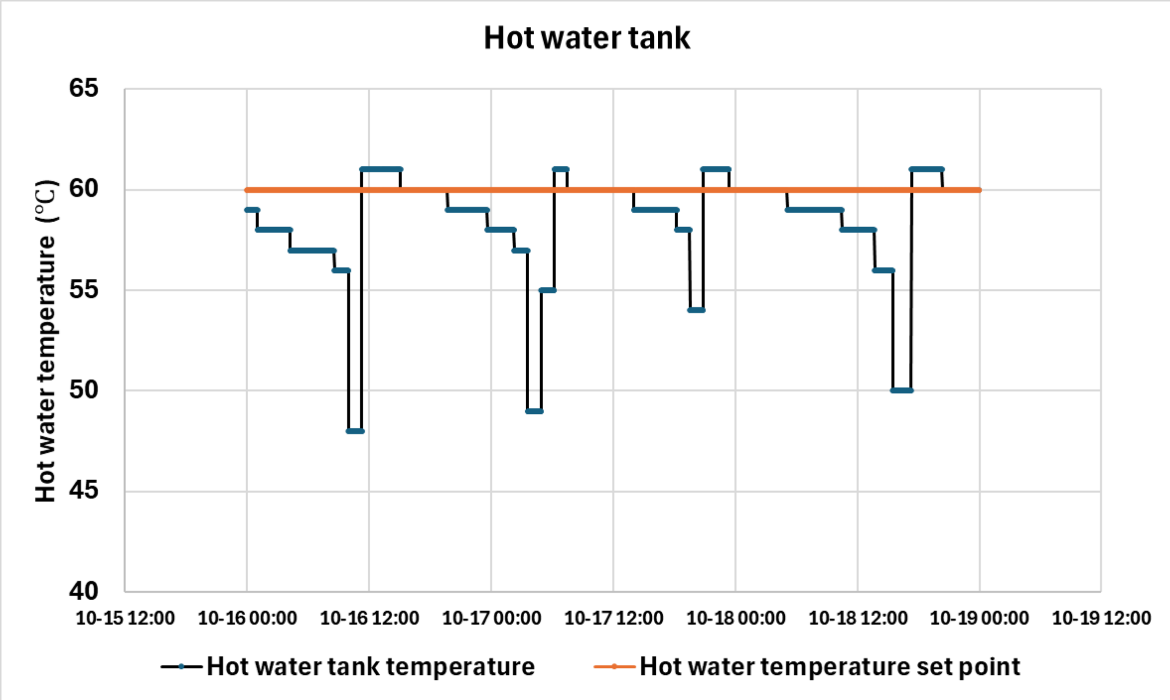

Figure 13. Hot water tank temperature during the 72-hour pre-test

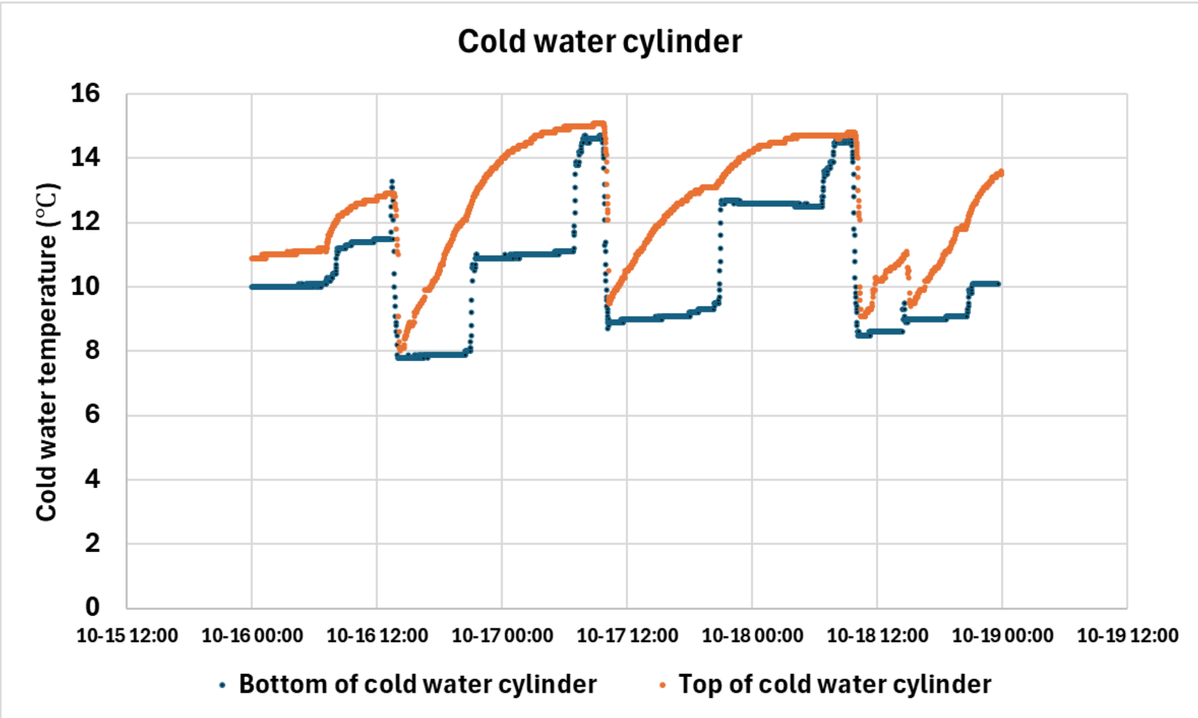

Figure 14. Cold water cylinder temperature during the 72-hour pre-test

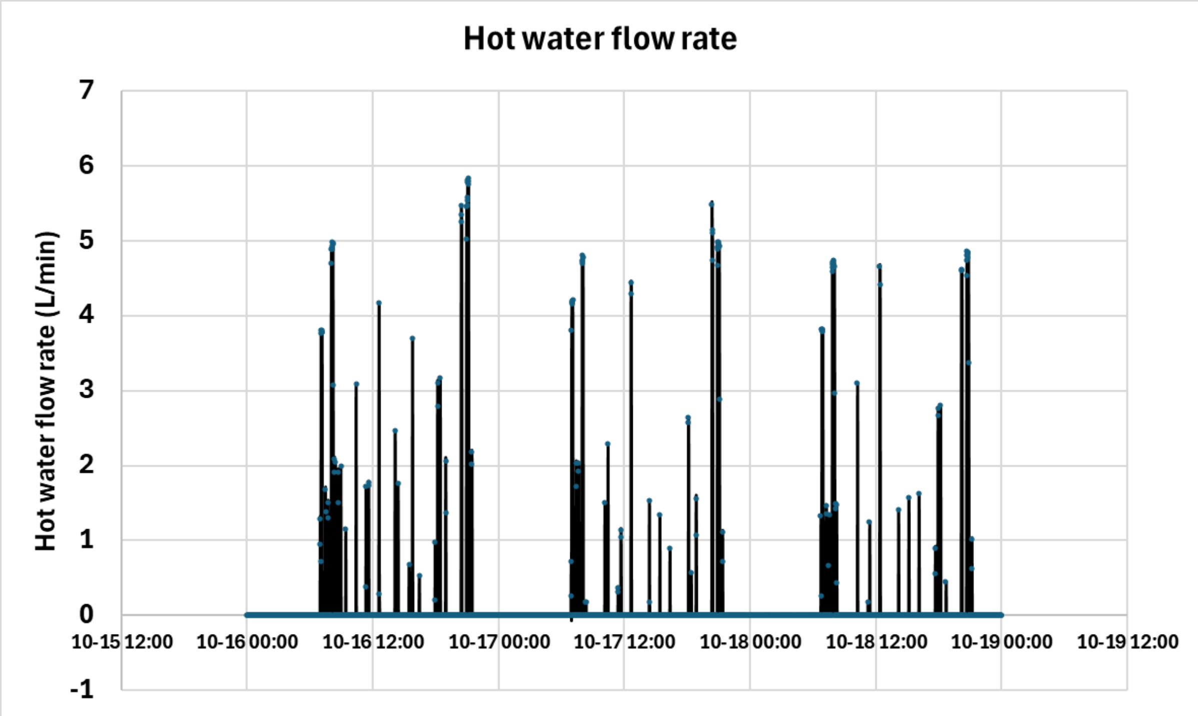

Figure 15. Hot water flow rate during the 72-hour pre-test

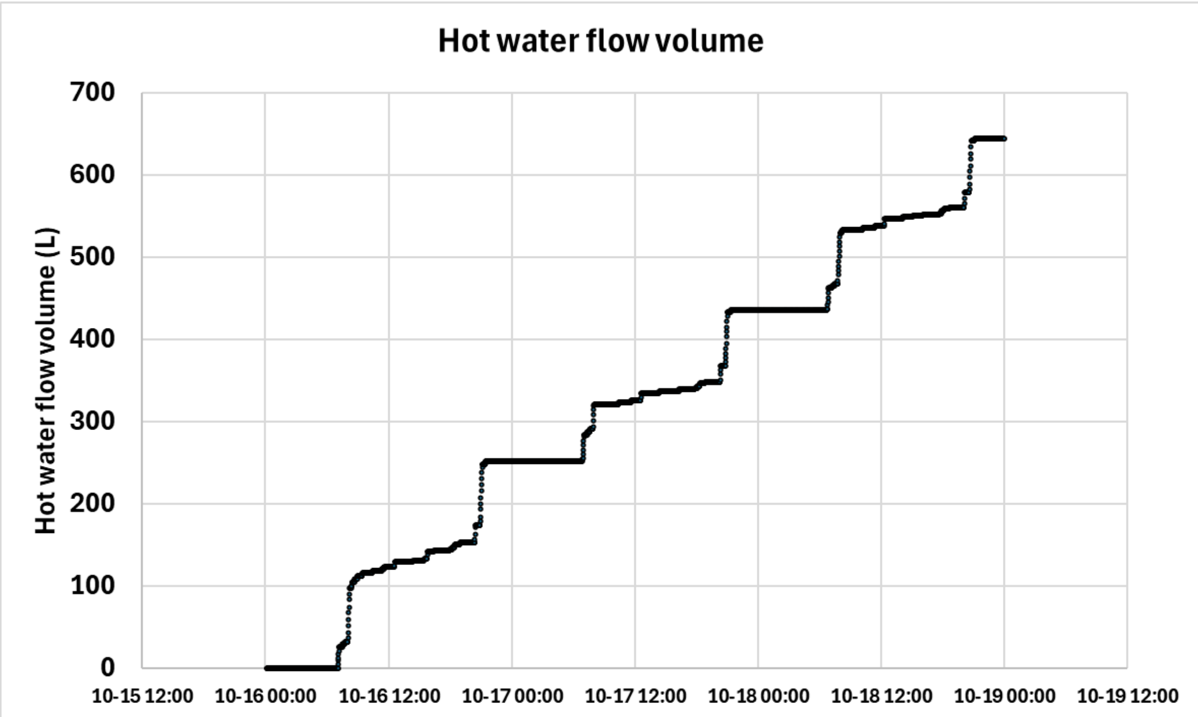

Figure 16. Hot water flow volume during the 72-hour pre-test

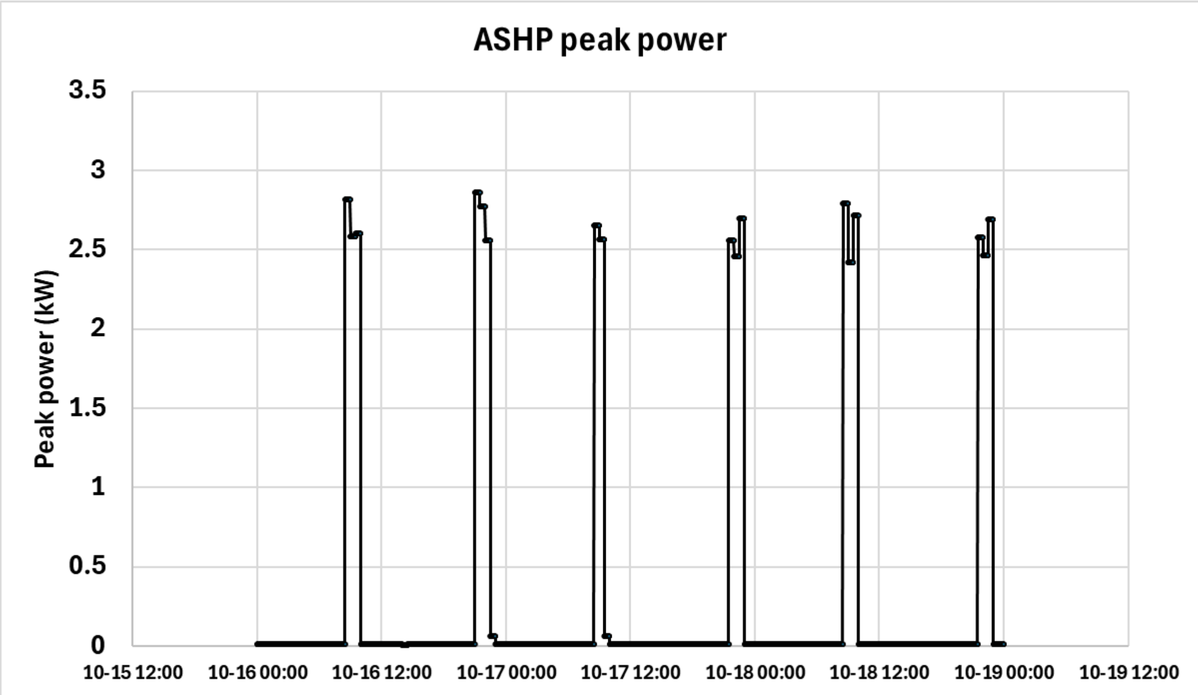

Figure 17. ASHP peak power during the 72-hour pre-test

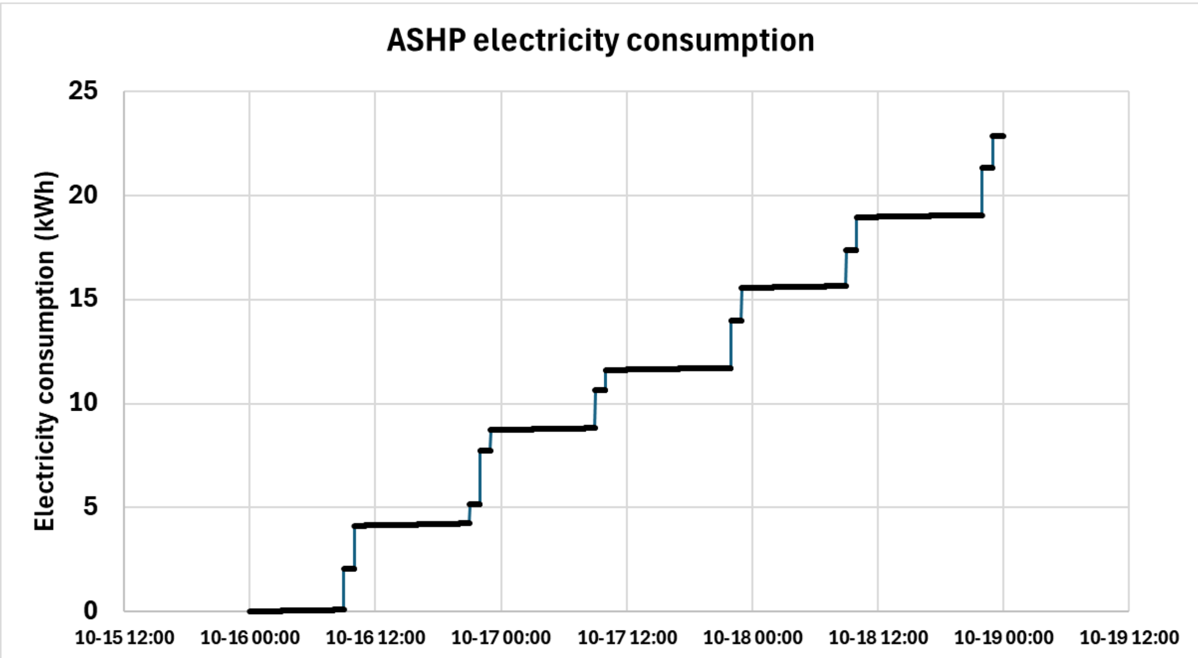

Figure 18. ASHP electricity consumption during the 72-hour pre-test

3.1.3 Test results under 5 °C, 7 °C and 14 °C chamber temperature

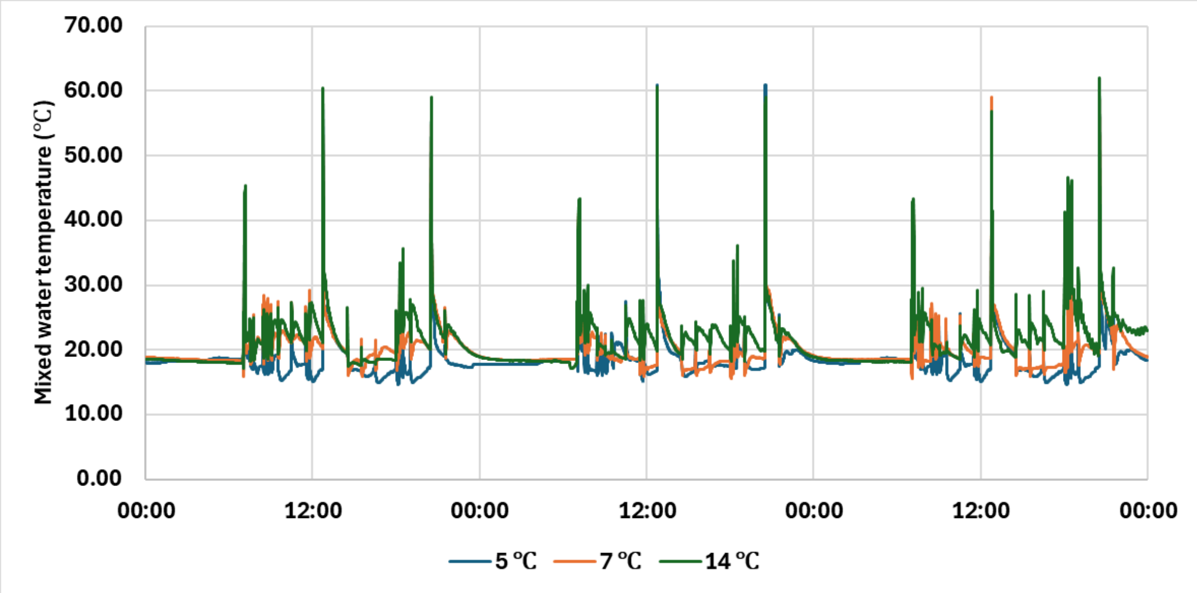

Figure 19. Mixed water temperature of the Kitchen sink tap during the 72-hour tests

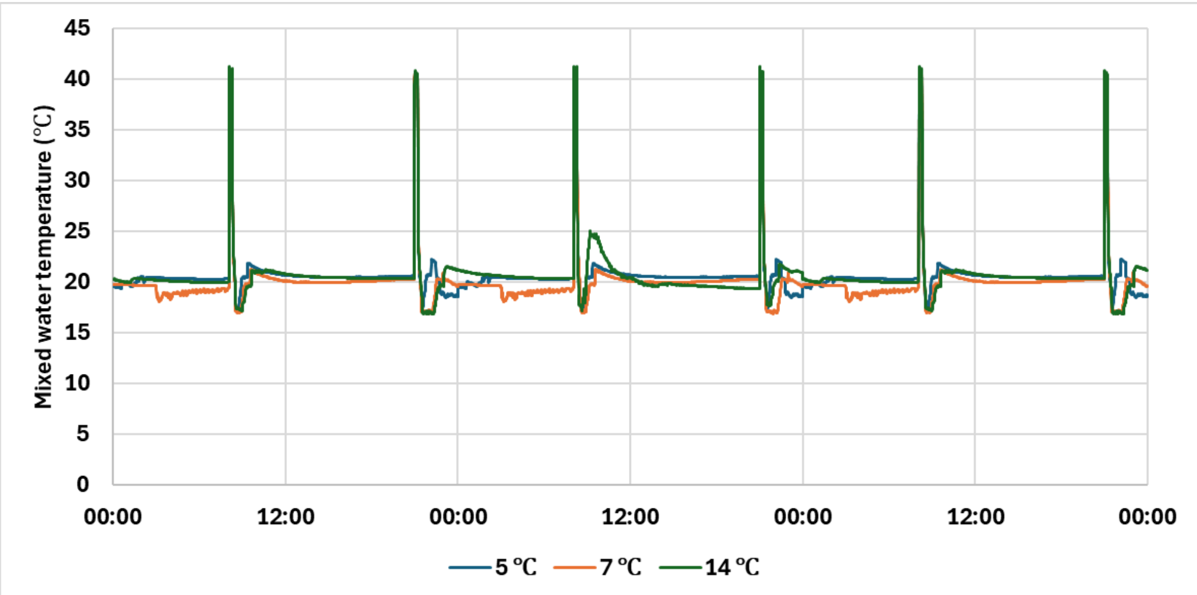

Figure 20. Mixed water temperature of the bath tap during the 72-hour tests

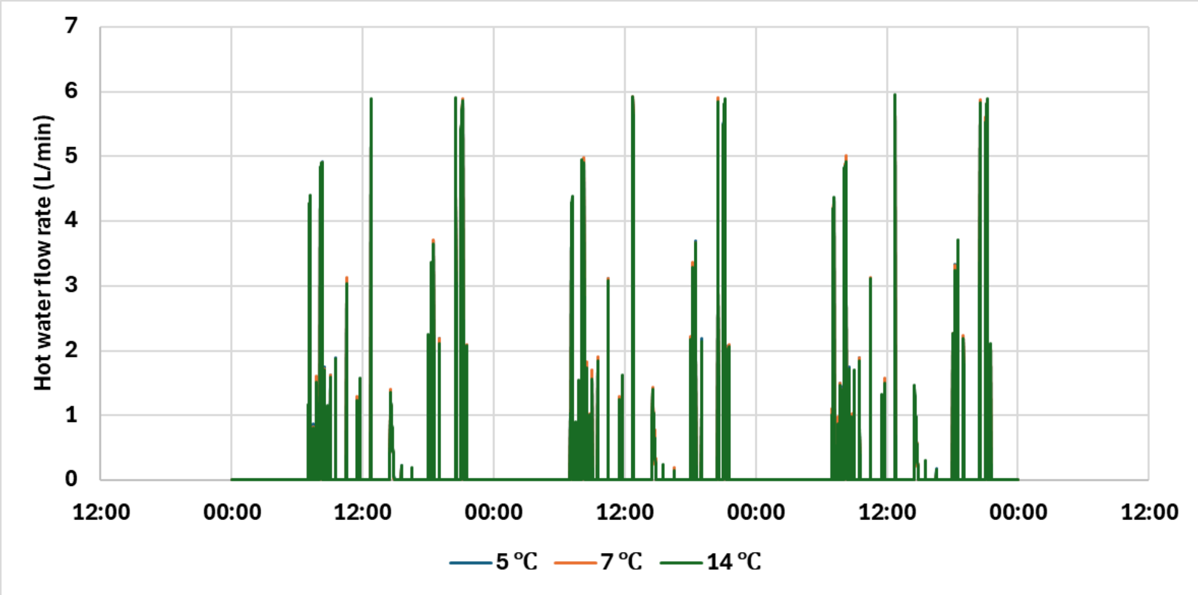

Figure 21. Hot water flow rate during the 72-hour tests

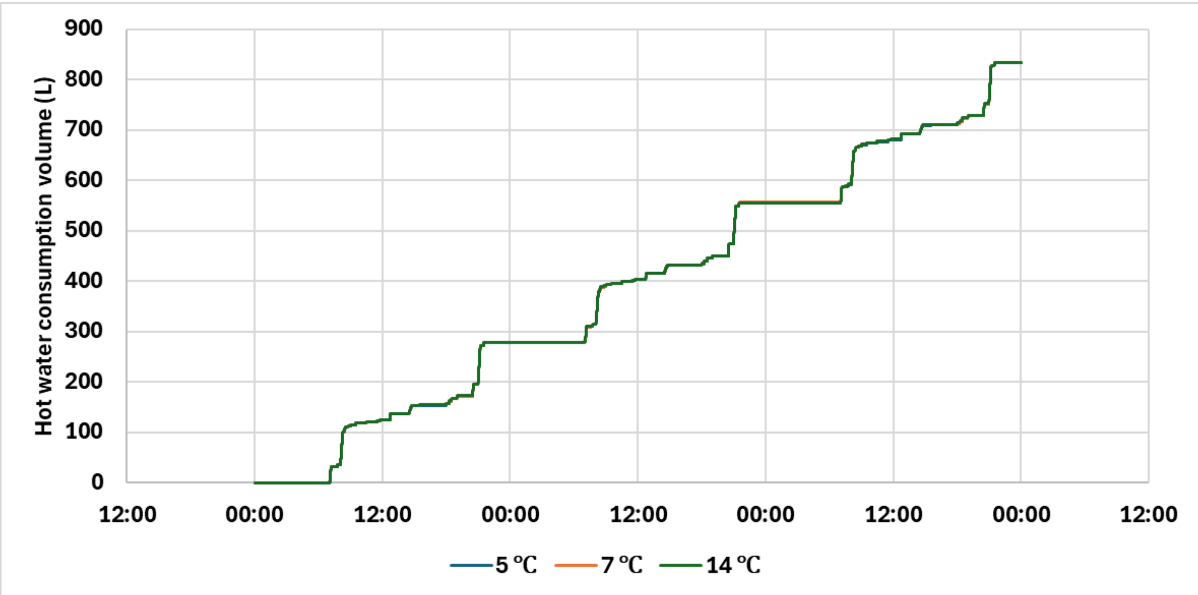

Figure 22. Hot water consumption volume during the 72-hour tests

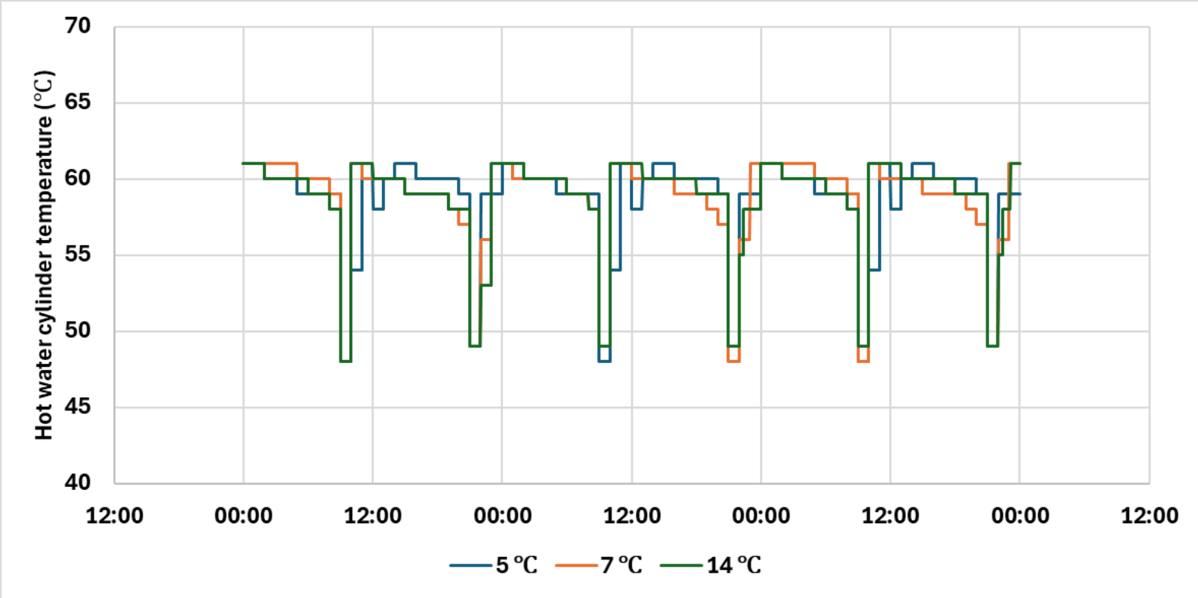

Figure 23. Hot water cylinder temperatures during 72-hour tests

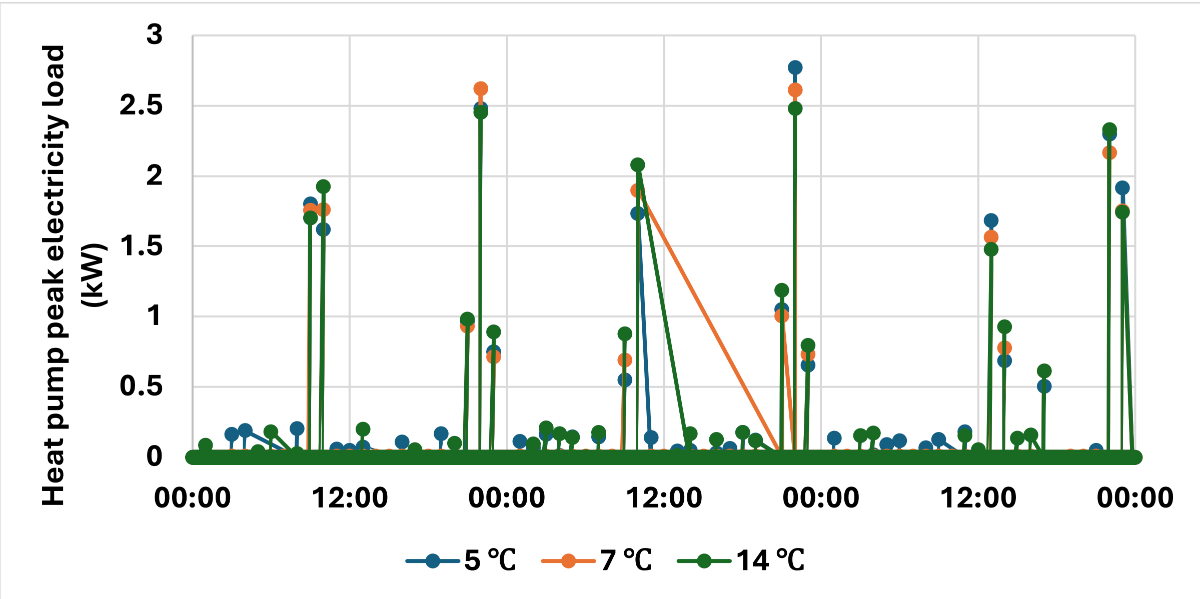

Figure 24. Heat pump peak electricity load during the 72-hour tests

$$DHW\ delivery\ efficiency = \frac{Total\ DHW\ Heating\ demand}{ASHP\ electricity\ consumption}$$

Table 6. Performance summary during the 72-hour tests

5℃ test	Day 1 20th Nov	Day 2 21th Nov	Day 3 22th Nov	72-hour 20-22 Nov
	kWh	kWh	kWh	kWh
ASHP electricity consumption	8.65	8.54	8.54	25.73
DHW Heating demand	15.92	15.53	15.88	47.33
DHW delivery efficiency	1.84	1.82	1.86	1.84
7℃ test	**Day 1 6th Nov**	**Day 2 7th Nov**	**Day 3 8th Nov**	**72-hour 6-8 Nov**
	kWh	kWh	kWh	kWh
ASHP electricity consumption	7.97	7.13	7.05	22.15
DHW Heating demand	15.82	15.98	15.38	47.18
DHW delivery efficiency	1.99	2.24	2.18	2.13
14℃ test	**Day 1 13th Nov**	**Day 2 14th Nov**	**Day 3 15th Nov**	**72-hour 13-15 Oct**
	kWh	kWh	kWh	kWh
ASHP electricity consumption	6.73	6.49	6.63	19.85
DHW Heating demand	15.92	15.65	15.69	47.26
DHW delivery efficiency	2.37	2.41	2.37	2.38

3.2 Curv Heat Pump

3.2.1 A 24-hour pre-test

An initial run with the Curv system revealed that it was not necessary to mix hot and cold water. As the Curv system is of a lower heat output than the Valliant system with longer heating up times, and as the tapping requirement was not to achieve exact temperatures but to achieve minimum temperatures, it was decided to run the Curv test with hot water only, without mixing it with cold water.

3.2.2 Test results under 5 ℃, 7 ℃ and 14 ℃ chamber temperature

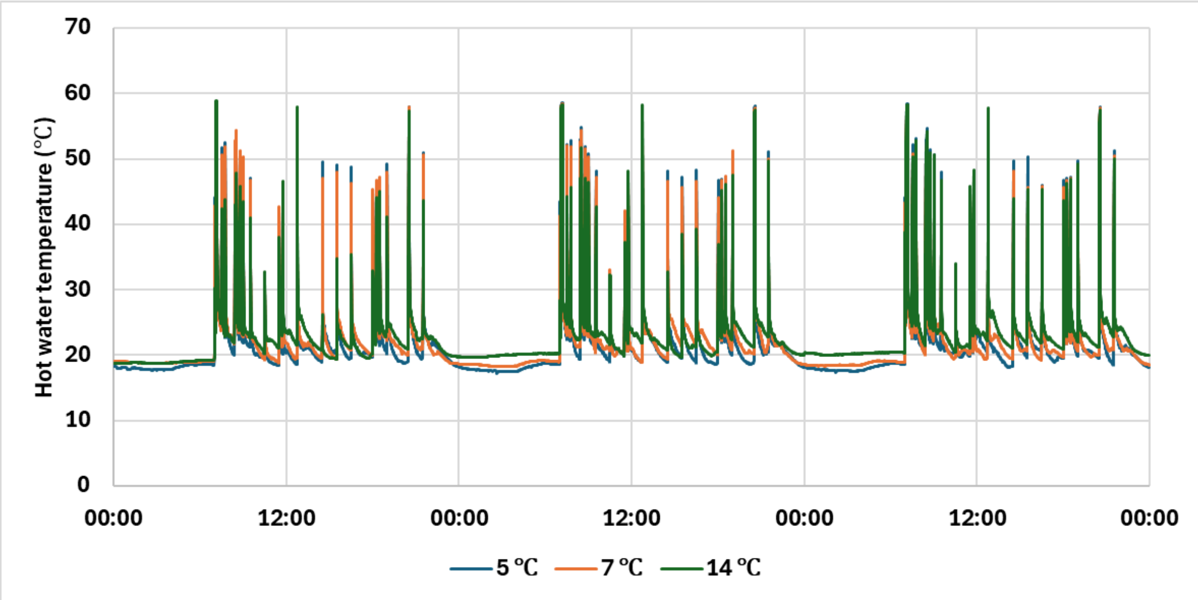

Figure 25 Hot water temperature of the Kitchen sink tap during the 72-hour tests

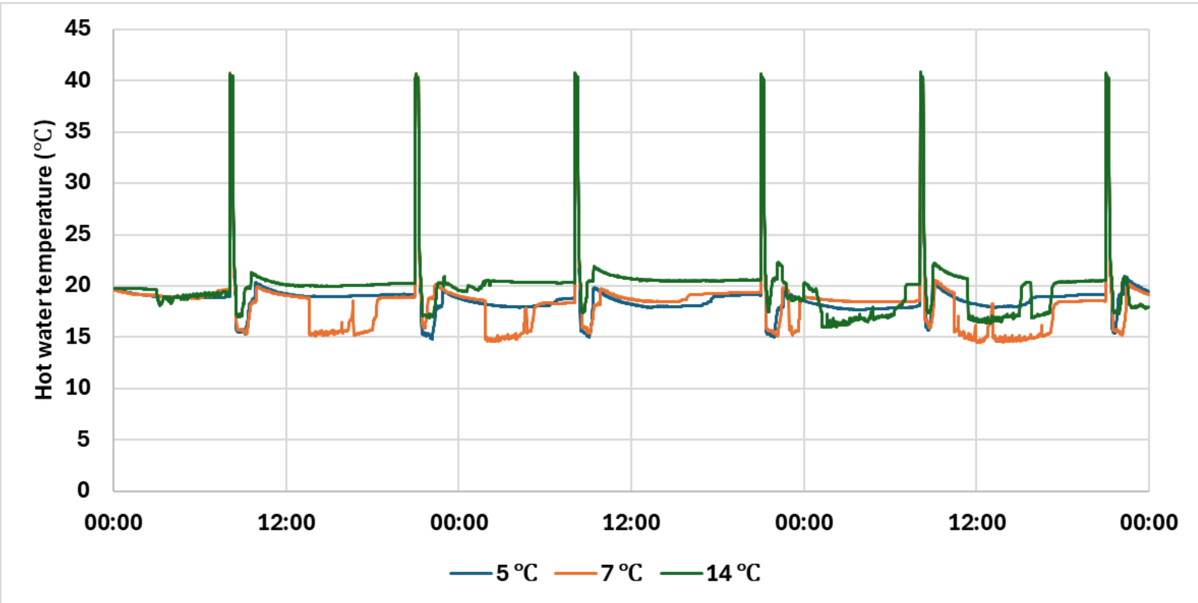

Figure 26 Hot water temperature of the bath tap during the 72-hour tests

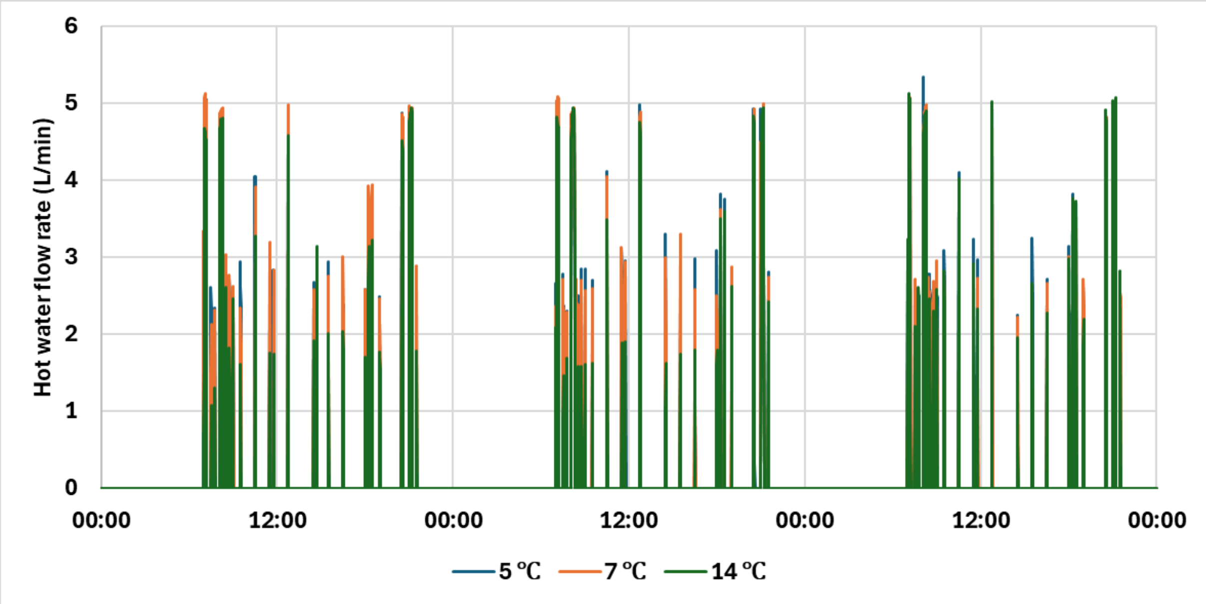

Figure 27 Hot water flow rate during the 72-hour tests

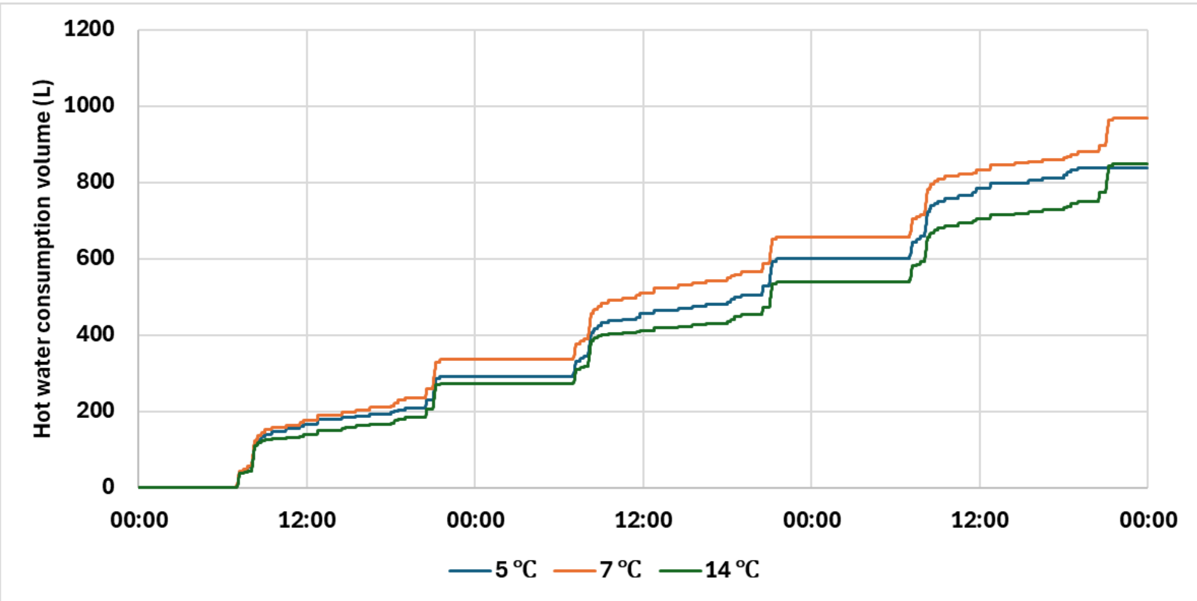

Figure 28 Hot water consumption volume during the 72-hour tests

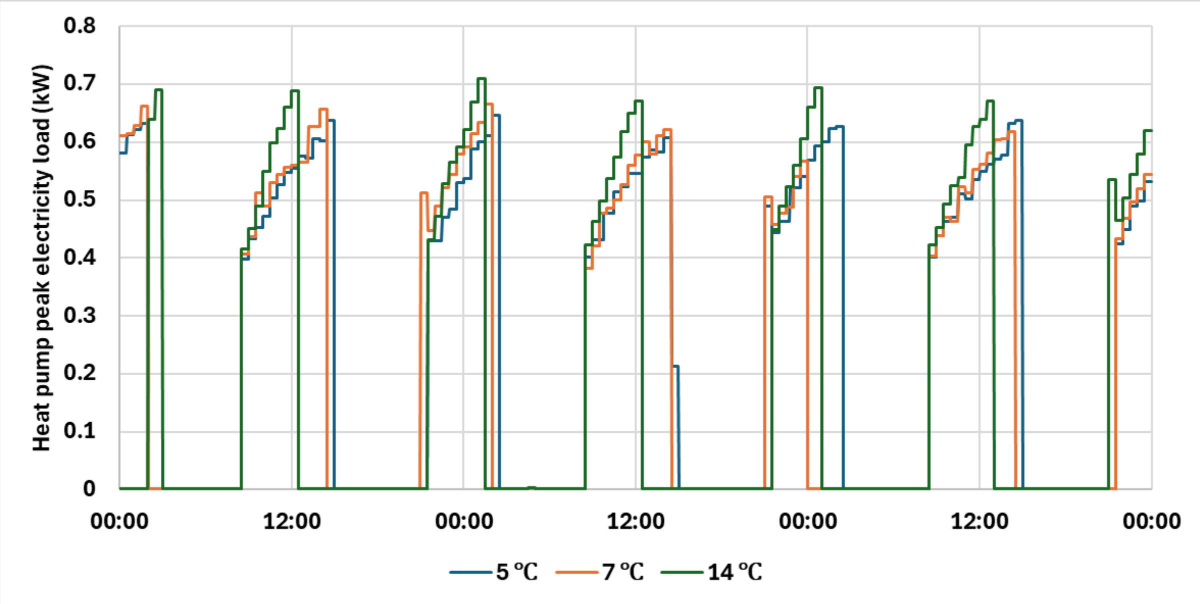

Figure 29 Heat pump peak electricity load during the 72-hour tests

Table 7 Performance summary during the 72-hour tests

5°C test	Day 1 17th Dec	Day 2 18th Dec	Day 3 19th Dec	72-hour 17-19th Dec
	kWh	kWh	kWh	kWh
ASHP electricity consumption	5.45	5.84	5.55	16.84
DHW Heating demand	11.12	11.71	11.23	34.06
DHW delivery efficiency	2.04	2.01	2.02	2.02
7°C test	**Day 1 12th Dec**	**Day 2 13th Dec**	**Day 3 14th Dec**	**72-hour 12-14th Dec**
	kWh	kWh	kWh	kWh
ASHP electricity consumption	5.39	5.33	5.19	15.91
DHW Heating demand	12.58	11.96	11.55	36.09
DHW delivery efficiency	2.33	2.24	2.23	2.27
14°C test	**Day 1 5th Dec**	**Day 2 6th Dec**	**Day 3 7th Dec**	**72-hour 5-7th Dec**
	kWh	kWh	kWh	kWh
ASHP electricity consumption	3.94	4.10	4.40	12.43
DHW Heating demand	9.98	10.11	11.77	31.87
DHW delivery efficiency	2.54	2.47	2.68	2.56

4 Discussion

Based on to the test results, both systems demonstrated the ability to meet domestic hot water needs under varying conditions. The Vaillant system offers higher stability and reliability due to its buffer tank, while the Curv system provides a more compact and energy-efficient solution.

4.1 Vaillant DHW System

The Vaillant DHW system, consisting of a 236-litre Unistor cylinder integrated with an aroTHERM air source heat pump (ASHP), was tested across varying chamber temperatures (5°C, 7°C, and 14°C) to assess its performance in delivering domestic hot water. The key parameters analysed included mixed water outlet temperatures, hot water flow rates, energy consumption, and DHW delivery efficiency.

4.1.1 Temperature Stability and Flow Rate Performance

The system maintained stable hot water temperatures across all tests. As shown in Figure 19 and Figure 20, the mixed water temperatures at the kitchen sink and bath taps were consistently within the target range of 25°C to 55°C, regardless of the chamber temperature. This indicates that the Vaillant system can effectively meet the hot water demand under diverse environmental conditions.

The flow rates recorded during the tests, illustrated in Figure 21, highlight that the system delivered the required water volume in line with the EN 16147 tapping profiles. The bath tap, which has the highest demand, maintained a steady flow rate of 4.8L/min for hot water and 8 L/min for mixed water, demonstrating the system's capacity to handle peak demands without noticeable performance drops.

4.1.2 Energy Consumption and Efficiency

Energy consumption data, shown in Figure 17 and Figure 24, reveals that the system's electricity usage decreased as the chamber temperature increased. At 5°C, the ASHP consumed an average of 8.58 kWh per day, whereas at 14°C, the consumption dropped to 6.62 kWh per day. This trend reflects the impact of ambient temperature on heat pump performance, with lower temperatures requiring more energy to maintain hot water temperatures.

Table 6 provides a summary of DHW delivery efficiency. The system achieved a delivery efficiency ranging from 1.84 at 5°C to 2.38 at 14°C. This demonstrates that while the system performs efficiently in mild conditions, its performance diminishes in colder environments. The buffer tank played a crucial role in reducing short cycling, enhancing system reliability and efficiency by maintaining a consistent water temperature in the cylinder.

4.1.3 Curv DHW System

The Curv DHW system is a stand-alone air source hot water cylinder (model HP200M3) with a capacity of 195 litres. Unlike Vaillant system, the Curv unit operates with an integrated but smaller buffer tank which is directly heated by the heat pump's condenser, making it a compact solution for domestic hot water delivery. The system was tested under identical conditions, with chamber temperatures set at 5°C, 7°C, and 14°C.

4.1.4 Temperature Stability and Flow Rate Performance

Figure 25 and Figure 26 illustrate the hot water temperatures at the kitchen sink and bath taps during the tests. The system maintained a consistent temperature output, achieving the target range of 25°C to 55°C. However, minor fluctuations were observed at lower chamber temperatures, indicating that the absence of a buffer tank may affect stability under certain conditions.

The recorded flow rates, depicted in Figure 27, show that the Curv system delivered hot water at the required volumes as per the tapping profiles. The system sustained a steady hot water flow rate of 5.0 L/min for the bath tap and 3.0 L/min for the kitchen sink tap, indicating its capability to meet high-demand scenarios without compromising performance.

4.1.5 Energy Consumption and Efficiency

Figure 29 and Table 7 provide insights into the system's energy consumption and DHW delivery efficiency. The Curv system exhibited lower electricity consumption compared to the Vaillant system. At 5°C, the system consumed 5.61 kWh per day on average, which reduced to 4.15 kWh per day at 14°C.

The system achieved a delivery efficiency ranging from 2.04 at 5°C to 2.56 at 14°C. Similarly to the Valliant system, this demonstrates that Curv system also performs more efficiently in in mild conditions, while its performance diminishes in colder environments.

According to the test results, both systems demonstrated the ability to meet domestic hot water needs under varying conditions. The Vaillant system offers higher stability and reliability due to its larger buffer tank, while the Curv system provides a more compact and energy-efficient solution.

5 Conclusions

This paper reports on the results of tests of two different heat pumps for domestic hot water delivery, under a standard tapping profile and within a controlled environment of eHome2 house inside Energy House 2.0. A standardised test protocol was developed by the research team to ensure a like for like comparison of the domestic hot water heating performance.

Both the Vaillant and Curv DHW systems were tested for their ability to meet domestic hot water demands under varying conditions.

The Vaillant system, featuring a 236-litre Unistor cylinder and aroTHERM air source heat pump (ASHP), demonstrated stability and reliability. It maintained consistent hot water temperatures within the target range (25°C–55°C) across varying environmental temperatures (5°C, 7°C, and 14°C). The system's performance in high-demand scenarios, such as bath taps, showed steady flow rates. Energy consumption decreased with higher ambient temperatures, reflecting improved efficiency. At 5°C, it consumed an average of 8.58 kWh per day, whereas at 14°C, the consumption dropped to 6.62 kWh per day. Its hot water delivery efficiency ranged from 1.84 at 5°C to 2.38 at 14°C.

The Curv system, a compact 195-litre stand-alone cylinder with a smaller buffer tank, offered a more energy-efficient solution. It maintained similar temperature stability, though minor fluctuations occurred at lower temperatures due to the smaller buffer tank. Flow rates were consistent, meeting required volumes for both bath and kitchen taps. Its energy consumption was lower than the Vaillant system, dropping from 5.61 kWh/day at 5°C to 4.15 kWh/day at 14°C. Its hot water delivery efficiency ranged from 2.04 at 5°C to 2.56 at 14°C.

In summary, both systems met the British Standard (BS EN 16147:2017, 2017). The Vaillant system is more stable and reliable, while the Curv system provides a more compact, energy-efficient alternative.

The outcome of this work increases the understanding of how a standardised domestic hot water demand can be fulfilled with different heat pumps.

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